STATE OF CONNECTICUT
DEPARTMENT OF ENVIRONMENTAL PROTECTION

A METHOD FOR ESTIMATING THE 7-DAY, 10-YEAR LOW FLOW OF STREAMS IN CONNECTICUT

By

Michael A. Cervione, Jr. and Robert L. Melvin,
U.S. Geological Survey,
and
Kathleen A. Cyr,
Connecticut Dept. of Environmental Protection

CONNECTICUT WATER RESOURCES BULLETIN NO. 34

1982

STATE OF CONNECTICUT

DEPARTMENT OF ENVIRONMENTAL PROTECTION

A METHOD FOR ESTIMATING THE 7-DAY, 10-YEAR LOW FLOW OF STREAMS IN CONNECTICUT

By

Michael A. Cervione, Jr. and Robert L. Melvin,
U.S. Geological Survey, and Kathleen A. Cyr,
Connecticut Dept. of Environmental Protection

Connecticut Water Resources Bulletin No. 34

1982

CONTENTS

ILLUSTRATIONS

TABLE

CONVERSION FACTORS

Factors shown below are used to convert the inch-pound units used in this report to the International System of metric units (SI):

Multiply Inch-pound unit	By	To obtain SI unit
feet (ft)	0.3048	meters (m)
miles (mi)	1.609	kilometers (km)
square miles (mi^2)	2.590	square kilometers (km^2)
cubic feet per second (ft^3/s)	.02832	cubic meters per second (m^3/s)
million gallons per day (Mgal/d)	3.785×10^3	cubic meters per day (m^3/d)

A METHOD FOR ESTIMATING THE 7-DAY, 10-YEAR LOW FLOW OF STREAMS IN CONNECTICUT

By Michael A. Cervione, Jr., Robert L. Melvin, and Kathleen A. Cyr

ABSTRACT

A method for estimating the 7-day, 10-year low flow of ungaged Connecticut streams is presented in this report. The 7-day, 10-year low flow is the statistical low-flow index most commonly used in Connecticut for water-resources planning and management. The method described is based upon the fact that low flows are sustained by the discharge of water from adjacent aquifers.

An equation for estimating the 7-day, 10-year low flow at an ungaged site on a stream unaffected by man's activities was determined by regression analysis. The analysis related the observed 7-day, 10-year low flow at 27 stream-gaging stations to the areal distribution of each major aquifer in the upstream drainage area. The standard error of estimate is 1.4 cubic feet per second.

The aquifer having the best water-yielding characteristics is coarse-grained stratified drift. Through the use of the regression equation, it is estimated that only 0.15 square mile of coarse-grained stratified drift in a drainage basin can yield a 7-day, 10-year low flow of 0.1 cubic foot per second. The till-mantled bedrock yields significantly lesser amounts of water to streams at times of low flow. However, a 7-day, 10-year low flow of 0.1 cubic foot per second (from the regression equation) can be expected from a drainage basin underlain exclusively by till-mantled bedrock if its upstream drainage area is 10 square miles or more.

INTRODUCTION

The low-flow characteristics of a stream are commonly critically important with respect to water supply, waste disposal, power generation and navigation. During drought, the economic and environmental well being of an entire region can be adversely affected. Water-resource planners and managers need information on the magnitude, frequency, and duration of low streamflows to minimize adverse impacts.

In Connecticut, the lowest annual mean discharge during 7 consecutive days with a recurrence interval of 10 years, is the low-flow index most commonly used in water-resources planning and management. This statistically derived value is termed the "7-day, 10-year low flow"; streamflows are greater than this value about 99 percent of the time in Connecticut streams. The probability of a 7-day low flow being less than the 7-day, 10-year low flow in any given year is 10 percent.

At present, the the 7-day, 10-year low flow information is used mostly by the Connecticut Dept. of Environmental Protection for developing low-flow criteria, which, in turn, are used for water-quality standards (Connecticut Dept. of Environmental Protection, 1980), for evaluating waste-water discharge applications, for siting of treatment plants and sanitary landfills, and for setting minimum release requirements below impoundments. Accordingly, the Connecticut Dept. of Environmental Protection has been engaged in a cooperative program with the U.S. Geological Survey to develop and refine techniques for estimating the 7-day, 10-year low flow of streams in the State.

Purpose and Scope

The 7-day, 10-year low flow can be determined at any site where streamflow has been measured for a sufficient period of time. Mostly, however, the information is needed at ungaged locations. The purpose of this report is to outline a method for estimating the 7-day, 10-year low flow at any site on any stream in Connecticut that is not affected by tide, does not have its flow artificially manipulated during low flow periods, and does not drain an area having an appreciable degree of urbanization. The method is based upon the fact that low flows are sustained by the discharge of water from adjacent aquifers. It utilizes an equation determined from a regression analysis relating the observed 7-day, 10-year low flow at 27 stream-gaging stations to the areal distribution of major water bearing units in the upstream drainage area.

Besides explaining the method used to estimate the 7-day, 10-year low flow at ungaged sites, the report discusses the standard error of estimate and lists the 7-day, 10-year low flow at gaged sites.

HYDROLOGIC FRAMEWORK

Geology, ground water and low flow

In Connecticut, low streamflows are sustained by ground-water discharge. This discharge, termed ground-water runoff, is a major source of streamflow throughout the year, with the exception of periods during and immediately after large storms, when most of the flow may be derived from surface runoff. During protracted dry periods, some aquifers may become depleted, and some streams may not flow. Low streamflows are most common in the growing season when precipitation is generally utilized by plants or to meet soil moisture needs. Streamflows are generally lowest during the latter part of this approximately 6-month period, as shown in figure 1.

The basic hydrologic framework for investigating ground-water contributions to streamflow and other aspects of streamflow variability is the drainage basin. In most parts of the State, the surface-water and ground-water drainage divides are coincident, and the only source of water is precipitation within the area bounded by the drainage divides. The pattern of ground-water circulation in a typical Connecticut drainage basin unaffected by man's activities is shown in figure 2.

Note that in a few areas, principally within north-central Connecticut, the extent of the ground-water flow system may be different from the surface-water drainage area and cannot be defined by topographic drainage divides. In a relatively few other basins, there are interbasin transfers of water. If either condition exists, the drainage basin may not constitute an appropriate framework for low-flow studies without additional information.

