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Hydrology of Southwestern Connecticut

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Trip B-3

HYDROGEOLOGY OF SOUTHWESTERN CONNECTICUT *

by

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INTRODUCTION

Geology affects the quantity and quality of water available in southwestern Connecticut, and the variability of both in time and space. Aquifers in the area are stratified drift, till, and bedrock; each has distinctive distribution, geometry, and water-bearing characteristics, all of which influence the type and extent of ground-water development. Mineral composition of rocks affects the quality of ground water and thus affects the quality of water available from streams, into which ground water discharges, as well as from aquifers. In addition, the extent of stratified drift and till in a drainage basin and geomorphic parameters of the basin affect the magnitude and variability of streamflow. Thus the hydrogeologist can apply a wide range of geologic knowledge in evaluating the water resources.

In this report, "southwestern Connecticut" refers to that part of the state drained by the Housatonic River and its tributaries downstream from Lake Lillinonah (Shepaug Dam) and all basins southwest of the Housatonic River that drain to Long Island Sound (figs. 1 and 2). As such, it includes two areas in which the U. S. Geological Survey has been conducting water-resources investigations, the lower Housatonic River basin and the southwestern coastal river basins. These studies have been made in cooperation with the State Water Resources Commission.

The authors acknowledge the cooperation of many industries and water companies who provided information used in this report. In addition we wish to thank personnel of those companies and organizations who kindly made their facilities available for the 1968 NEIGC field trip: the Naugatuck Chemical Division of UniRoyal, Inc., the Bridgeport Hydraulic Company, and the U. S. Army Corps of Engineers.

THE STRATIFIED-DRIFT AQUIFER

In southwestern Connecticut, stratified drift is the principal aquifer in terms of large scale ground-water development, and the discussion in this report will deal principally with this aquifer. Wells tapping bedrock far outnumber those tapping stratified drift, but the yields of individual bedrock and till wells are generally adequate to serve only homes and small commercial establishments. For example, the median yield of 725 wells drilled in bedrock in southwestern Connecticut is 5.3 gpm (gallons per minute), and only a few individual well yields exceed 50 gpm. On the other hand, the median yield of 64 wells tapping stratified drift is 262 gpm; individual yields generally exceed 100 gpm, and a few exceed 2,000 gpm.

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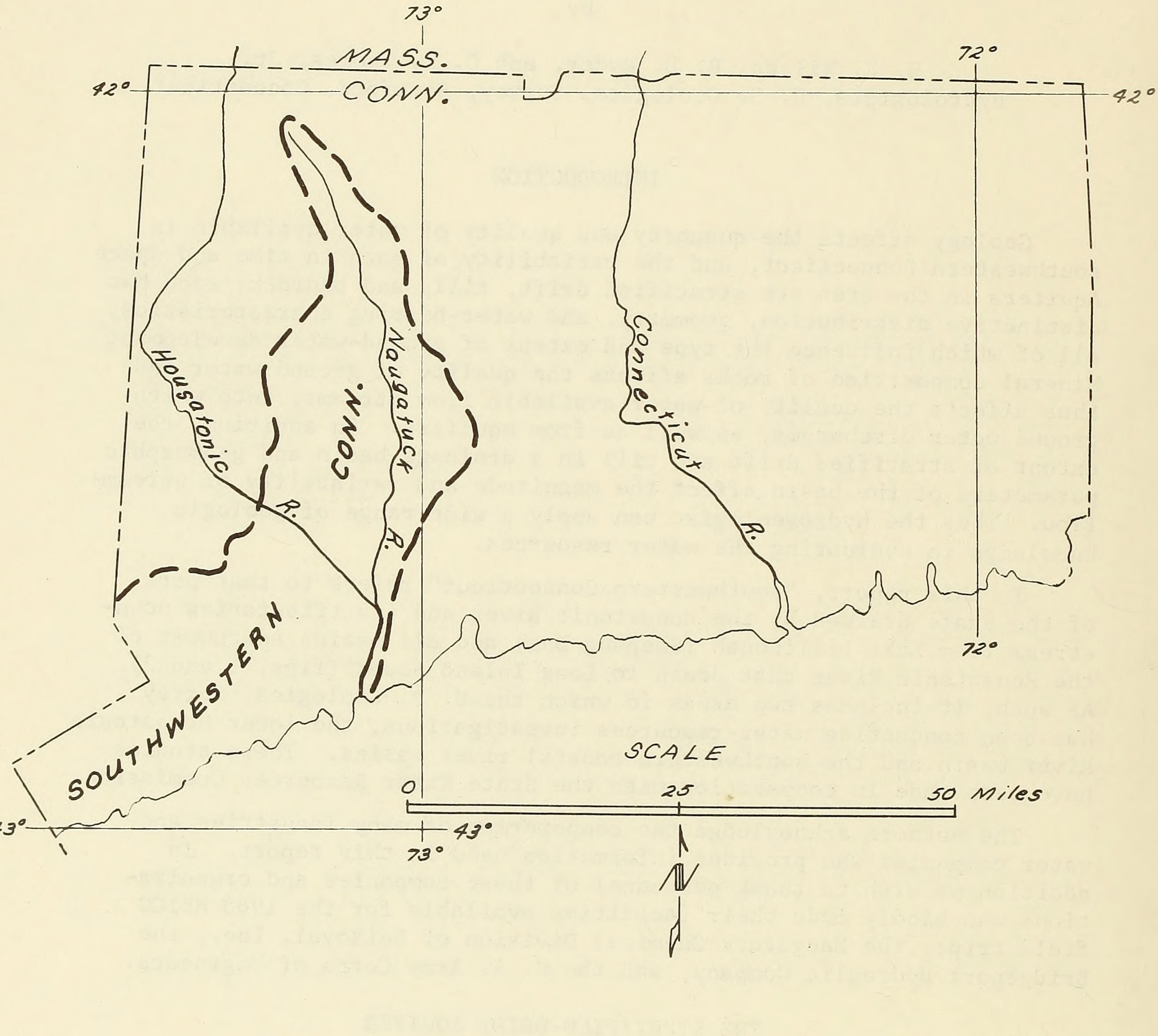


Fig. 1. Map showing location of southwestern Connecticut area.

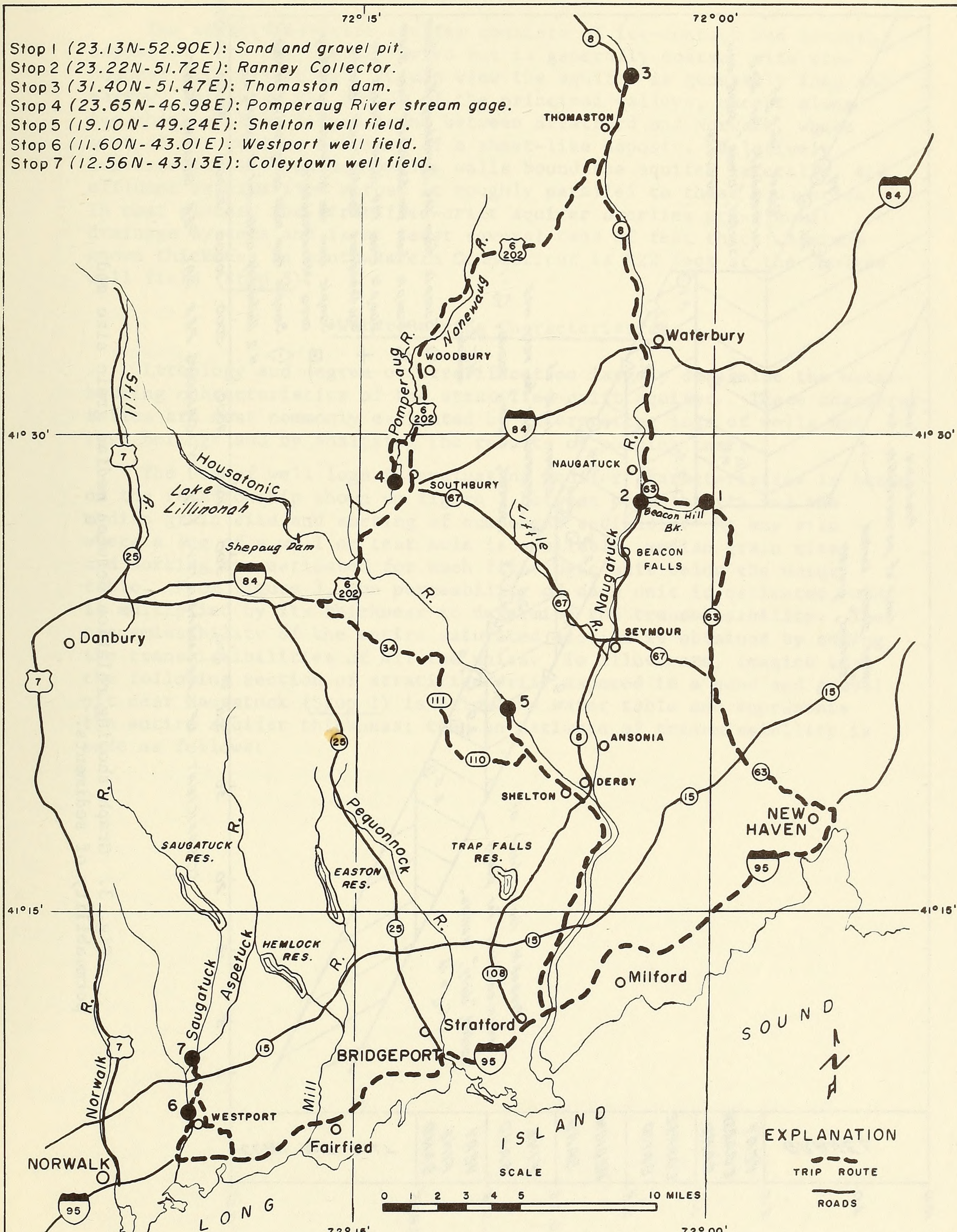


Fig. 2. Map showing route of hydrogeology field trip, southwestern Connecticut.

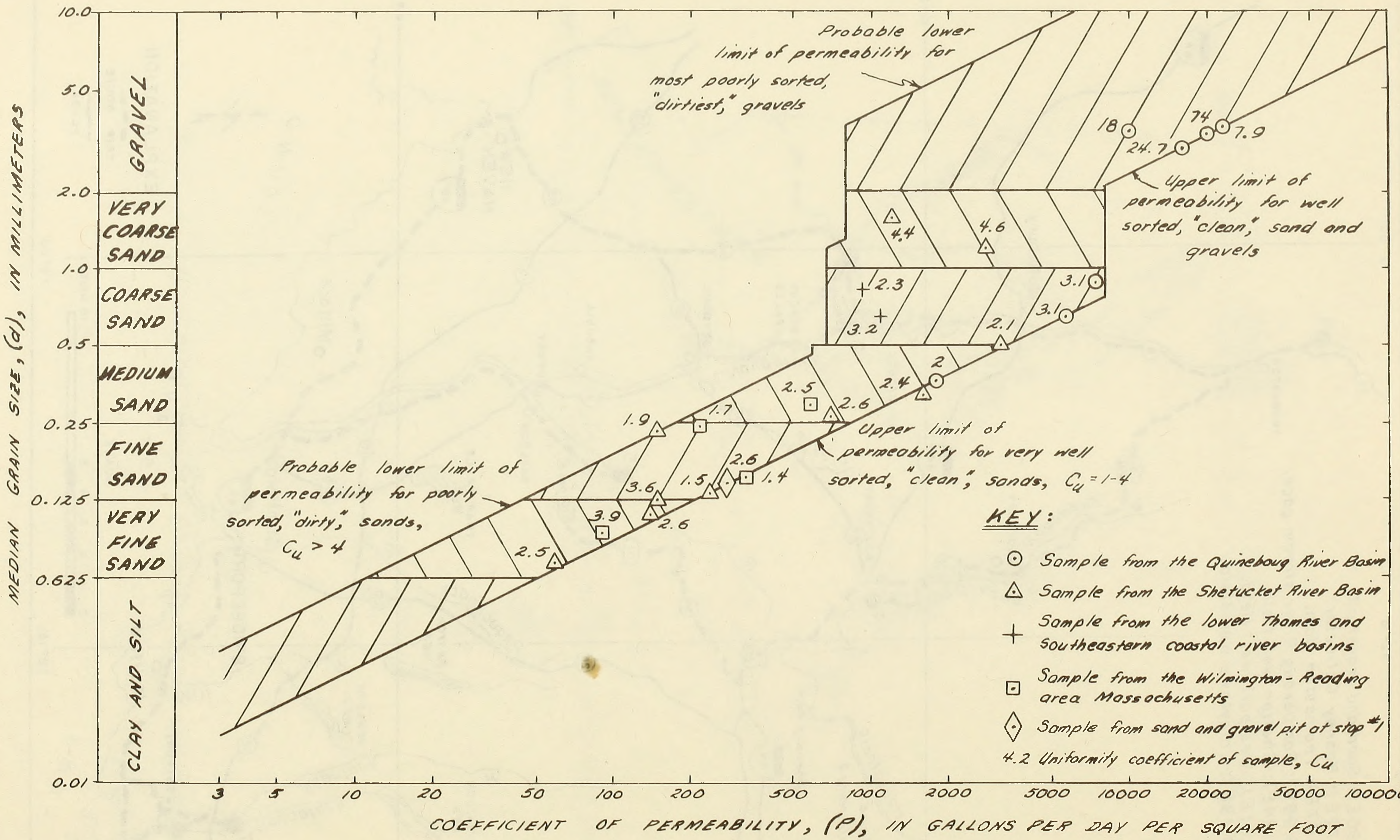


Fig. 3. Graph showing relation between median grain size and permeability of sediments.