The geology of a drainage basin significantly affects the time-distribution of streamflow and particularly the low-flow characteristics. Basins in Connecticut and adjacent parts of New England and New York are underlain by three major water-bearing geologic units or aquifers: stratified drift, till, and bedrock. Stratified drift is an unconsolidated sediment composed of interbedded layers of gravel, sand, silt, and clay. These deposits are generally restricted to valley areas that served as drainage ways for glacial meltwater or were the sites of temporary glacial lakes. The stratified drift in a basin can be further characterized as either "coarse-grained" (dominantly fine sand to gravel), or "fine-grained" (dominantly very fine sand, silt, and clay). Coarse-grained stratified drift has relatively high hydraulic conductivities and storage coefficients and, consequently, has the best water-yielding characteristics of the geologic units. Previous studies summarized by Cervione and others (1972) indicate that in areas directly underlain by this material both average annual recharge from precipitation and average annual ground-water runoff are approximately three times greater than from till and bedrock areas.

Fine-grained stratified drift, conversely, has poor water-yielding characteristics. Information (Ryder and others, 1981) suggests that areas directly underlain by this material are hydrologically similar to till and bedrock, in respect to ground-water runoff to streams. Extensive fine-grained stratified drift is not common except in the north-central part of the State.

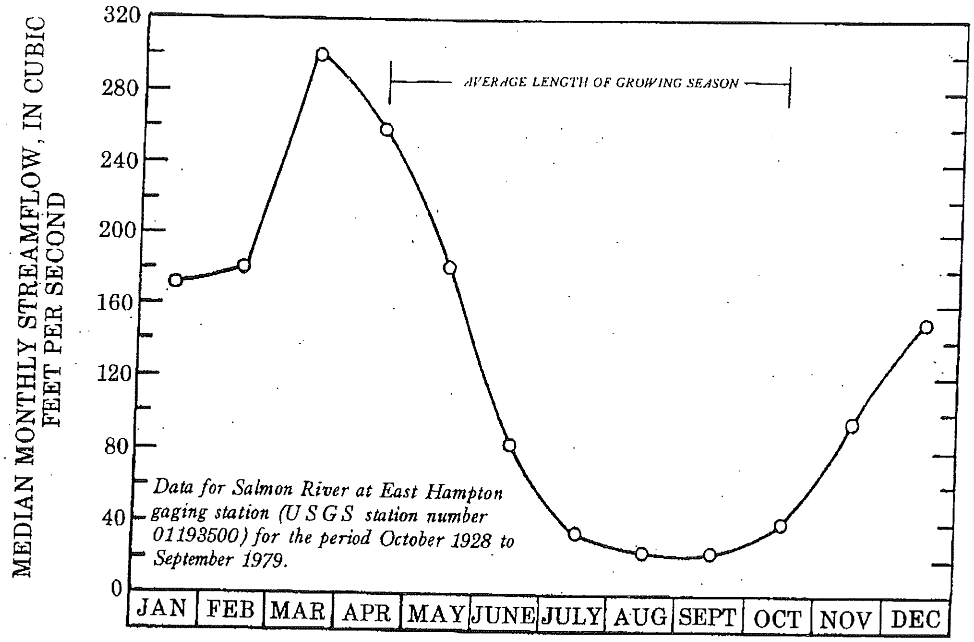
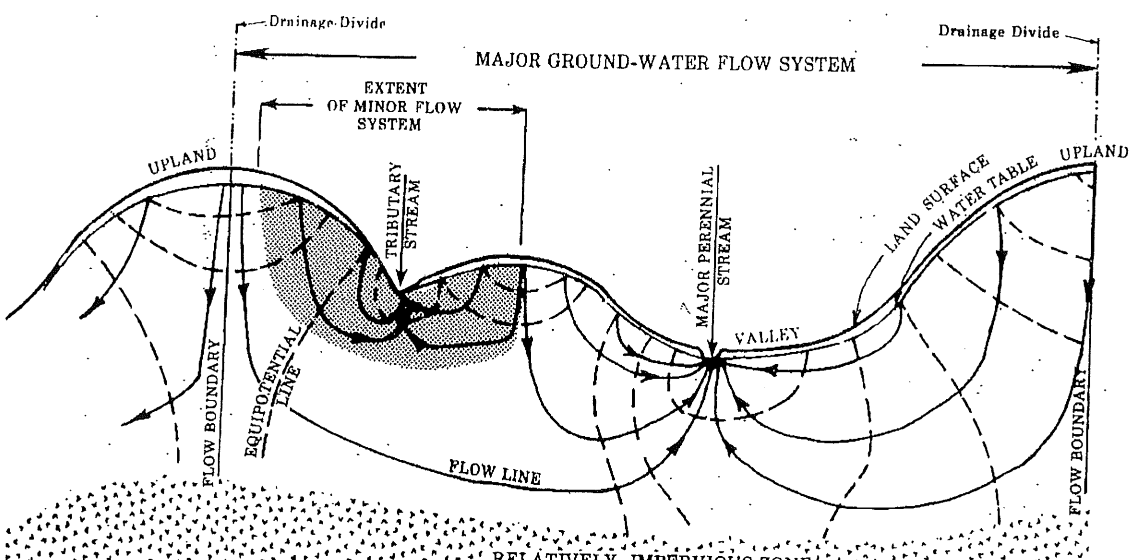


Figure 1.--Seasonal pattern of streamflow in Connecticut

This hydrograph illustrates the typical seasonal pattern of flows. During the growing season, most precipitation is returned to the atmosphere by evaporation and transpiration and there is relatively little surface runoff or ground-water recharge.



Source: Cervione and others (1972)

Figure 2.--Generalized ground-water circulation within a typical Connecticut drainage basin

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

Till is an unconsolidated, non-stratified heterogeneous sediment, deposited directly by glacial ice. Most bedrock in the State is overlain by till that averages less than 10 feet thick. Bedrock in Connecticut may be aggregated into two general types: crystalline bedrock that includes a variety of metamorphic and igneous rocks, and sedimentary bedrock, composed predominantly of sandstone and shale that underlies the central part of the State. Bedrock of one type or another underlies every drainage basin. In some, it is discontinuously mantled by till, whereas in others, it is covered by both till and stratified drift. Surficial geologic maps, available for almost all parts of the State, show the areal distribution of these units. The Connecticut Dept. of Environmental Protection has recently published an information directory (Henney, 1981) that lists available geologic maps and instructions for obtaining them.

Till and bedrock are considered as a hydrologic unit in subsequent analyses and the unit is termed "till-mantled bedrock." This consolidation is warranted in that both materials have significantly lower average hydraulic conductivities and storage coefficients than coarse-grained stratified drift and hence poorer water-yielding characteristics. From a practical perspective, it is also not possible to differentiate on available geologic maps the areas underlain only by exposed bedrock from those where the bedrock is overlain by saturated or unsaturated till. Where fine-grained stratified drift has been mapped as the surficial geologic unit, it has also been included in the "till-mantled bedrock" hydrologic unit.

Ground-water contributions to streamflow are governed principally by the transmissivity (average hydraulic conductivity times saturated thickness) and storage coefficient of the water-yielding units, the average hydraulic gradient, and the area of stream channel through which the ground water discharges. Another factor not considered in this or previous studies is differences in the quantity of ground-water evapotranspiration from one basin to another. If all other conditions were equal, the differences in ground-water runoff to streams from one site to another would be proportional to differences in the quantity of ground-water evapotranspiration in the upstream drainage areas.

M. P. Thomas' study of the relationship between surficial geology and the time-distribution of streamflow (Thomas, 1966) was the first to quantify the relationship between geology of a drainage area and the magnitude and frequency of low flows in Connecticut. In this study, flow-duration curves (cumulative frequency curves showing the average period of time specific daily flows are equaled or exceeded) from several continuous record stream-gaging stations were evaluated with respect to the geology of the drainage basin. The results, summarized in a family of flow-duration curves, are shown in figure 3.

The lower part of these curves (flows equaled or exceeded 80 to 99.9 percent of the time) show that the magnitudes of low flows are related to the relative percentage of the drainage area directly underlain by coarse-grained stratified drift rather than till-mantled bedrock. As pointed out by Thomas, the relatively large ground-water runoff from stratified drift is a reflection of its large infiltration and storage capacity and its ability to transmit water.

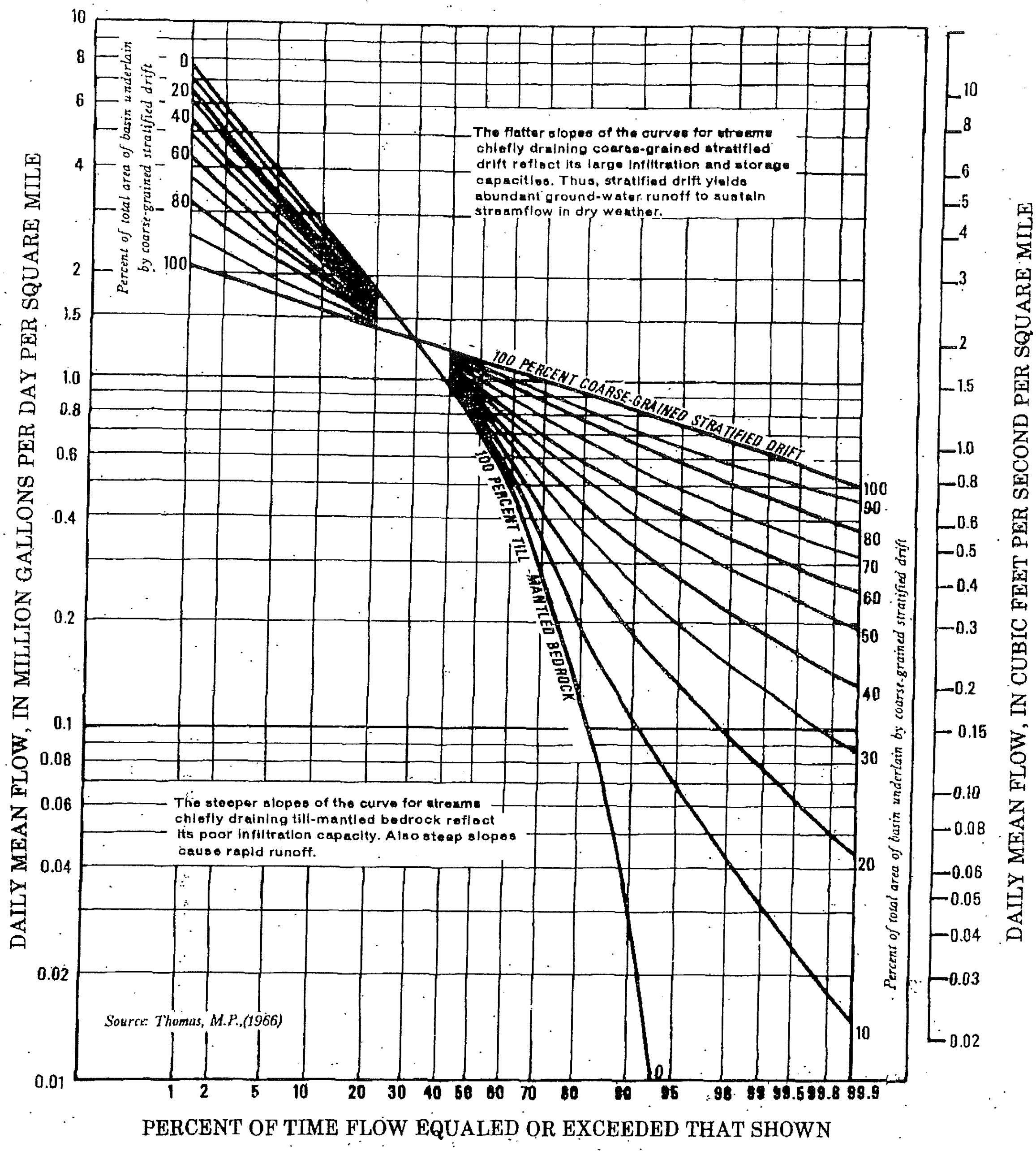


Figure 3.--Regional duration curves showing effects of basin geology on streamflow

Curves are for unregulated streams having a mean flow of 1.16 million gallons per day per square mile and are based on the period October 1930 to September 1960.

Analytical or numerical solutions to ground-water-flow equations can be used to quantify ground-water discharge to streams. The parameters needed for solution of the flow equations such as transmissivity, storage coefficient, and hydraulic gradient are costly to define over large areas. The investigation of flow duration by Thomas (1966) and of frequency and duration of low streamflow (Brackley and Thomas, 1979) used only the areal distribution of the major water-bearing units, parameters that could readily be determined statewide. The method for estimating the 7-day, 10-year low flow outlined in the following section also uses as input the areal distribution of coarse-grained stratified drift and till-mantled bedrock.