Description

The stratified-drift aquifer consists of ice-contact and outwash deposits. Its texture is varied but is generally coarse, with pronounced stratification. In map view the aquifer is generally long and narrow, following the trends of the principal valleys, except along the shore of Long Island Sound between Stratford and Norwalk, where most of the aquifer consists of a sheet-like deposit. Relatively impermeable till-bedrock valley walls bound the aquifer laterally, and effluent streams flow across it roughly parallel to these boundaries. In most places, the stratified-drift aquifer overlies pre-glacial drainage systems and is at least several tens of feet thick; maximum known thickness in southwestern Connecticut is 222 feet at the Shelton well field (Stop 5).

Water-Bearing Characteristics

Lithology and degree of stratification largely determine the water-bearing characteristics of the stratified-drift aquifer. These characteristics are most commonly evaluated by interpreting logs of wells and test borings and by analyzing the results of pumping tests.

The use of well logs in evaluating aquifer characteristics is based on the relationship shown on figure 3 between permeability and the median grain size and sorting of component sediments. At any site where a log of a well or test hole is available, median grain size and sorting are estimated for each lithologic unit below the water table. From figure 3, the permeability of each unit is estimated, and is multiplied by its thickness to determine the transmissibility. The transmissibility of the entire saturated section is obtained by adding the transmissibilities of all the units. To illustrate, imagine that the following section of stratified drift exposed in a sand and gravel pit near Naugatuck (Stop 1) is below the water table and represents the entire aquifer thickness; then an estimate of transmissibility is made as follows:

Section Description	Thickness of unit (m) ft	Estimated permeability (P) gpd/ft^2	Estimated transmissibility (T) gpd/ft
Pebble to cobble gravel and medium to very coarse sand	5.0	4,000	20,000
Very fine to well sorted sand	0.5	100	50
Poorly sorted pebble to cobble gravel with medium to very coarse sand and some boulders	5.0	1,000	5,000
Well sorted very fine and fine sand with some medium sand	4.0	280 1/	1,120
Pebble to cobble gravel with boulders, little very coarse and coarse sand	4.5	1,000	4,500
Well sorted very fine sand, some fine sand	3.5	150	525
Silt and very fine sand	20.0	45	900
	m = 42.5		T = 32,095

1/ Permeability determined in laboratory from horizontal undisturbed sample. See plot on figure 3.

Stratification similar to that seen in this and many other sand and gravel pits results in differences in permeability in the horizontal and vertical directions. For example, the vertical permeability of the 4-foot sand bed described above (Stop 1) was only 31 gpd/ft^2 (gallons per day per square foot) compared to the horizontal permeability of 280 gpd/ft^2 (a ratio of 1:9) despite the uniform texture of the sand. Even greater permeability differences can be expected between beds of contrasting texture; perhaps in a complete section of sand and gravel the horizontal permeability is as much as 100 times the vertical permeability.

Differences in horizontal and vertical permeability reduce substantially the potential specific capacities of wells screened in only part of the aquifer. Pumping from partially screened wells causes flow lines to converge vertically toward the screens, thus bringing the relatively low vertical component of permeability into play. In southwestern Connecticut, the combined effect of partial penetration and relatively low vertical permeability may account for more than one half of the drawdown in a typical screened well.

The pumping test is one of the most useful tools available to the hydrogeologist for quantitatively evaluating aquifer characteristics. However, the abrupt changes in both vertical and lateral directions within the stratified-drift aquifer often make it difficult to obtain meaningful results. Some of these difficulties are illustrated by the results of a pumping test conducted by the U. S. Geological Survey in the Pomperaug River valley, Southbury (just north of Stop 4). During this test, a production well screened in the lower one-third of the aquifer was pumped at a rate of 278 gpm for 4 days, and water levels were measured in 8 observation wells.

As shown in the time-drawdown pattern on figure 4, the aquifer responds initially after pumping begins as if under artesian conditions. Then the effects of either delayed gravity drainage or vertical flow components, or a combination of both, cause the rate of drawdown to diminish. These effects may last for days or weeks, during which drawdown may be erratic and may even appear to have stabilized. However, if the test lasts long enough, drawdown rates again increase and the distribution of drawdown with time approaches the Theis model (Theis, 1935).

On a plot of time versus drawdown, the Theis type curve must be fitted to those points representing times after the effects of delayed gravity yield or vertical flow components have dissipated. It is sometimes difficult to judge from the data plot of a single observation well, such as that shown on figure 4, just when -- or whether -- these effects have ceased. However, when data from a number of observation wells are plotted together, they may appear to approach a single Theis type curve. If transmissibility is computed from the best fit of these data to the type curve, it will usually be in close agreement with a value of transmissibility estimated from logs and specific capacity. Analyses of the data from the test at Southbury indicated that about ten more days of pumping would be required to insure a definitive match of time-drawdown data from one observation well to the Theis type curve.

Most pumping tests conducted by well drillers in southwestern Connecticut last a day or less. As can be seen from the above discussion, such tests are difficult to interpret using the Theis method. Thus, prerequisites to obtaining meaningful results from pumping tests include a familiarity with geologic conditions at the site, an understanding of how these conditions may affect drawdowns, and a close control on test conditions.

Induced Infiltration

Many water companies in southwestern Connecticut derive part of their ground-water supply from induced infiltration of streamflow. In Woodbury, for example, the Watertown Fire District derives much ground water from infiltration of water from the Nonewaug River, which has been diverted into a gravel-lined canal that passes through the well field. At periods of low flow, streamflow is augmented by releasing water from an upstream dam and reservoir. Similarly, the Seymour Water Company has placed its Oxford wells alongside the Little River and

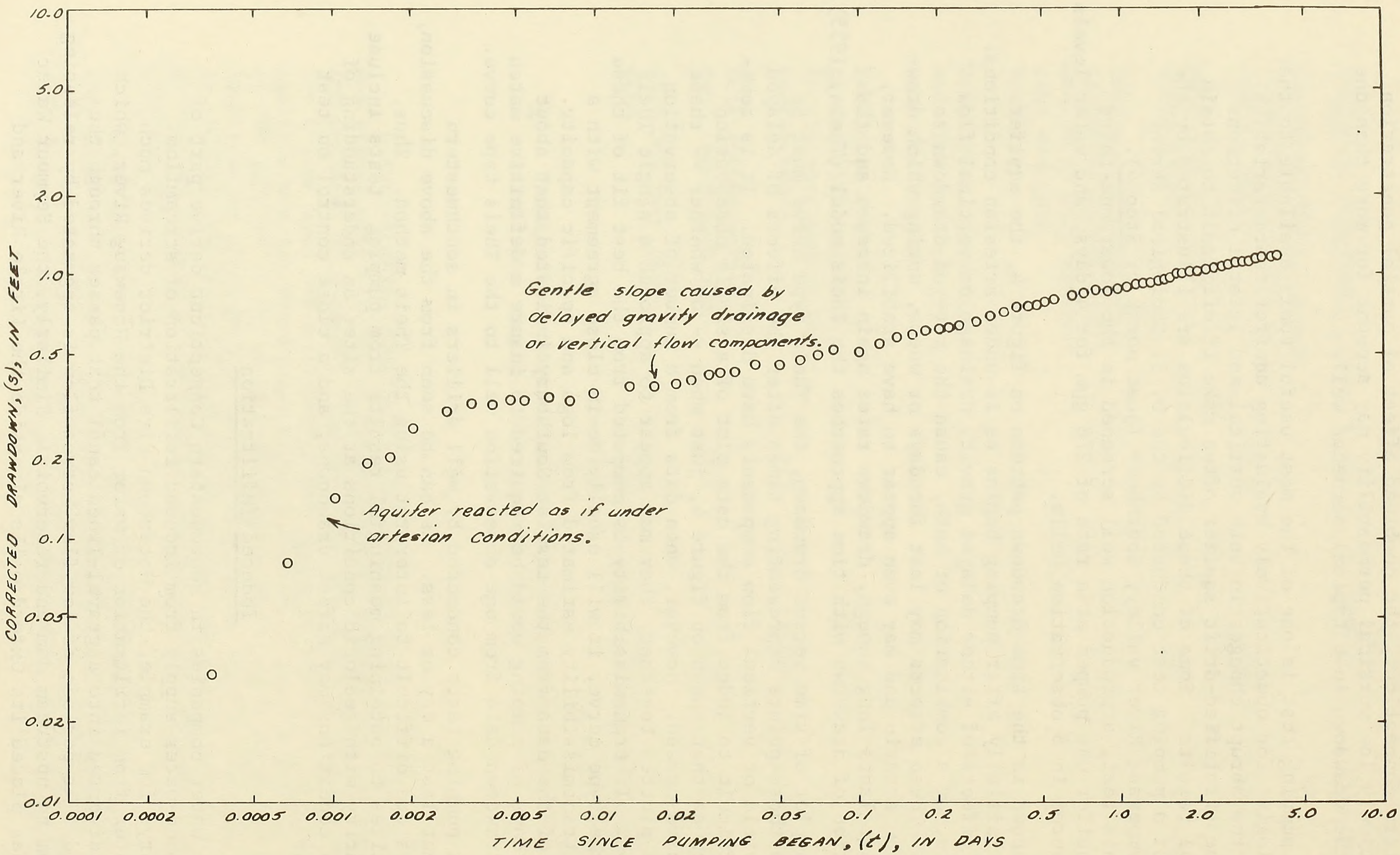


Fig. 4. Graph of time-drawdown data from an observation well, Southbury pumping test.

various man-made side channels. At the Shelton well field (Stop 5), the Bridgeport Hydraulic Company has placed its eight production wells in a line 50-100 feet from the Housatonic River. These wells, which pumped about 3,100 mg (million gallons) during 1965, derive much of their supply from the river. Both the Westport well field (Stop 6) and the Coleytown well field (Stop 7) of the Bridgeport Hydraulic Company derive much of their pumpage, which totaled 737 mg in 1965, from the Saugatuck River.

The yearly amount of water available for induced infiltration from a stream depends not only on the amount and time distribution of streamflow, but more importantly on (1) the vertical transmission capacities of the streambed deposits; (2) the area of the streambed under which the cones of depression from pumping wells have extended; and (3) the depth and temperature of the water. Of these, the physical properties that determine streambed transmission capacities--thickness and vertical permeability--are the most difficult to evaluate. Little quantitative information is available in Connecticut, but in some cases it has been possible to determine the combined effects of permeability and thickness and thereby determine a potential infiltration rate.

A field variable-head permeameter has been used by U. S. Geological Survey personnel to determine approximate potential infiltration rates. Many problems limit the reliability of this method, but the results suggest that in the Pomperaug River valley the infiltration rates of the upper foot of gravelly streambed deposits are in the range of 100-400 gpd/ft^2 per foot of stream depth.

The infiltration rate of the streambed of Beacon Hill Brook was determined from pumping-test and streamflow data. Loss of streamflow over a 640-foot reach of stream was measured twice during a 3-month pumping test of 2 Connecticut Water Company wells. Assuming the water level was drawn down below the stream bottom over this reach, and considering a possible ±5 percent error in the streamflow measurements, the calculated average infiltration rate is between 70 and 150 gpd/ft^2 per foot of stream depth at 16°C. Using a similar but somewhat less accurate method, the infiltration rate of the streambeds of the Saugatuck and Aspetuck Rivers in the vicinity of the Coleytown well field was estimated at 68 gpd/ft^2 per foot of depth at 16°C.

Knowledge of the importance of stream geometry and streambed characteristics has been utilized to improve infiltration rates at some sites. Examples of channel diversions in Woodbury and Oxford are mentioned above. At the Westport well field (Stop 6) periodic dredging of the Saugatuck River bottom removes fine-grained material that gradually accumulates behind a dam situated downstream. An immediate rise in pumping levels results as gravelly streambed deposits are exposed. On the other hand, dredging of the Naugatuck River streambed near the Ranney Collector (Stop 2) has failed to produce any noticeable increase in infiltration rate. Downstream from the Coleytown well field (Stop 7) small dams have been built across the two infiltrating streams. The dams have increased the depths and surface areas of the streams, thereby increasing the amount of infiltration.

Development of Ground Water

Historical Development

The stratified-drift aquifer in southwestern Connecticut has been tapped by dug wells for homes and shops since the earliest times of settlement. However, during the 20th century, the popularity of dug wells has declined considerably. Many dug wells have been replaced by drilled bedrock wells, and most new homes are supplied by individual bedrock wells, or by a public-supply system.

Industries have tapped the stratified-drift aquifer in southwestern Connecticut with drilled wells since the early 1900's. Much of the development took place in the highly industrialized Naugatuck River valley and in areas along Long Island Sound. Some industrial wells were drilled in the Naugatuck River valley in the 1920's and 1930's, but the major development occurred during World War II, when increased industrial output spurred exploration for additional water. During 1940-47, at least 22 industrial wells tapping stratified drift were drilled in the valley.

The large and generally haphazard development of ground water during the 1940's contributed to water-quality problems which have largely been responsible for the subsequent decline in ground-water use from private industrial wells. Along the southwestern Connecticut coast, especially in the Bridgeport area, salt water encroachment led to the eventual abandonment of most industrial wells. In the Naugatuck River valley, highly mineralized ground water caused problems of screen encrustation, declining yields, and water treatment.

In the 20 years following 1947, only seven new industrial wells tapped the stratified-drift aquifer in the Naugatuck River valley, and 12 of the war-time wells were abandoned. Many industries have found it uneconomical to develop or continue with their own supplies. Still, the valley remains the major center of industrial pumpage. In 1965, approximately 7.2 mgd (million gallons per day) were pumped from industrial wells in southwestern Connecticut, most of which (6.2 mgd) came from the Naugatuck valley.

In contrast to declining development of ground water by private industries, development by public-supply water companies has increased markedly over the last two decades. Of 47 public-supply wells in use during the mid-1960's only a few were drilled prior to 1950. The stimulus for this development results from increased demands for water and rising costs for obtaining and developing the few available reservoir sites that remain. In some towns of southwestern Connecticut, the Bridgeport Hydraulic Company turned to ground water when their service area expanded to areas above their reservoirs and to areas underlain by relatively large aquifers. The water companies are more flexible than industries in their choice of sites, and they have been able to place wells in areas where the quality of water is relatively unaffected by man and in areas remote from possible salt-water contamination.

In 1965, 12 water companies (or their subsidiaries) pumped an average of 17.7 mgd from wells tapping stratified-drift in southwestern Connecticut.

Of this amount, nearly half (8.5 mgd) came from Bridgeport Hydraulic Company's Shelton well field, which is located along the Housatonic River at Shelton (Stop 5). Almost all of these companies utilize ground water as a supplement to, or in combination with surface-water reservoirs. A few large public water supplies such as those of the Water Department of the City of Waterbury and the Greenwich Water Company, continue to use surface supplies exclusively.

Exploration and development of ground-water supplies from the stratified-drift aquifer has largely been undertaken by individual companies, with each firm utilizing drillers, private consultants, or their own personnel. More recently the U. S. Geological Survey has conducted basin-wide water-resources investigations, and Regional Planning Agencies have sponsored regional studies and plans. These studies provide a basis for planning systematic development and use of the ground-water resource.

Examples of Development

Several installations for ground-water withdrawal are described below to illustrate some of the conditions and problems encountered in developing ground water from the stratified-drift aquifer in southwestern Connecticut. Each installation has certain features that make it particularly interesting or distinctive.

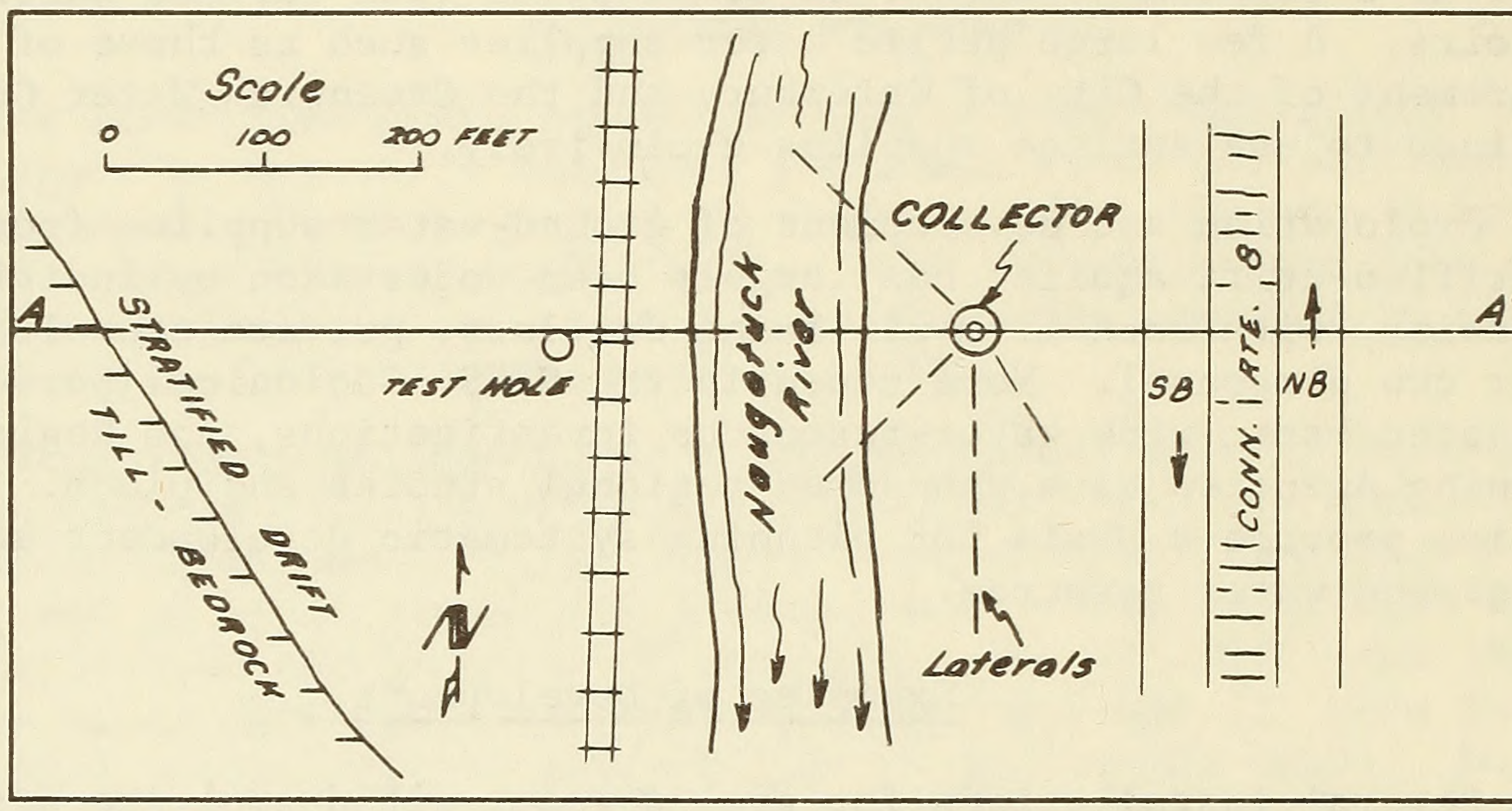
Ranney Collector (Stop 2). One of three Ranney Collectors in Connecticut is located in Naugatuck next to the Naugatuck River (fig. 5). The well was installed in 1949 for the Naugatuck Chemical Company, now a division of UniRoyal, Inc.

A Ranney Collector is specifically designed to induce stream infiltration over a large area by utilizing slotted horizontal laterals extending radially from the base of a large-diameter vertical caisson. The installation at Naugatuck consists of a 13-foot diameter concrete caisson, 87 feet deep, with eight laterals ranging in length from 4 feet to 400 feet. (See fig. 5.) The laterals are 8 inches in diameter and have half-inch slots. Results of tests conducted during the first year of operation indicated a maximum sustained pumping capacity of 1,830 gpm at a drawdown of about 68 feet.

During the two decades following the installation of the Ranney Collector, several problems arose, including withdrawal of relatively highly mineralized water, encrustation of the laterals, pumping of sand and silt, and a decline in operating yield.

Commercial analyses of water samples from the collector during 1952-66 showed an average concentration of 342 mg/l (milligrams per liter) total dissolved solids, including an average of 7.3 mg/l iron and 5.7 mg/l manganese. Iron concentrations as high as 14.0 mg/l were reported, and in some samples reported manganese concentrations exceeded those of iron. Neither the Naugatuck River nor the natural ground water in the area is known to have such large concentrations of iron and manganese. The high concentrations of these elements in the collector water may be due to the solution of iron and manganese from the sand and gravel aquifer by infiltrating river water of low pH. The pH of most samples of the river at Beacon Falls ranged between 3.1 and 6.0.

In 1967, an inspection of the collector showed that the insides of the laterals were coated with a slimy encrustation 2 inches thick,



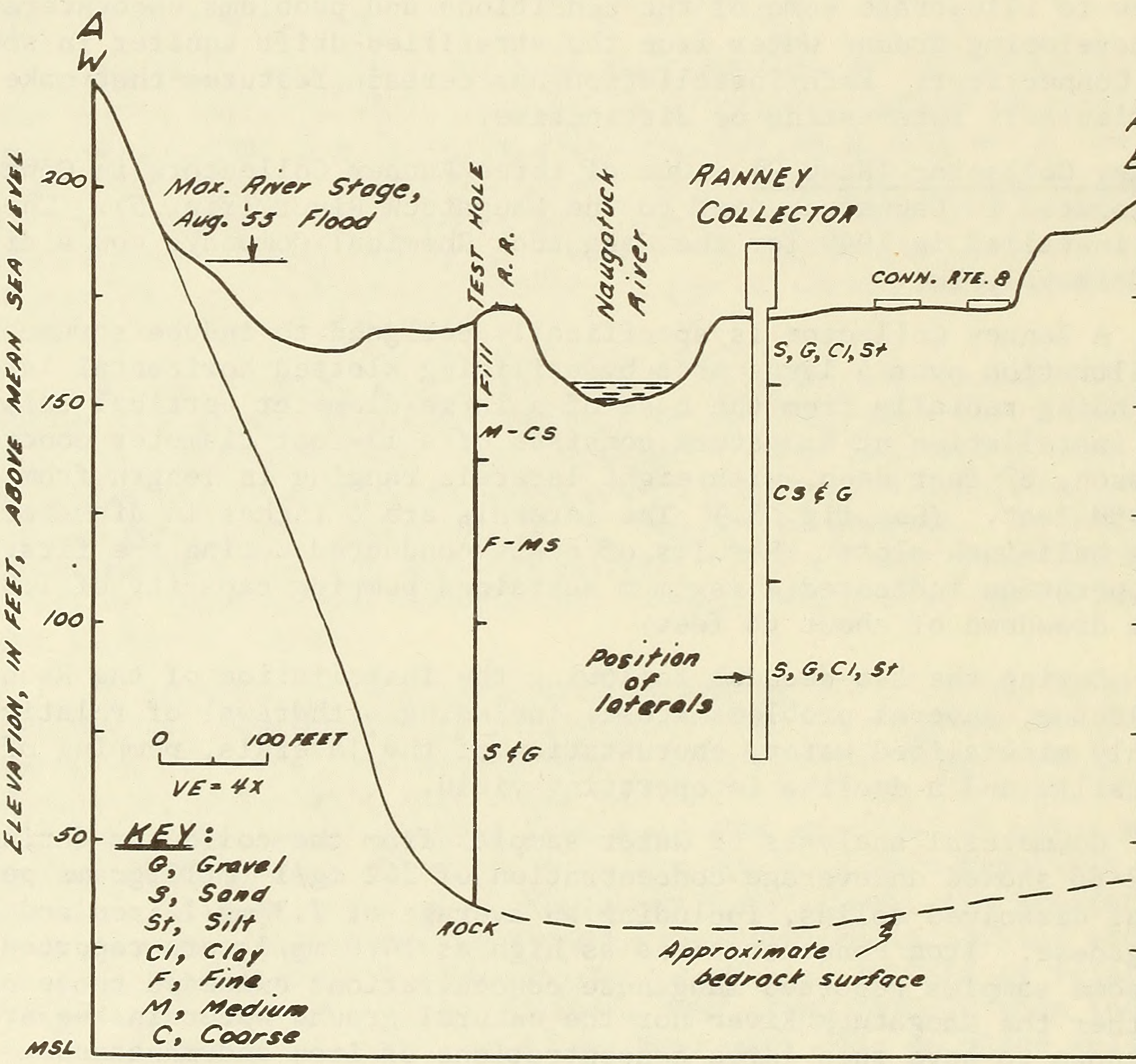


Fig. 5. Map and cross section at site of Ranney Collector, Naugatuck.

which thus reduced the diameter by half. As a result, entrance velocities increased and sand and silt entering the laterals were carried into the caisson. By reducing the pumping rate, a higher pumping level is maintained, turbulence is reduced, and the amount of suspended sediment carried into the system is minimized.