A map showing the estimated 7-day, 10-year low flow of streams in part of central New England was prepared by Brackley and Thomas (1979). The flow values on this map are divided into several classes (e.g., "less than 0.1" to "greater than 50" cubic feet per second) and were determined from records of long-term gaging stations, correlation of short-term or partial-record sites with long-term gaging stations, and regional relationships between the total drainage area and flow per square mile from areas underlain by stratified drift and areas underlain by till and bedrock. This report is a continuation of that effort. The focus, however, is on providing a simple method for estimating the 7-day, 10-year low flow at an ungaged site rather than mapping the statewide distribution of this flow characteristic.

REGRESSION ANALYSIS

An effective way for statistically defining the dependency of a streamflow characteristic on one or more independent variables, such as drainage area, average rainfall, or area of stratified drift, is to develop an equation by multiple regression techniques. Once the equation that adequately defines the relationship is derived, the characteristic of interest can be estimated for any site, providing that the site meets the established criteria and that the appropriate values of the independent variables can be determined.

The conceptual model used in the subsequent regression analysis is an outgrowth of Thomas' earlier studies (Thomas, 1966; Thomas and Cervione, 1970) and can be stated as follows: The 7-day, 10-year low flow at any site on a stream is dependent on the proportion of upstream drainage area underlain by coarse-grained stratified drift and the proportion underlain by till-mantled bedrock.

This relatively simple model and resulting analysis incorporates the following assumptions:

1) The 7-day, 10-year low flow at any site on any stream unaffected by man's activities is derived entirely from ground-water runoff.

2) The water-bearing units that contribute to ground-water runoff can be aggregated into two broad classes. The first, termed "coarse-grained stratified drift", is characterized by relatively high ground-water storage per unit area and relatively high transmissivity. The second, termed "till-mantled bedrock," also includes minor areas of fine-grained stratified drift and is characterized by relatively low ground-water storage per unit area and relatively low transmissivity.

3) The magnitude of the 7-day, 10-year low flow is a function of the amount of ground-water runoff from each water-bearing unit and the areal extent of each unit can be used as a surrogate parameter.

4) The extent of the ground-water and surface-water drainage areas contributing to the streamflow are coincident and are defined by the topographic drainage divides.

5) Areal differences in ground-water evapotranspiration are not large enough to affect 7-day, 10-year low flows significantly.

Variables and Data-Selection Criteria

The dependent streamflow characteristic is the 7-day, 10-year low flow (in cubic feet per second) as determined by the log-Pearson type III technique (Riggs, 1968) for 27 stream-gaging stations in Connecticut and nearby parts of adjacent states.

Drainage areas at gaging stations ranged from 0.94 to 132 square miles. The stream-gaging stations used in the analysis and their 7-day, 10-year low flows are listed in table 1; each station is located in figure 4.

The base period to which the flows apply is the reference period April 1, 1941, to March 31, 1971. Fourteen gaging stations had the full 30 years of record; six had between 20 and 30 years of record; and seven had between 10 and 20 years of record. Ten years was considered the minimum record length possible to accurately extrapolate to 30 years.

A correlation technique, based on a comparison of flow-duration curves, was used to determine the reference period 7-day, 10-year low flow at stations with less than the required 30-year record. First, a nearby gaging station with similar geologic characteristics that had been operating throughout the 30-year reference period was selected. Flow duration curves for this long-term station were then plotted for (1) the 30-year reference period and (2) the period concurrent with the record at the station of interest. The two curves were compared and in each case plotted

Table 1.—Gaging stations used for 7-day, 10-year low flow analysis

(Flow data are for reference period April 1, 1941 to March 31, 1971)

USGS Station no.	Gaging station	Drainage area (square miles)	Area underlain by coarse-grained stratified drift (square miles)	Area underlain by till-mantled bedrock (square miles)	7-day, 10-year low flow computed from streamflow records (cubic feet per second)	Record length within the reference period (years)	7-day, 10-year low flow computed by regression equation (cubic feet per second)
01119500	Willimantic River nr South Coventry, CT	122	21.5	100	14	30	15
01120500	Stafford Brook nr Woodstock Valley, CT	4.15	0.04	4.11	0	20	0.07
01121000	Mount Hope River nr Warrenville, CT	28.6	1.2	27.4	0.8	30	1.1
01123000	Little River nr Hanover, CT	30.4	5.3	25.1	4.6	20	3.8
01165500	Moss Brook at Wendall Depot, MA	12.3	.8	11.5	.5	30	.7
01169000	North River at Shattuckville, MA	88.4	3.6	84.8	7.4	30	3.3
01180000	Sykes Brook at Knightville, MA	1.64	0	1.64	.05	25	.02
01181000	West Branch Westfield River at Huntington, MA	93.7	2.1	91.6	5.0	30	2.3
01184490	Broad Brook at Broad Brook, CT	15.6	5.3	10.3	4.5	10	3.7
01187400	Valley Brook nr West Hartland, CT	7.33	.50	6.83	.2	30	.4
01187800	Nepaug River nr Nepaug, CT	23.5	3.9	19.6	2.3	30	2.9
01188000	Burlington Brook nr Burlington, CT	4.13	1.37	2.76	.6	30	.9
01189000	Pequabuck River at Forestville, CT	45.4	16.0	29.4	13	30	11
01190200	Mill Brook at Newington, CT	2.65	.75	1.90	.4	13	.5
01192600	South Branch Salmon Brook at Buckingham, CT	.94	.50	.44	.3	10	.3
01192650	Roaring Brook at Hopewell, CT	24.3	6.7	17.6	4.3	10	4.7
01193800	Hemlock Valley Brook nr Hadlyme, CT	2.62	.23	2.39	.2	10	.2
01196500	Quinnipiac River at Wallingford, CT	110	42.7	67.3	30	30	29
01198500	Blackberry River at Canaan, CT	45.9	6.0	39.9	3.0	22	4.4
01199200	Guinea Brook at Ellsworth, CT	3.50	0	3.50	0	10	.04
01201500	Still River nr Lanesville, CT	67.5	19.5	48.0	15	30	14
01203000	Shepaug River nr Roxbury, CT	132	11.3	121	5.3	30	8.8
01204000	Pomperaug River at Southbury, CT	75.0	9.8	65.2	5.8	30	7.2
01204800	Coppermill Brook nr Monroe, CT	2.45	.37	2.08	.08	13	.2
01206400	Leadmine Brook nr Harwinton, CT	19.6	1.12	18.5	.5	30	.9
01300000	Blind Brook at Rye, NY	9.20	.23	8.97	.4	27	.2
01300500	Beaver Swamp Brook at Mamaroneck, NY	4.71	.24	4.47	.06	27	.2