Since the fall of 1965, the supply from the Ranney Collector has been augmented by water piped into the well from the mouth of Beacon Hill Brook, 700 feet to the south. During the first three months of 1967, pumpage from the brook averaged about 1.0 mgd, and total withdrawal from the Ranney Collector averaged about 1.5 mgd. The addition of relatively good quality brook water results in a blend more satisfactory for plant operation. In one sample of the blended water, the concentration of total dissolved solids was reported as 125 mg/l, iron as 3.9 mg/l, and manganese as 1.4 mg/l.

Shelton well field. The Shelton well field (also called the Housatonic well field) probably is the largest of its kind in New England. It consists of a line of eight wells, each capable of pumping 3 mgd, located on a low terrace adjacent to the Housatonic River (fig. 6).

The Shelton well field is part of the extensive water-supply system of the Bridgeport Hydraulic Company. The wells pump nearly full time during the summer months and operate at a reduced schedule during the remainder of the year. Water is pumped uphill to Trap Falls Reservoir in Shelton, where it is distributed, along with water from other sources, to several towns in Fairfield County. In 1965, approximately 3,100 mg (million gallons) were pumped from the well field, representing nearly half of the total amount of water distributed from Trap Falls Reservoir.

The first extensive test drilling of this area was started in 1951. The logs of many of these holes record "refusal" at about 100 feet; the deepest test hole was 111 feet. Refusal was believed to be bedrock, and therefore three production wells were drilled with depths averaging 95 feet. However, seismic studies made in 1953 and 1957 suggested that bedrock was more than 200 feet below the surface in many parts of the area. Additional test drilling verified the geophysical results and indicated that "refusal" in the earlier test holes was in fact boulders. In 1954 two deeper production wells were drilled, and during 1964-67, eight additional deeper wells were drilled and five of the older wells abandoned.

The eight wells in use in 1968 average 207 feet in depth. All are 24 inches in diameter and are finished with 30 feet of 250-slot screen. The wells were tested at rates ranging from 2,118 to 2,513 gpm, averaging 2,360 gpm. Specific capacities varied widely from 16.9 to 50.3 gpm/ft (gallons per minute per foot).

The large individual well yields at the Shelton well field are the consequence of the high transmissibility of the aquifer, the availability of large drawdowns, and the large potential for induced infiltration. The section at the Shelton well field consists of interbedded sand and gravel (fig. 6) whose average permeability, estimated from well logs, is probably in the range of 700-1000 gpd/ft^2. The exceptionally great thickness of the aquifer is the result of glacial overdeepening of the bedrock floor of the valley. Thus, whereas the specific capacities are about average for wells tapping the stratified-drift aquifer, the availability of large drawdowns permits high pumping rates. In yield

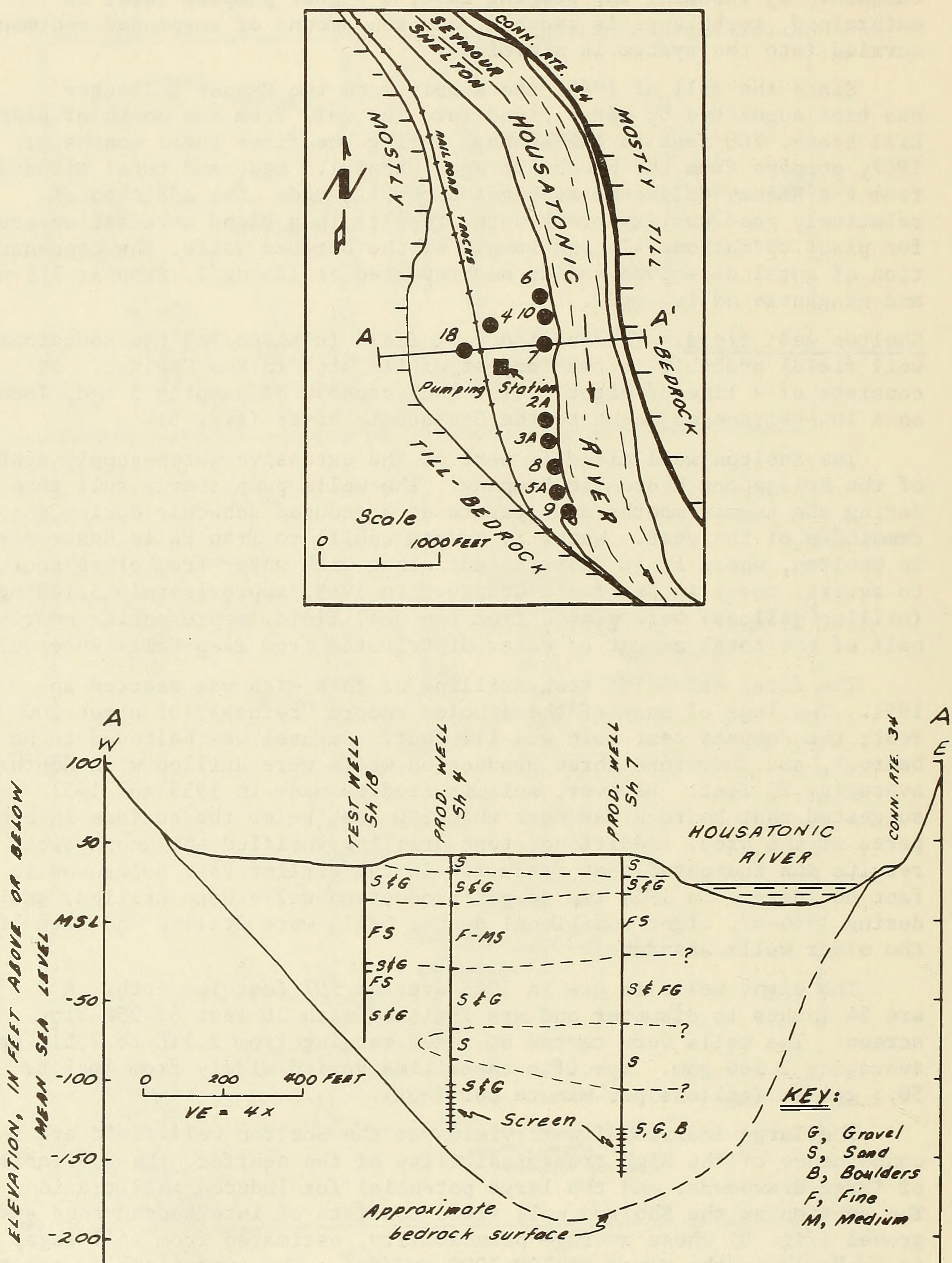


Fig. 6. Map and cross section at Shelton well field.

tests of eight wells, average pumping level was 97 feet, and maximum was 135 feet. The natural recharge area to the aquifer is restricted, and it is assumed that a large part of the pumpage is derived from induced infiltration, despite the presence of fine-grained river channel deposits. The Housatonic River at the site is of good quality and has a large volume of water potentially available. Near the well field the river is about 600 feet wide and 10 feet deep, and only rarely does average daily flow drop below the expected maximum pumpage of 25-30 mgd. The large drawdowns near the river probably permit maximum potential infiltration to occur under prevailing conditions.

Westport well field. The Westport well field (Stop 6) of the Bridgeport Hydraulic Company dates back to the early 1900's when a shallow dug well was the only public water supply for the town. The well field is located along the Saugatuck River in the Town of Westport (see location map, fig. 7). It consists of four wells spaced upstream from a low dam that marks the upstream extent of salt water. Well Wp 9 (No. 3), dug in 1953, is on the east side of the river about 150 feet upstream from the dam. This well is 20 feet deep, 48 inches in diameter, and has 12 feet of screen. Wells Wp 10 (No. 4), Wp 11 (No. 5) and Wp 12 (No. 6), are spaced about 450, 650, and 100 feet, respectively, upstream from the dam on the west side of the river (fig. 7). Well Wp 10 was constructed by the caisson method in 1953 and wells Wp 11 and Wp 12 were drilled in 1953 and 1957, respectively. Wells Wp 10, Wp 11, and Wp 12 are gravel packed, 69, 68, and 90 feet deep, respectively, and are finished with screens 37, 25, and 26 feet long set to the bottom of the stratified-drift aquifer.

Yields of individual wells range from 700 to 2,100 gpm. The maximum pumping rate of the well field is 8.1 mgd; total pumpage during 1966 was 293 mg and in 1967 it was 340 mg. Originally designed as a peaking facility, the well field in 1968 operated almost continuously. The continuous operation sometimes causes salt water from below the dam to intrude the aquifer. The concentration of chloride in samples of water analyzed by the U. S. Geological Survey in August 1964 ranged from 36 mg/l at well Wp 11 to 1,280 mg/l at well Wp 12. Reduced pumpage from well Wp 12 and channeling of the Saugatuck River around wells Wp 10, Wp 11, and Wp 12 has apparently halted further encroachment of salt water.

Coleytown well field. The Coleytown well field (Stop 3) is situated in Westport about 400 feet upstream from the confluence of the Aspetuck River and the East Branch of the Saugatuck River (see location map, fig. 8). It consists of production wells Wp 29 (No. 1) and Wp 30 (No. 2). Both wells are gravel packed, 59 feet deep, 24 inches in diameter and are finished with 250-slot screens 20 and 25 feet long. Because silty sand makes up the bottom of the stratified-drift aquifer, neither well is finished to bedrock; the log of well Wp 29 indicates that bedrock is 84 feet below land surface. Well Wp 29 was tested at a yield of 1,520 gpm with 34 feet of drawdown and well Wp 30 was tested at a yield of 1,100 gpm. The maximum pumping rate of the well field is 3.5 mgd, and the wells supplied 696 mg in 1966 and 205 mg in 1967. Much of the water is derived from induced infiltration of both rivers; in fact, pumpage has so greatly reduced streamflow at U. S. Geological Survey continuous-record gaging station 2095, about 2,000 feet downstream from the well field, that the station was discontinued in 1967.

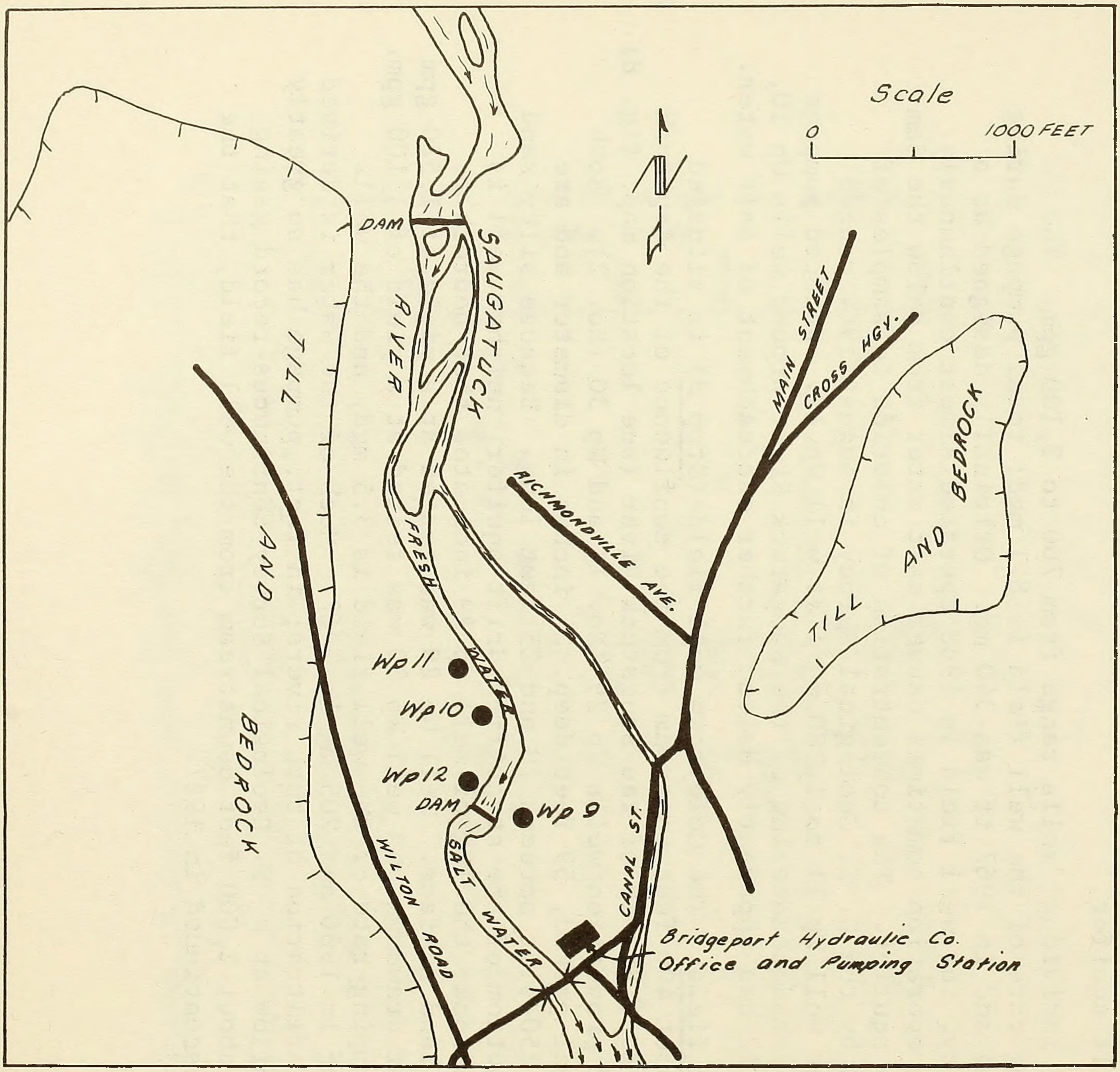


Fig. 7. Map of Westport well field.

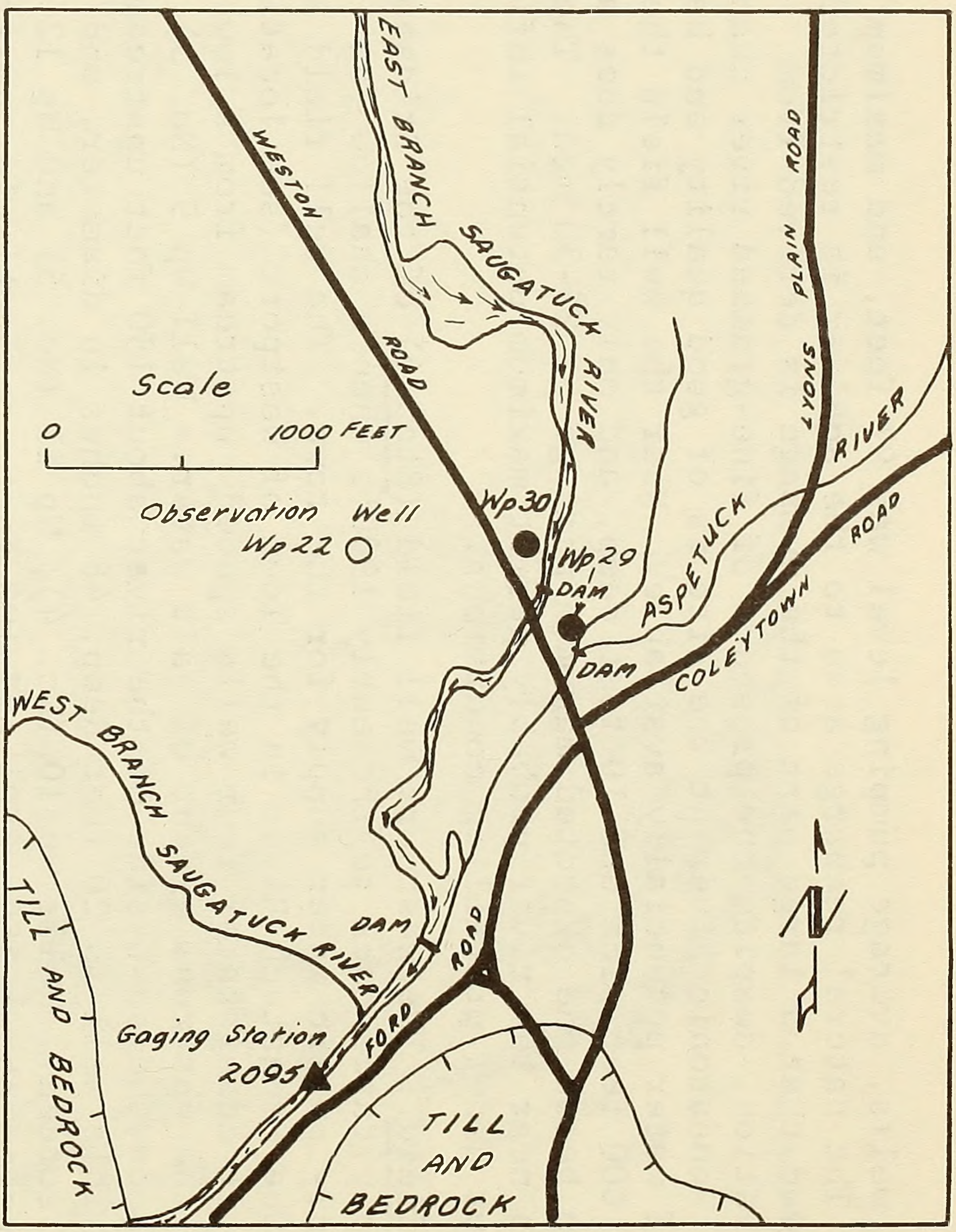


Fig. 8. Map of Coleytown well field.

WATER QUALITY

When water reaches the land surface it contains small amounts of dissolved solids. For example, monthly samples of precipitation in southwestern Connecticut had a dissolved-solids content that ranged from 6 to 96 mg/l, and the median value was 21 mg/l. Most samples were acidic; median pH was 4.6

As water moves over and through earth materials, it generally becomes more highly mineralized. In rural areas of southwestern Connecticut, water quality reflects principally the natural effects of climate and geology; in urban and industrialized areas its quality reflects the activities of man. Contrasts between the quality of water in natural environments and in environments affected by man are illustrated for water in streams on figure 9 and for water from wells on figure 12.

Under natural conditions, the quality of water in streams varies with stream discharge, as shown on figure 10, reflecting various mixtures of overland runoff and ground-water runoff. Specific conductance (a measure of the dissolved-solids concentrations) of water in streams is highest at low stream discharges when most of the streamflow is derived from ground water. The quality of water in streams during periods of low discharge can be used to determine areal variations in the quality of ground water and the relationship of geology to water quality.

Water samples collected from streams during periods of low discharge at 44 sites in southwestern Connecticut show that, under natural conditions, the quality of water from various noncarbonate rocks and sediments derived from them is generally similar, is soft, and is relatively low in dissolved solids. The sample collected from the Pomperaug River, which shows a hardness of 56 mg/l and maximum dissolved-solids content of 105 mg/l (see fig. 9), is representative of samples collected from noncarbonate rock terranes. On the other hand, a sample collected from Ridgefield Brook, which drains an area largely underlain by carbonate rocks and sediments derived from them, had a hardness measured at 215 mg/l and a dissolved-solids content of 268 mg/l.

In industrial and urban areas of southwestern Connecticut, the chemical characteristics of streams are determined more by man's activities than by climate and geology. Addition of domestic and industrial wastes to the streams alters the pH and increases the concentrations of such constituents as sulfate, chloride, iron, and total dissolved solids. The Naugatuck River is one of the most heavily contaminated streams in the State. Ranges in concentrations of various constituents in this river, based on 23 samples taken at Beacon Falls, are shown on figure 9 in comparison with stream quality under natural conditions as represented by the Pomperaug River.

Continuous records of specific conductance of the Naugatuck River at Beacon Falls, as shown on figure 11, indicate that at times the dissolved-solids concentration and streamflow vary inversely in the same relationship as shown for the uncontaminated Pomperaug River. However, figure 11 shows, for a 12-day period in July 1966, that specific conductance fluctuates widely several times during the course of a single day. During the same 12-day period, there was practically no variation in specific conductance in the water of Hall Meadow Brook, a natural stream in the headwaters of the Naugatuck River basin (fig. 11).

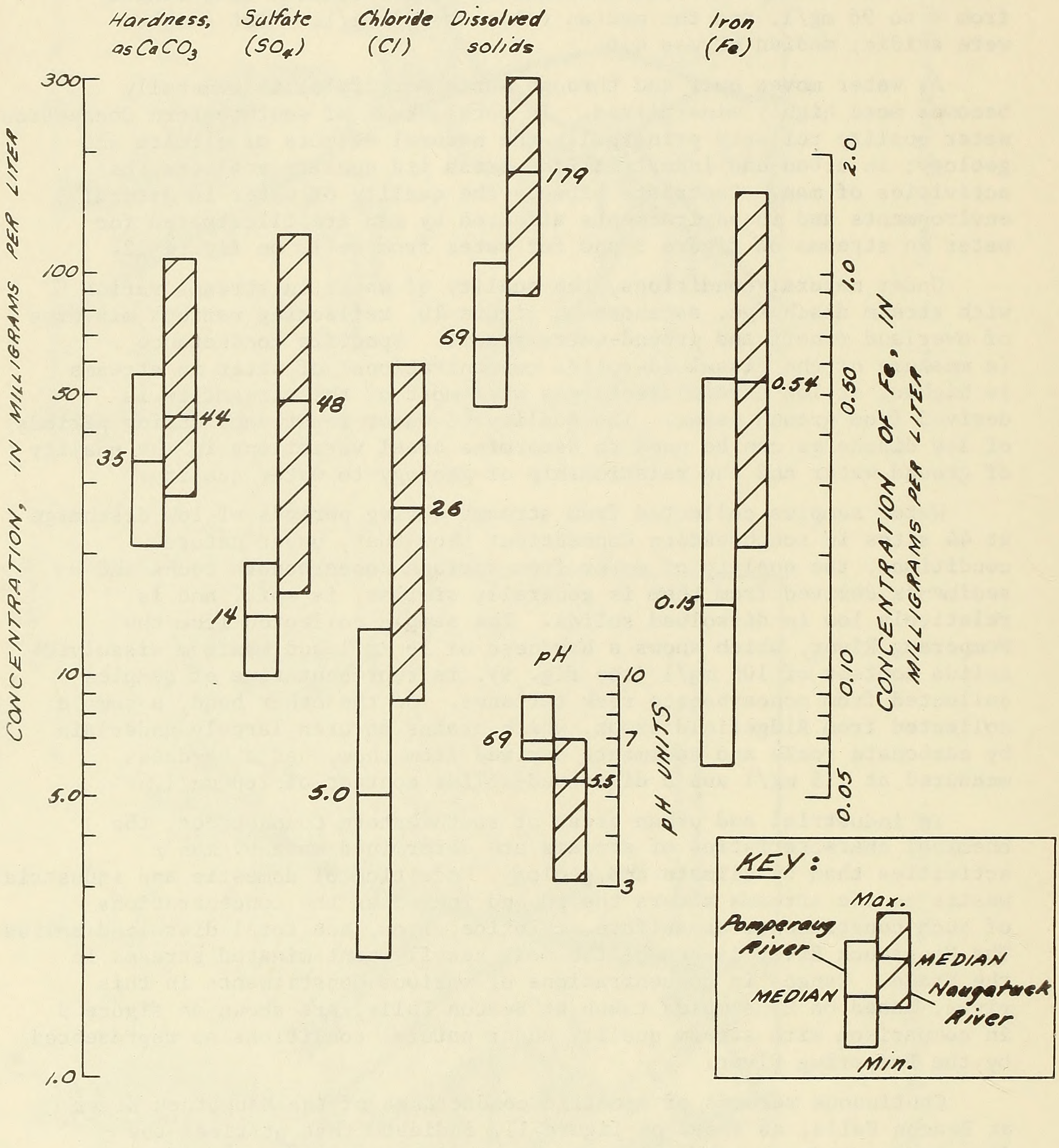


Fig. 9. Graph showing ranges in concentrations of selected constituents in water samples of the Naugatuck River and Pomperaug River.