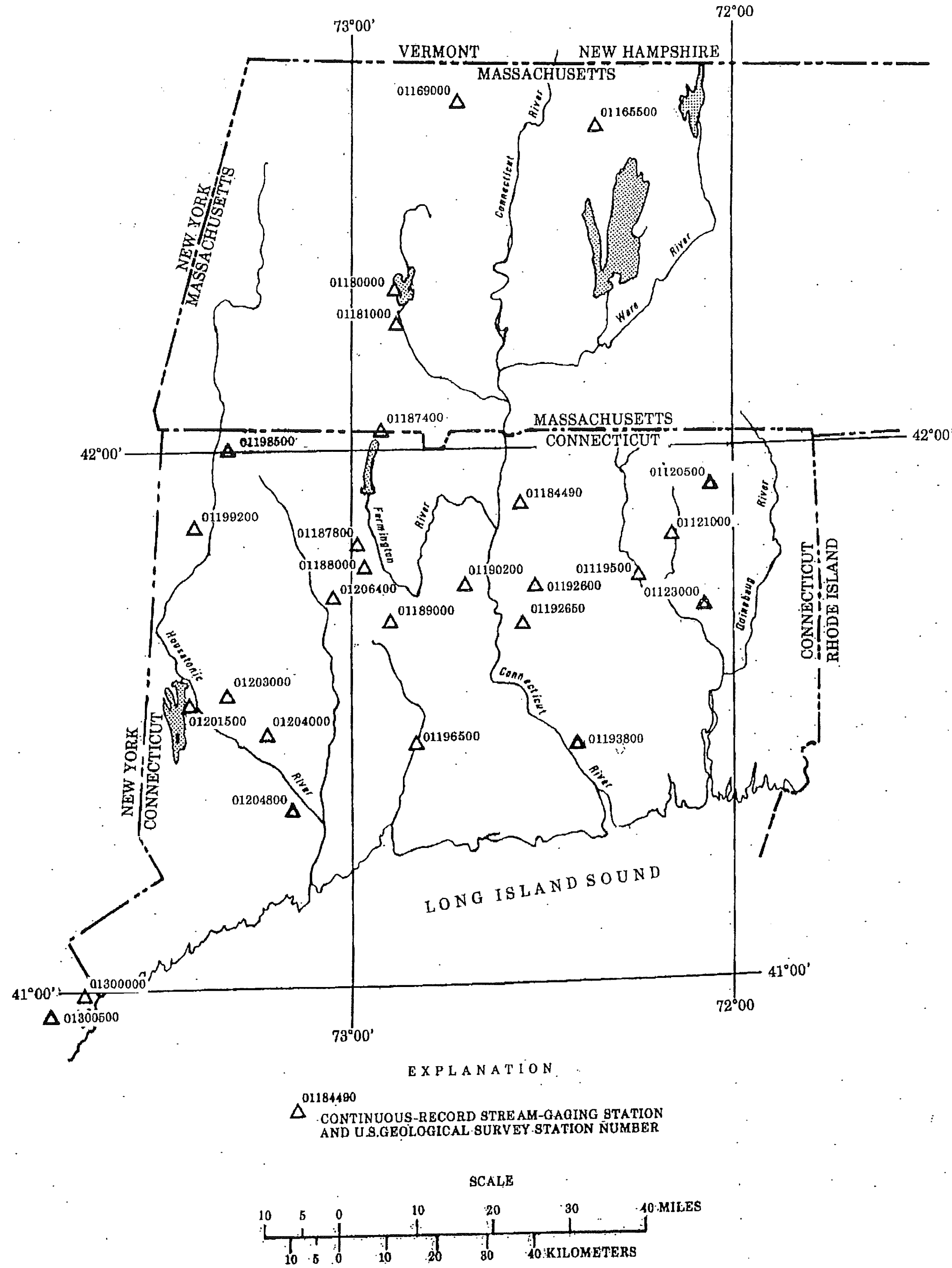


Figure 4.--Streamflow stations used in regression analysis

parallel, indicating a similar distribution of streamflow for both the reference period and the shorter concurrent period. This same relationship between flows for the reference period and the shorter time period was assumed to exist for the station of interest and a flow-duration curve for its period of record was constructed.

Data from the long-term stations used in this study show that the 7-day, 10-year low flow for the 30-year reference period and for the shorter concurrent periods of record are approximately equivalent to the 99-percent duration flow. Accordingly, the 99-percent duration flow at the short-term station of interest was adjusted in proportion to the difference between the 99-percent duration flows for the 30-year reference period and the shorter period of concurrent record at the long-term station. The resulting value is the reference period 7-day, 10-year low flow used in subsequent analysis.

The independent variables used in the regression analysis are the area of coarse-grained stratified drift and the area of till-mantled bedrock (both in square miles). The drainage area underlain by each water-bearing unit is given for each gaging station in table 1.

The 27 gaging stations used in the analysis were selected after a careful screening of more than twice that number having long records. Stations were not used if the flow pattern was affected by man's activities, as determined by records from water users and verified by evaluating the lower part of their flow-duration curves. Stations were also not used if their drainage areas were significantly affected by urbanization which reduces infiltration capacity and decreases low flows.

Regression Results

A regression equation that describes a relationship between the 7-day, 10-year low flow at gaging stations and the proportion of upstream drainage area underlain by coarse-grained stratified drift and till-mantled bedrock was computed by a procedure in the Statistical Analysis System Users Guide (Helwig and Council, 1979, p. 391-396) called "Stepwise".

The equation had the form:

$$Q_{7,10} = aA_{sd} + bA_{till},$$

where $Q_{7,10}$ is the 7-day, 10-year low flow, in cubic feet per second; a and b are regression constants; A_{sd} is the drainage area underlain by coarse-grained stratified drift, in square miles; and A_{till} is the drainage area underlain by till-mantled bedrock, in square miles. The model adds the flow contribution from the area of coarse-grained stratified drift to the flow contribution from the area of till-mantled bedrock.

The resultant regression equation is:

$$Q_{7,10} = 0.67A_{sd} + 0.01A_{till},$$

with a standard error of estimate of 1.4 cubic feet per second. The standard error of estimate was computed as

$$Sy = \sqrt{\frac{(Y - Yc)^2}{N - M}}$$

where Sy is the standard error of estimate in cubic feet per second; Y is the value of the 7-day, 10-year low flow computed from the streamflow records at the gaging stations; Yc is the value of the 7-day, 10-year low flow computed by the regression equation; N is the number of gaging stations used in the analysis; and M is the number of lost degrees of freedom (in this case, two). The values of Y and Yc for the 27 gaging stations used in the regression are listed in table 1 and are plotted against each other in figure 5.