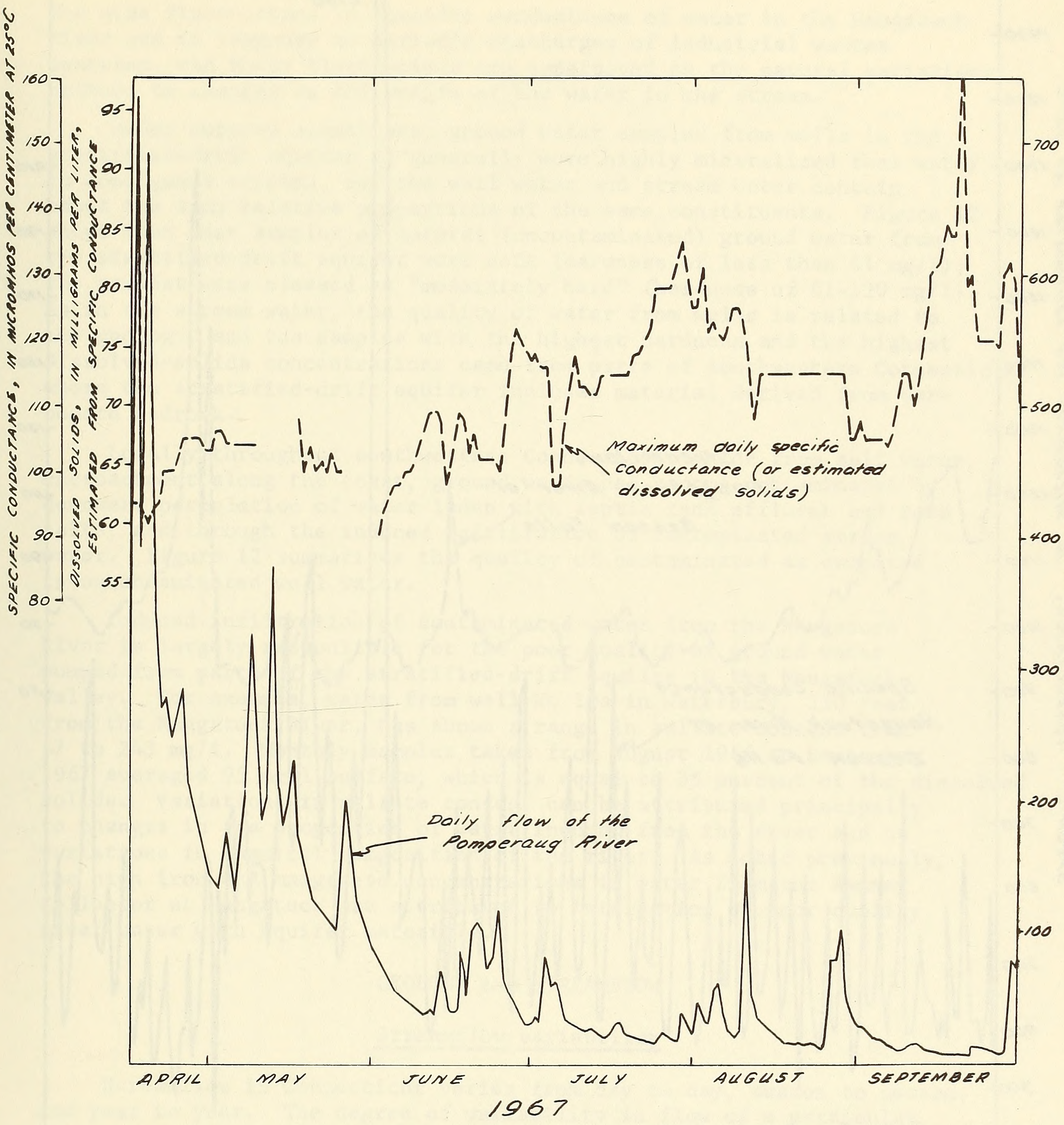


Fig. 10. Graph of specific conductance and streamflow, Pomperaug River at Southbury.

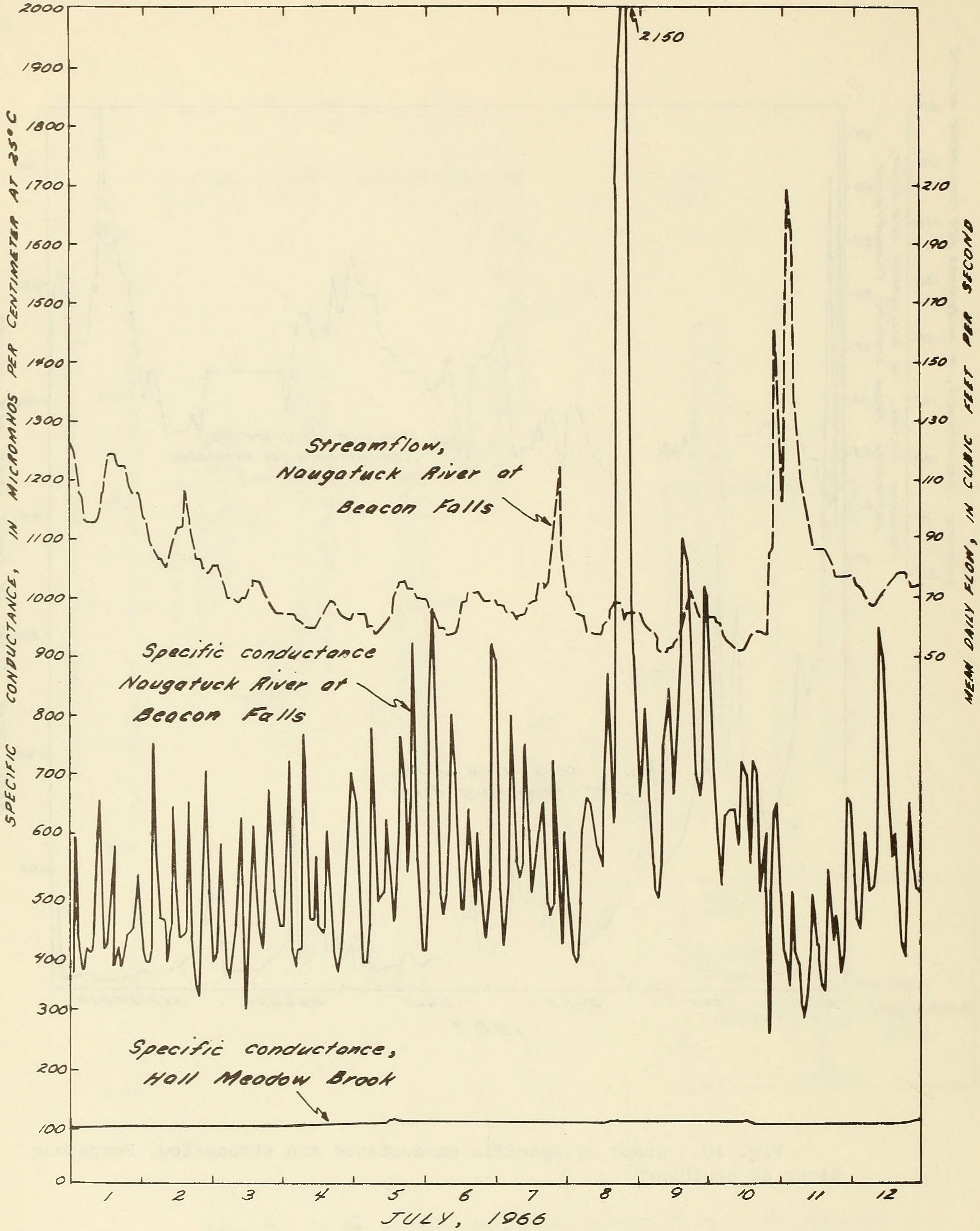


Fig. 11. Graph of specific conductance and streamflow, Naugatuck River at Beacon Falls.

The wide fluctuations in specific conductance of water in the Naugatuck River are in response to periodic discharges of industrial wastes upstream, and these fluctuations are superposed on the natural variations related to changes in the origin of the water in the stream.

Under natural conditions, ground water sampled from wells in the stratified-drift aquifer is generally more highly mineralized than water in contiguous streams, but the well water and stream water contain about the same relative proportions of the same constituents. Figure 12 shows that most samples of natural (uncontaminated) ground water from the stratified-drift aquifer were soft (hardness of less than 61 mg/1); the hardest were classed as "moderately hard" (hardness of 61-120 mg/1). As in the stream water, the quality of water from wells is related to the geology, and the samples with the highest hardness and the highest dissolved-solids concentrations came from parts of southwestern Connecticut where the stratified-drift aquifer includes material derived from carbonate bedrock.

Locally throughout southwestern Connecticut, aside from salt water encroachment along the coast, ground water has become contaminated by downward percolation of water laden with septic tank effluent and road salts, and through the induced infiltration of contaminated stream water. Figure 12 summarizes the quality of contaminated as compared to uncontaminated well water.

Induced infiltration of contaminated water from the Naugatuck River is largely responsible for the poor quality of ground water pumped from parts of the stratified-drift aquifer in the Naugatuck valley. For example, water from well Wb 10a in Waterbury, 250 feet from the Naugatuck River, has shown a range in sulfate content from 67 to 243 mg/1. Monthly samples taken from August 1966 to September 1967 averaged 95 mg/1 sulfate, which is equal to 35 percent of the dissolved solids. Variations in sulfate content can be attributed principally to changes in the proportion of water induced from the river and to variations in chemical composition of the river. As noted previously, the high iron and manganese concentrations in water from the Ranney Collector at Naugatuck are attributed to interaction of poor quality river water with aquifer materials.

GEOLOGY AND STREAMFLOW

Streamflow variability

Streamflow in Connecticut varies from day to day, season to season, and year to year. The degree of variability in flow of a particular stream is controlled by many complex factors, including those related to geology, geomorphology, and climate. Continuing studies in Connecticut suggest that the underlying stratified drift and till in a drainage basin integrate many of the geologic and geomorphic parameters that affect streamflow variability.

The variation in rate of streamflow may be expressed conveniently by means of flow-duration curves; the curves in figure 13 are examples. They show the percentage of time any particular mean daily flow was equaled or exceeded during 1931-60. They are adjusted to a statewide average flow of 1.80 cubic feet per second per square mile to reduce

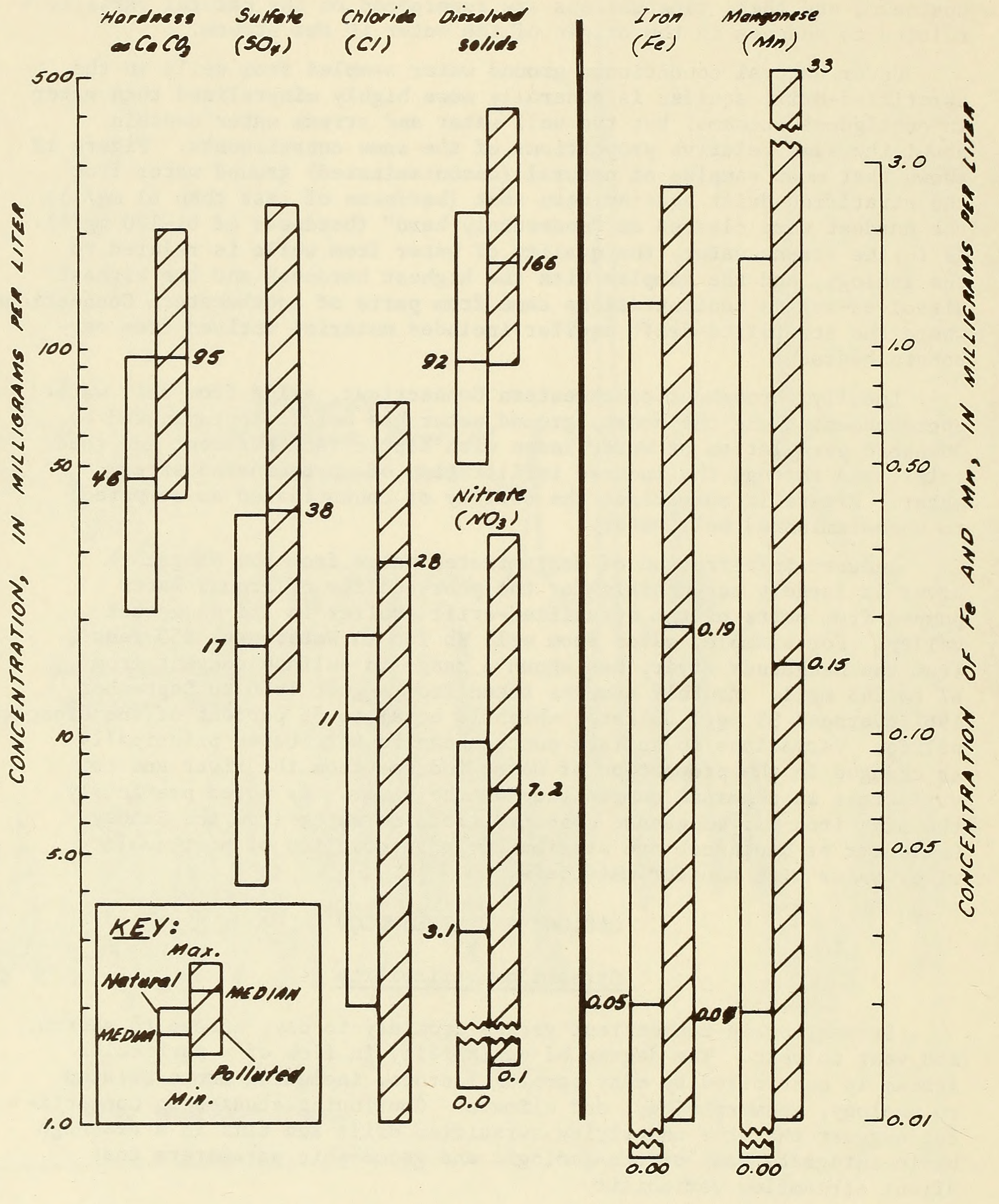


Fig. 12. Graph showing ranges in concentration of selected constituents in samples of contaminated and uncontaminated ground water.

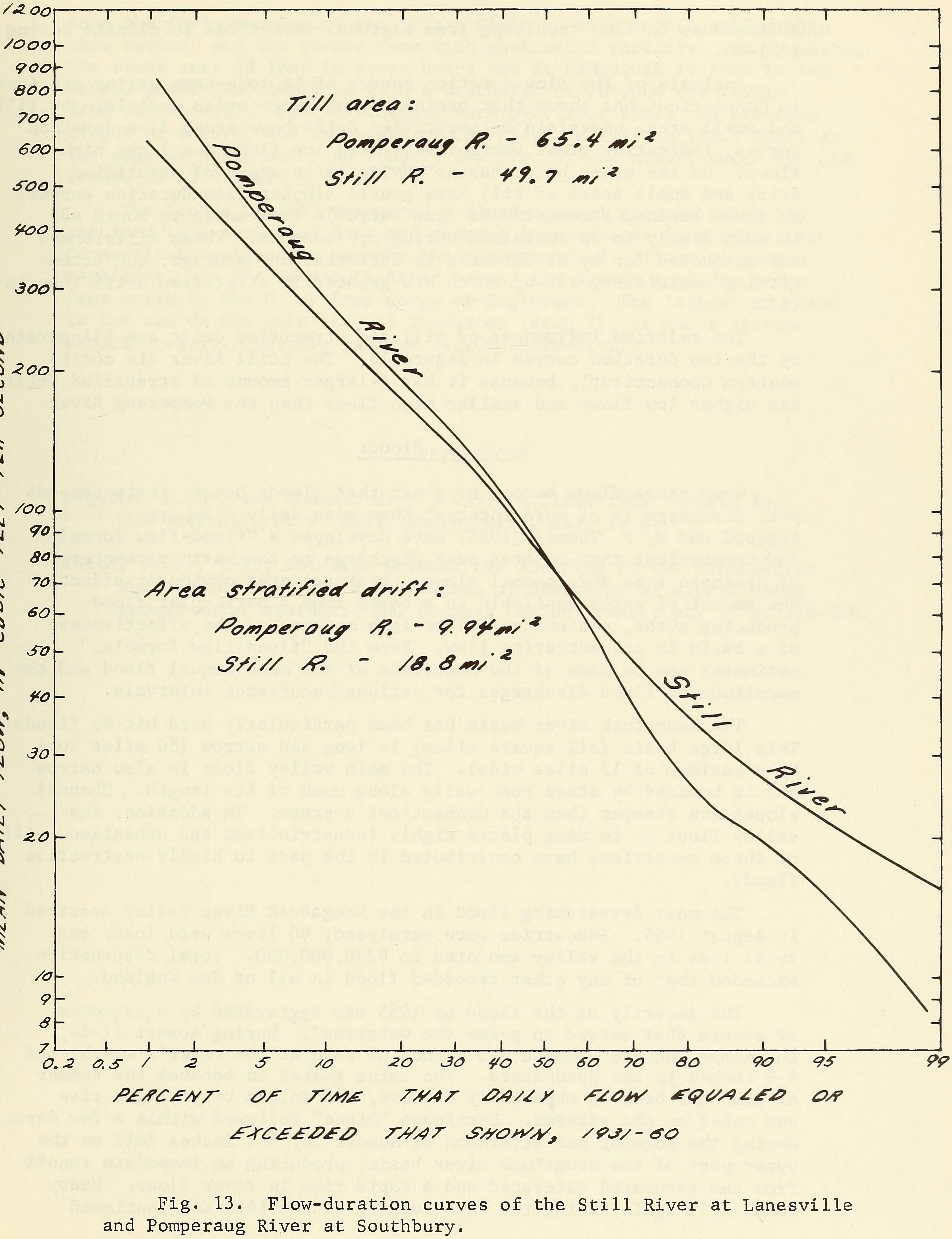


Fig. 13. Flow-duration curves of the Still River at Lanesville and Pomperaug River at Southbury.

differences in flow resulting from regional variations in climate during 1931-60.

Analysis of the flow-duration curves of 28 long-term gaging stations in Connecticut has shown that basins having large areas underlain by till and small areas underlain by stratified drift have steep flow-duration curves, indicating great variability--very low flows and large high flows. On the other hand, basins having large areas of stratified drift and small areas of till have gently sloping flow-duration curves. In these basins, streamflow is less variable from month to month and is more likely to be sustained during dry seasons. These differences are accounted for by differences in infiltration, storage, and transmitting capacities, all of which are greater in stratified drift than in till.

The relative influences of till and stratified drift are illustrated by the two duration curves in figure 13. The Still River (in northwestern Connecticut), because it has a larger amount of stratified drift, has higher low flows and smaller high flows than the Pomperaug River.

Floods

When streamflows become so great that floods occur, instantaneous peak discharge is of more interest than mean daily discharge. B. L. Bigwood and M. P. Thomas (1955) have developed a "flood-flow formula" for Connecticut that relates peak discharge to the basin parameters of drainage area and channel slope. Drainage area obviously affects the amount of water available in a basin from a particular flood-producing event, and channel slope is a measure of the effectiveness of a basin in concentrating flow. From the "flood-flow formula," estimates can be made of the magnitude of the mean annual flood and the magnitude of flood discharges for various recurrence intervals.

The Naugatuck River basin has been particularly hard hit by floods. This large basin (312 square miles) is long and narrow (50 miles long by a maximum of 12 miles wide). The main valley floor is also narrow and is bounded by steep rock walls along much of its length. Channel slopes are steeper than the Connecticut average. In addition, the valley floor is in many places highly industrialized and urbanized. All of these conditions have contributed in the past to highly destructive floods.

The most devastating flood in the Naugatuck River valley occurred in August 1955. Industries were paralyzed, 40 lives were lost, and total loss in the valley amounted to $230,000,000. Total destruction exceeded that of any other recorded flood in all of New England.

The severity of the flood of 1955 was aggravated by a sequence of events that served to prime the watershed. During August 11-14, Hurricane "Connie" dumped 4-5 inches of rain at the river's mouth, and 8-9 inches in the headwaters. The rains soaked in because the summer of 1955 had been an especially dry one, and only a very slight rise was noted on the streams. Hurricane "Diane" followed within a few days. During the morning and afternoon of August 18, 3-4 inches fell on the upper part of the Naugatuck River basin, producing an immediate runoff from the saturated watershed and a rapid rise in river flows. Heavy rains fell again during the late evening of the 18th and continued into the early morning of the 19th. Eight to nine inches fell within this period, and the rivers rose with phenomenal rapidity. At Thomaston the river rose 19 feet in seven hours and at Naugatuck 19 feet in ten hours, peaking at 10:30 am with a discharge of 106,000 cfs (cubic feet per second). Peak discharges were over four times the previous floods of record, and the stage of 25.7 feet (elevation 182.9 feet) at the gage at Naugatuck (at Stop 2; see fig. 5) was almost twice the old record of 13.9 feet.

The floods of 1955 triggered a flood-control program which has resulted in a series of dams and channel improvements in southwestern Connecticut designed to prevent the recurrence of a flood of such a magnitude. In the Naugatuck River basin, the system includes seven dams built by the U. S. Army Corps of Engineers. The largest of these is the dam on the main stem at Thomaston (Stop 3); it has a storage capacity of 13.7 billion gallons (42,000 acre-feet).

REFERENCES

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

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.

ROAD LOG FOR TRIP B-3

Topographic Quadrangles, 1:24,000, 7½ minutes:

Ansonia	Newtown
Bridgeport	Sherwood Point
Long Hill	Southbury
Milford	Thomaston
Mount Carmel	Waterbury
Naugatuck	Westport
New Haven	Woodbury

MILES Start Kline Geology Laboratory, NEW HAVEN QUADRANGLE

0.0 Start mileage count, leave parking lot, turn left (north) onto Whitney Ave.

0.4 Turn left (west) onto Edwards St.

0.6 Turn right (north) onto Prospect St. and then immediately left (west) onto Hillside Pl.

1.0 N.Y., N.H. and H. Railroad tracks, bear left onto Henry St.

1.5 Turn left (south) onto Sherman Ave.

1.9 Turn right (west) onto Rt. 69, Whalley Ave.

4.1 Bear left (northwest) onto Rts. 63 and 67.

7.2 NAUGATUCK QUADRANGLE.

7.5 Junction Rt. 67, proceed straight (north) on Rt. 63.

9.9 MOUNT CARMEL QUADRANGLE, on Rt. 63.

13.9 NAUGATUCK QUADRANGLE, on Rt. 63.

14.4 Stop 1. (23.13N-52.90E): Sand and gravel pit to the right (north) of Rt. 63, 1.5 miles west of intersection of Rts. 63 and 42.

Topics to be discussed:
- Aquifer materials.
- Aquifer coefficients.
- Effect of aquifer materials on aquifer characteristics.

14.4 Continue west on Rt. 63.

14.6 Wells of Connecticut Water Co. (Naugatuck Div.) on left (south) tap sand and gravel. Normally used only to supplement reservoir supplies during summer months, but operated continuously during drought of 1965-66. Pumpage results in measurable induced infiltration of Beacon Hill Brook. Water samples collected monthly from one of the wells for complete analysis.

16.1 Wells at Peter Paul, Inc. on left (south) tap sand and gravel.

17.4 Junction Rt. 8, turn left (south) onto Rt. 8; two left hand turns necessary.

17.7 UniRoyal, Inc. (Chemical Div.) on right (west) across Naugatuck River. Industrial wastes discharged into river.

18.6 Stop 2. (23.22N-51.72E): Ranney Collector, UniRoyal, Inc., 1.2 miles south of intersection of Rts. 8 and 63.

Topics to be discussed:
Aquifer characteristics in Naugatuck River valley.
Effect of induced infiltration on quality of ground water.
Variations of the quality of the Naugatuck River.
Construction characteristics of a collector well.

18.6 Go south on Rt. 8 to run-around at weighing station, proceed north on Rt. 8 following Naugatuck River upstream.

20.7 WATERBURY QUADRANGLE.

22.5 Cross Naugatuck River on Rt. 8.

22.9 Town of Waterbury sewage treatment plant and incinerator.

23.7 Several industrial wells on flood plain of the Naugatuck River on the right (east). Most have problems of screen incrustation, declining yield, and highly mineralized ground water. Water from well Wb 10a has been analyzed for sulfate since 1944.

25.0 Mixmaster junction of Interstate Rt. 84 and Rt. 8, proceed north on Rt. 8.

25.7 City of Waterbury. Few active wells in the city. Municipal water company supplies water for industrial and domestic purposes entirely from extensive reservoir system.

28.3 Chase Brass Co. on right (east) uses 4.5 mgd (million gallons per day) mostly from the Naugatuck River, except in warm months when three wells supply about 1.5 mgd of cooler ground water. Downstream from this point the Naugatuck River receives an increased amount of industrial pollution from the Waterbury-Naugatuck urban area.

29.1 Deeply weathered crystalline bedrock in road cut on the left (west).

30.3 U.S.G.S. test boring at drive-in theater on right (east) penetrated 75 ft. of saturated gravel.

30.8 THOMASTON QUADRANGLE.

31.1 Dredging operation for sand and gravel in channel of Naugatuck River to the right (east). Agitation by dredging causes aeration of the water, dissolved oxygen was 18% higher than upstream site in October 1967.