This equation is considered suitable for estimating the 7-day, 10-year low flow at ungaged sites, as it represents the actual physical system, expresses the water-yielding characteristics of each major aquifer in realistic proportions, and has a reasonable standard error of estimate. The standard error of estimate reflects (1) the number of stations used, (2) the physical model, and (3) the accuracy of measuring drainage areas and the distribution of geologic materials.

The 7-day, 10-year low flow is dominated by runoff from the coarse-grained stratified-drift aquifer. According to the equation, 0.15 square mile of coarse-grained stratified drift in a drainage basin can yield a 7-day, 10-year low flow of 0.1 cubic foot per second. On the other hand, a 7-day, 10-year low flow of 0.1 cubic foot per second can be expected from a drainage basin underlain exclusively by till-mantled bedrock only if the upstream drainage area is 10 square miles or more.

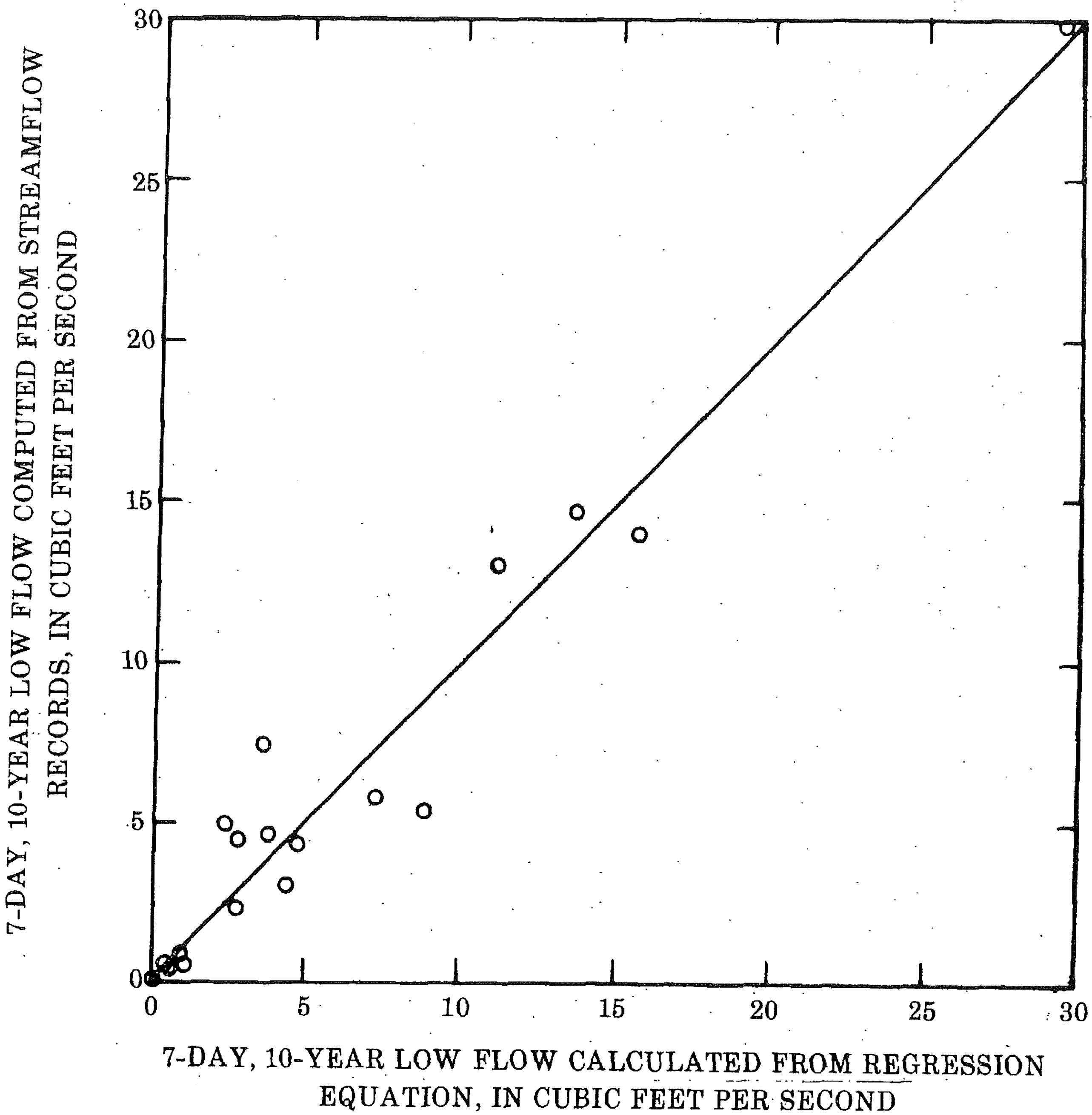


Figure 5.--Observed versus calculated 7-day, 10-year low flows at 27 gaging stations

APPLICATION OF METHOD

The tools required in estimating the 7-day, 10-year low flow at any site on any stream in the State that is not tidal and is not significantly affected by man's activities are the equation given in the previous section, together with a topographic map and a surficial geologic map. The user should be careful to determine that man's activities or urbanization do not significantly affect the low flows of the ungaged stream being studied prior to applying this technique. If the geologic map has a topographic base with contours showing altitude, only that map is required.

A useful set of U.S. Geological Survey 7½-minute topographic maps at a scale of 1:24,000 is on file at the Natural Resources Center of the Connecticut Dept. of Environmental Protection. Basin drainage divides have been delineated on this statewide set of small scale maps.

Figure 6 illustrates the method of estimating the 7-day, 10-year low flow at an ungaged site. The site selected as an example is on the Skungamaug River at State Highway 31 near North Coventry. The segment of the geologic map used in figure 6 was taken from a map showing textures of unconsolidated materials in the Connecticut Valley urban area (Stone and others, 1979). Because this map has contours indicating altitude of land surface and shows areas underlain by coarse-grained stratified drift, it is the only map required. This map is of a convenient size (scale of 1:125,000) to serve as an illustration for a basin having a drainage area of nearly 25 square miles; however, the basin drainage divide and the area of coarse-grained stratified drift can be delineated more accurately on the 1:24,000 scale maps. The 7-day, 10-year low flow is estimated as follows:

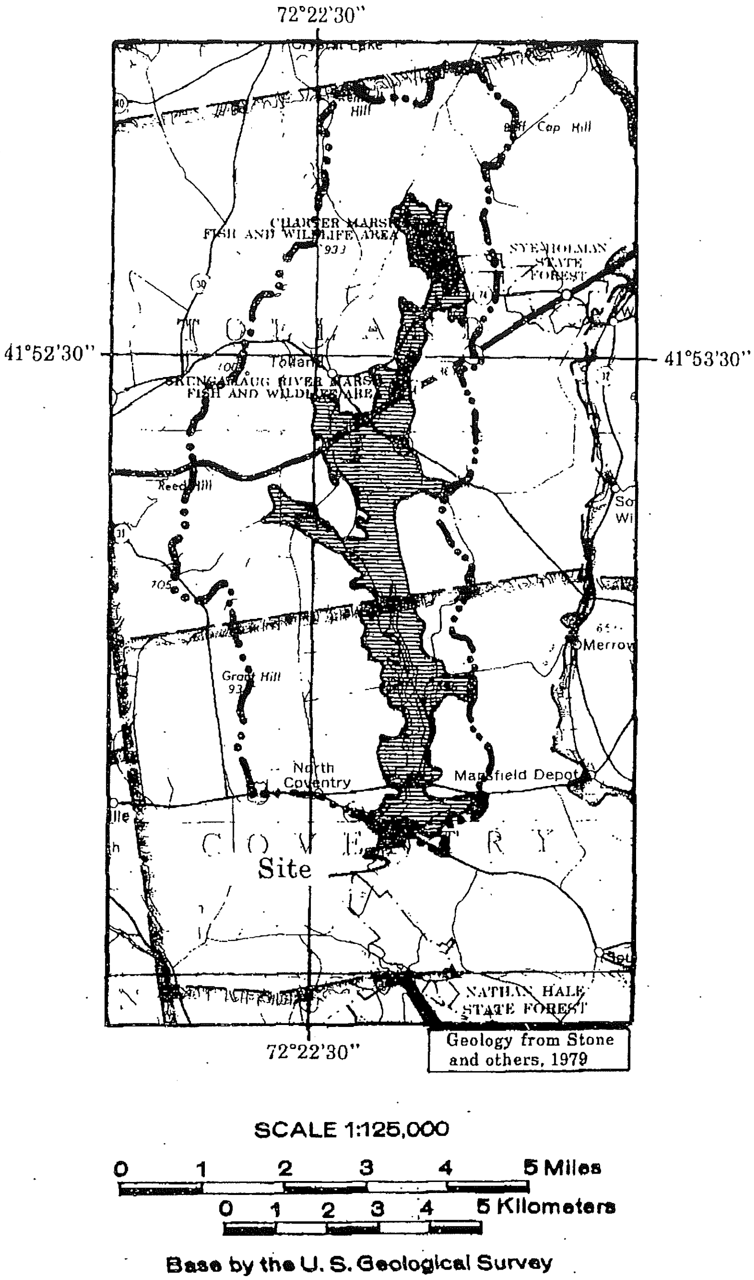
1. The basin drainage divide upstream from the site is drawn on the map by use of the topographic contours.

2. The area enclosed by the drainage divide is measured as 24.7 square miles.

3. The area of coarse-grained stratified drift contained within the drainage divide is measured as 4.7 square miles. The area of till-mantled bedrock is equal to the total drainage area less the area of coarse-grained stratified drift, or 20.0 square miles.

4. The estimating equation to be used is: $Q_{7,10} = 0.67\ A_{sd} + 0.01\ A_{till}$.

5. The estimated 7-day, 10-year low flow is computed to be 3.3 cubic feet per second [$Q_{7,10} = (0.67)(4.7) + (0.01)(20.0) = 3.3$].



EXPLANATION

Coarse-grained stratified drift

Basin drainage divide

EXAMPLE

1. Basin drainage divide is drawn on map.
2. Area enclosed by divide is measured as 24.7 square miles.
3. Area of coarse-grained stratified drift is measured as 4.7 square miles, and area of till-mantled bedrock is 20.0 square miles.
4. Using equation

$Q_{7,10} = 0.67\ A_{sd} + 0.01\ A_{till}$,
the estimated $Q_{7,10}$ =
$0.67(4.7) + 0.01(20.0)$ =
3.3 cubic feet per second

Figure 6.--Method of estimating the 7-day, 10-year low flow at an ungaged site

Method is described for a site on the Skungamaug River at State Highway 31 near North Coventry.

SUMMARY AND CONCLUSIONS

The 7-day, 10-year low flow can be estimated for any site on any stream in Connecticut that is not affected by tide, does not have its flow artificially controlled during low flow periods, and does not drain an area having appreciable urbanization.

In Connecticut, low streamflows are sustained by discharge from adjacent aquifers. The aquifers of Connecticut can be categorized in two general groups: coarse-grained stratified drift and till-mantled bedrock. The coarse-grained stratified drift has by far the best water-yielding characteristics. The till-mantled bedrock yields considerably less water to streams at times of low flow; however, it can provide a significant amount of water to streams having large drainage basins.

A regression equation that adequately describes the relationship between the 7-day, 10-year low flow at 27 stream-gaging stations and the proportion of upstream drainage area underlain by coarse-grained stratified drift and till-mantled bedrock was computed. This equation for estimating the 7-day, 10-year low flow at ungaged sites is:

$$Q_{7,10} = 0.67\ A_{sd} + 0.01\ A_{till},$$

where $Q_{7,10}$ is the 7-day, 10-year low flow, in cubic feet per second; A_{sd} is the drainage area underlain by coarse-grained stratified drift, in square miles; and A_{till} is the drainage area underlain by till-mantled bedrock, in square miles. The standard error of estimate is ± 1.4 cubic feet per second.

Drainage basins having much coarse-grained stratified drift will yield relatively large annual low flows. The estimating equation indicates that a drainage basin of only 10 square miles would have a 7-day, 10-year low flow of 6.7 cubic feet per second (a relatively large low flow) if the basin were totally underlain by coarse-grained stratified drift. A basin of the same size, but totally underlain by till-mantled bedrock, would have an estimated 7-day, 10-year low flow of only 0.1 cubic foot per second. Basins lacking coarse-grained stratified drift deposits can yield significant quantities of water if the upstream drainage area is large. A till-mantled bedrock basin having 100 square miles of drainage area would yield a 7-day, 10-year low flow of 1.0 cubic foot per second. However, drainage basins in Connecticut greater than about 20 square miles that are totally underlain by till-mantled bedrock are rare.