33.3 Reynolds Bridge, to the left(west) large outcrop of intricately folded and layered crystalline bedrock.

34.5 Seth Thomas Clock Co. (now a division of General Time Corp.) on left (west). Well drilled there in 1936 was reportedly tested at 1,300 gpm (gallons per minute) with a drawdown of 24 ft.

35.5 Exit Rt. 8 to Rts 6 and 202 west and cross Naugatuck River, U.S.G.S. stream gage 2069.

35.8 Turn right (north) in Thomaston onto Rt. 222.

36.4 Turn right (east) off Rt. 222 at sign to Thomaston Dam.

37.1 Stop 3. (31.40N-51.47E): Thomaston Dam, U. S. Army Corps of Engineers, 1.3 miles northeast of Thomaston.

Topics to be discussed:
Variation of streamflow with time and geology.
Variation of natural quality of streamflow.
Flooding in Naugatuck River valley.

37.1 Return to Rt. 8 south.

40.2 On Rt. 8, exit at Rts. 6 and 202 west, proceed southwest on these routes.

40.8 Junction Rt. 109, proceed on Rts. 6 and 202.

41.0 Thomaston Water Co. wells on left (south). Bedrock overdeepened by glacial scour; at least 104 ft. of stratified drift at one site.

41.5 Black Rock Pond State Park to the right; LUNCH STOP.

43.5 WATERBURY QUADRANGLE.

45.7 WOODBURY QUADRANGLE.

46.4 Drainage divide of Pomperaug River basin. Meinzer and Stearns published a classic study of the hydrologic budget of this basin in 1929.

48.5 Junction Rt. 61, proceed southwest on Rts. 6 and 202. Yields of Watertown Water Co. wells 0.5 mi. to north in Nonewaug River valley are augmented by induced infiltration from a stream that is diverted into a channel; flow in the channel is regulated by an upstream reservoir.

50.1 U.S.G.S. stream gage 2036 on Nonewaug River to the left (south).

52.2 Nonewaug River; U.S.G.S. test hole to the right (west) penetrated 62 ft. of sand and gravel overlying reddish till.

53.4 Center of Woodbury, proceed on Rts. 6 and 202.

53.8 Outcrop of Triassic trap on left (east).

54.0 U.S.G.S. observation well Wy 1 on left (east) used by Meinzer and Stearns in their study of the Pomperaug River basin and measured regularly since 1944.

55.7 Gravel pits and dredging operation across valley to the right (west).

56.6 SOUTHBURY QUADRANGLE.

56.7 Turn right (west) onto Rt. 67.

57.0 WOODBURY QUADRANGLE. U.S.G.S. test holes penetrated 60-70 ft. of stratified drift beneath the flood plain. Section is predominantly fine sand, which at eastern margin of flood plain is underlain by gravel.

57.2 Pomperaug River. Measurements with field permeameter indicate permeabilities of 300-400 gpd/sq. ft. for streambed materials.

57.5 Turn left (south) onto Poverty Road.

57.7 SOUTHBURY QUADRANGLE.

58.0 Ice-contact morphological features to the left (east).

58.5 Heritage Village, recipient of several architectural awards. Developers have constructed a waste-water disposal system and a water supply system consisting of two screened wells tapping sand and gravel with individual yields of 275 gpm.

59.1 Stop 4. (23.65N-46.98E): Pomperaug River stream gage 2040, 0.7 mi. west of Southbury.

Topics to be discussed:
- Effects of evapotranspiration on ground-water levels and streamflow.
- Continuous records of quality of the Pomperaug River.
- Meinzer's hydrologic budget as compared to new data.
- Permeabilities of streambed materials.
- Aquifer characteristics as demonstrated by controlled long-term pumping test.

59.1 Return to Rts. 6 and 202.

61.3 SOUTHBURY QUADRANGLE.

61.6 Turn right (south) onto Rts. 6 and 202.

62.8 Bear left onto Rt. 67, proceed to Interstate Rt. 84 south.

63.1 Turn right (southwest) onto I-84 south toward Danbury.

65.5 Approach narrow gap. Former channel of Pomperaug River plugged with at least 100 ft. of till and stratified drift. To north, bedrock valley overdeepened by glacial scour; altitude of bedrock surface is less than 50 ft. above msl (mean sea level).

66.7 Housatonic River (Lake Zoar); algal blooms are common in late summer. At deepest point altitude of bedrock surface is below msl.

67.5 NEWTOWN QUADRANGLE.

69.4 Exit I-84 to Rt. 34 - Sandy Hook.

69.6 Turn left (southeast) at I-84 ramp onto Rt. 34. Pootatuck River basin upstream from Sandy Hook is underlain by about 33 percent stratified drift.

70.0 Exposure of coarse-grained stratified drift in large gravel pits.

71.7 SOUTHBURY QUADRANGLE.

75.7 Turn right (south) onto Rt. 111.

76.7 LONG HILL QUADRANGLE.

77.6 Turn left (southeast) onto Barn Hill Rd.

79.1 Top of Bran Hill, a drumlin; one well penetrates 120 ft. of till overlying bedrock.

79.7 Turn left (east) onto unnamed road.

80.1 Turn left (east) onto Rt. 110.

80.4 Cross Means Brook.

83.0 ANSONIA QUADRANGLE.

83.1 Housatonic River valley to left (east).

83.3 Turn sharp left (northwest) onto Indian Well Rd. at sign to Indian Wells State Park.

83.8 LONG HILL QUADRANGLE.

85.3 Turn right across railroad tracks, Shelton well field on right (east).

85.5 Stop 5. (19.10N-49.24E): Shelton well field pumping station, Bridgeport Hydraulic Co., 2.2 mi. northeast of intersection of Rt. 110 and Indian Well Rd.

Topic to be discussed:
- Development of largest well field in New England.
- Areal extent, thickness, and lithology of stratified-drift aquifer at site.
- Induced infiltration.
- Quality of Housatonic River.

85.5 Return to Rt. 110 via Indian Well Rd.

87.6 ANSONIA QUADRANGLE.

87.9 Bear left onto Rt. 110.

89.1 Head of estuary of Housatonic River is at the Shelton-Derby dam across Housatonic River on left (northeast). Oldest dam on Housatonic River, built in 1806.

89.8 Center of Shelton.

91.8-92.2 Upstream extent of salt water in Housatonic River fluctuates within this reach depending upon flow of the river and height of tides.

92.6 Well next to the river at Industrial Lofting and Manufacturing Co. on left (southeast) reportedly does not pump salt water.

95.3 Sikorsky Aircraft on left (east). Test holes in stratified drift yielded salt water; plant supplied by Bridgeport Hydraulic Co.

95.7 MILFORD QUADRANGLE.

98.2 Junction Rts. 113 and 110, bear left (south) onto Rt. 110.

99.6 Junction U.S. Rt. 1, turn right (southwest) of traffic circle onto Rt. 1 and proceed to Interstate-95, Connecticut Turnpike, west.

99.9 Rt. I-95, west.

100.1 BRIDGEPORT QUADRANGLE.

100.2 Toll booths.

102.7 Wells at Town of Stratford incinerator penetrated 52 to 58 ft. of sand and silt overlying bedrock. U.S.G.S. test hole 1 mi. southeast penetrated 107 ft. of very fine sand and silt grading down to clay and did not reach bedrock.

103.7 Cross Yellow Mill Channel, Bridgeport Harbor to left (south). Test hole for bridge reached bedrock at 85 ft. below msl and penetrated 81 ft. of silt and clay. Low-lying areas of Bridgeport underlain by fine-grained outwash plain deposits.

104.3 - 104.5 Cross Poquonock River estuary, Long Island Sound to left (south), salt water extends about 1.5 miles upstream to the right (north). During the 1930's and 1940's, a number of industrial wells located along the river tapping stratified drift as well as bedrock produced salty water and were abandoned. Most industries in the city are now supplied water by the Bridgeport Hydraulic Co.; no data are available as to the present extent of salt water in these aquifers. Test hole at east end of bridge reached bedrock at 121 ft. below msl and penetrated 97 ft. of very fine sand and silt overlain by 15 ft. of estuarine deposits.

108.4 WESTPORT QUADRANGLE.

109.8 Cross Mill River estuary, salt water extends about 1.5 mi. upstream to a small dam that also marks the head of tide. Model analysis of a relatively extensive stratified drift aquifer upstream from the dam indicates that an annual ground-water withdrawal of 3.7 mgd is available 7 years out of 10. Well tapping bedrock at DuPont Co. on left (south) was abandoned because it yielded salty water. Maximum known depth of bedrock at I-95 is 96 ft. below msl where a State Highway test hole penetrated 110 ft. of very fine sand and silt.

112.0 SHERWOOD POINT QUADRANGLE.

116.1 Cross Saugatuck River estuary, salt water extends about 2 mi. upstream to a small dam that also marks the head of tide. Maximum known depth of bedrock at I-95 is 70 ft. below msl where a State Highway test hole penetrated 60 ft. of fine to very coarse sand. Bedrock valley is glacially overdeepened upstream.

116.4 Exit I-95 at exit 17 to Rt. 33 north.

116.6 Turn left (north) off exit ramp onto Rt. 33.

116.9 WESTPORT QUADRANGLE, at traffic circle proceed north on Rt. 33 at western edge of Saugatuck River estuary.

118.2 Junction U.S. Rt. 1, proceed north on Rt. 33.

118.6 Junction Rt. 136, proceed north on Rt. 33.

119.0 Turn right (east) onto Boltan Lane to dirt road on right.

119.1 Stop 6. (11.60N-43.01E): Westport well field, Bridgeport Hydraulic Co., 0.5 mi. north of Junction Rts. 136 and 33.

Topics to be discussed:

Development of well field including artificial recharge to offset salt water intrusion.

Effects of induced infiltration on quality of pumped water.

119.1 Return to Rt. 33 and turn left (south).

119.5 Turn left (east) onto Rt. 136 and cross Saugatuck River estuary. State Highway test hole at west end of bridge penetrated 101 ft. of sand and gravel without reaching bedrock although large outcrop is visible to the right on a small island in middle of the river.

119.6 Westport well field pumping station.

119.7 Proceed northeast on Canal St. at traffic circle.

119.9 Turn left at traffic light onto Rt. 57, Main St.

120.1 Bear left at "Y", proceed on Rt. 57.

120.4 Turn left (northwest) at traffic light onto Clinton Ave.

121.7 Stream-gaging station 2095 on Saugatuck River on the left, abandoned because of regulation upstream by Saugatuck Reservoir as well as loss of streamflow at Coleytown well field. Thickness of stratified drift aquifer is 0 ft. here, bedrock exposed in small outcrop on river bank immediately downstream.

121.8 Bear left at small traffic circle.

121.9 Turn left onto Rt. 57, Weston Rd., cross Aspetuck River, production well no. 1, Coleytown well field, on right.

122.1 Cross Saugatuck River and turn right onto dirt road.
Stop 7. (12.56N-43.13E): Coleytown well field, Bridgeport Hydraulic Co., at Rt. 57 bridges over Aspetuck River and Saugatuck River.

Topics to be discussed:

Development of well field, need, method of development.
Effect of induced infiltration on streamflow.
Field measurement of rate of streambed infiltration.
Effects of long-term pumping on ground-water levels.

122.1 Return to Rt. 57.

122.2 Turn left (southeast) onto Rt. 57.

123.3 Bear left (south) onto Rts. 136 and 57.

123.7 Turn left onto Rt. 136.

125.0 Turn left (east) onto U.S. Rt. 1.

126.1 Turn right (south) onto Sherwood Island Connection at sign to Sherwood Island State Park.

127.0 SHERWOOD POINT QUADRANGLE.

127.3 Cross I-95, turn left onto I-95 eastbound entrance ramp to New Haven.

128.6 WESTPORT QUADRANGLE.

132.2 BRIDGEPORT QUADRANGLE.

141.2 Toll booths.

141.3 MILFORD QUADRANGLE.

142.5 Cross Housatonic River. Bedrock outcrops on west bank; maximum depth of rock beneath river is at 115 ft below msl.

144.4 Milford Water Co. wells to the right (southeast); two wells supplied about 0.6 mgd in 1965.

148.4 ANSONIA QUADRANGLE.

150.1 NEW HAVEN QUADRANGLE.

152.7 Toll booths, proceed east on I-95.

156.1 Turn left (north) onto I-91 exit north, proceed north on I-91.

157.0 Turn right onto exit 3, Trumbull St. in New Haven, proceed west on Trumbull St.

157.7 Turn right (northeast) onto Whitney Ave.

158.0 Turn left (west) into parking lot, proceed to Kline Geology Laboratory.