SELECTED REFERENCES

Brackley, R.A. and Thomas, M.P., 1979, Map showing estimated 7-day, 10-year low flow of streams in the Connecticut Valley urban area, central New England: U.S. Geological Survey Miscellaneous Investigations Map I-1074-H.

Cervione, M.A., Jr., Mazzaferro, D.L., and Melvin, R.L., 1972, Water-resources inventory of Connecticut, part 6, upper Housatonic River basin: Connecticut Water Resources Bulletin 21, 84 p.

Connecticut Department of Environmental Protection, 1980, Connecticut water-quality standards and criteria: Water Resources Unit interim report, 28 p.

Helwig, J.T., and Council, K.A., eds., 1979, SAS Users Guide, Raleigh, NC, SAS Institute Inc., p. 391-396.

Henney, L.H., compiler, 1981, Natural resources information directory for the State of Connecticut: Connecticut Department of Environmental Protection, 39 p.

Riggs, H.C., 1968, Frequency curves: U.S. Geological Survey Techniques of Water-Resources Investigations, book 4, chap. A2, 15 p.

Ryder, R.B., Thomas, M.P., and Weiss, L.A., 1981, Water resources inventory of Connecticut, part 7, upper Connecticut River basin: Connecticut Water Resources Bulletin 24, 84 p.

Stone, J.R., London, E.H., and Langer, W.H., 1979, Map showing textures of unconsolidated materials, Connecticut Valley urban area, central New England: U.S. Geological Survey Miscellaneous Investigations Map I-1074-B.

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

Thomas, M.P., and Cervione, M.A., Jr., 1970, A proposed streamflow data program for Connecticut: Connecticut Water Resources Bulletin 23, 18 p.

REPORTS DEALING WITH WATER RESOURCES IN CONNECTICUT

The bulletins in print are for sale by the Department of Environmental Protection, Natural Resources Center, State Office Building, Hartford, CT 06115, telephone 566-3540. Those out of print, indicated by an asterisk (*), are on file for reference at the Center where additional water resource information is available also.

*1. Chemical and physical quality of water resources in Connecticut, 1955-1958; F. H. Pauszek.
*2. Ground-water levels in Connecticut, 1956-1959; A. M. LaSala, Jr.
*3. Records and logs of selected wells and test borings, records of springs, and chemical analyses of water in the Farmington-Granby area, Connecticut; A. D. Randall, 1964.
*4. Records and logs of selected wells and test borings, and chemical analyses of water in north-central Connecticut; R. V. Cushman, J. A. Baker, and R. L. Meikle, 1964.
5. Records of logs of selected wells and test borings, and chemical analyses of water in the Bristol-Plainville-Southington area, Connecticut; A. M. LaSala, Jr. and R. L. Meikle, 1964.
6. A preliminary appraisal of water quality in the Housatonic River basin in Connecticut; F. H. Pauszek and R. J. Edmonds, 1965.
7. Ground-water levels in Connecticut, 1960-1964; R. L. Meikle and J. A. Baker, 1965.
*8. Water resources inventory of Connecticut, part 1, Quinebaug River basin; A. D. Randall, M. P. Thomas, C. E. Thomas, Jr., and J. A. Baker, 1966.
*9. Hydrogeologic data in the Quinebaug River basin, Connecticut; C. E. Thomas, Jr., A. D. Randall, and M. P. Thomas, 1966.
*10. Records and logs of selected wells and test borings, ground-water levels in selected observation wells, and freshwater inflow into the Connecticut River at the CANEL site, Middletown, Connecticut; J. A. Baker, 1966.
*11. Water resources inventory of Connecticut, part 2, Shetucket River basin; M. P. Thomas, G. A. Bednar, C. E. Thomas, Jr., and W. E. Wilson, 1967.
*12. Hydrogeologic data for the Shetucket River basin, Connecticut; C. E. Thomas, Jr., G. A. Bednar, M. P. Thomas, and W. E. Wilson, 1967.
13. Ground-water levels in Connecticut, 1965-1966; R. L. Meikle, 1967.
*14. Ground-water resources of the Hamden-Wallingford area, Connecticut; A. M. LaSala, Jr., 1968.
*15. Water resources inventory of Connecticut, part 3, lower Thames and southeastern coastal river basins, Connecticut; C. E. Thomas, Jr., M. A. Cervione, Jr., and I. G. Grossman, 1968.
*16. Hydrogeologic data for the lower Thames and southeastern coastal river basins, Connecticut; M. A. Cervione, Jr., I. G. Grossman, and C. E. Thomas, Jr., 1968.
*17. Water resources inventory of Connecticut, part 4, southwestern coastal river basins; R. B. Ryder, M. A. Cervione, Jr., C. E. Thomas, Jr., and M. P. Thomas, 1970.
*18. Hydrogeologic data for the southwestern coastal river basins, Connecticut; M. P. Thomas, R. B. Ryder, and C. E. Thomas, Jr., 1969.
19. Water resources inventory of Connecticut, part 5, lower Housatonic River basin; W. E. Wilson, E. L. Burke, and C. E. Thomas, Jr., 1974.
*20. Hydrogeologic data for the lower Housatonic River basin, Connecticut; I. G. Grossman and W. E. Wilson, 1970.
21. Water resources inventory of Connecticut, part 6, upper Housatonic River basin; M. A. Cervione, Jr., D. L. Mazzaferro, and R. L. Melvin, 1972.
*22. Hydrogeologic data for the upper Housatonic River basin, Connecticut; R. L. Melvin, 1970.
*23. A proposed streamflow data program for Connecticut; M. P. Thomas and M. A. Cervione, Jr., 1970.
24. Water resources inventory of Connecticut, part 7, upper Connecticut River basin, Connecticut; R. B. Ryder, L. A. Weiss, and M. P. Thomas, 1981.
25. Hydrogeologic data for the upper Connecticut River basin, Connecticut; R. B. Ryder and L. A. Weiss, 1971.
26. Hydrogeologic data for the Quinnipiac River basin, Connecticut, D. L. Mazzaferro, 1973.
27. Water resources inventory of Connecticut, part 8, Quinnipiac River basin, Connecticut, D. L. Mazzaferro, E. H. Handman, and M. P. Thomas, 1979.
28. Hydrogeologic data for the Farmington River basin, Connecticut, H. T. Hopkins and E. H. Handman, 1975.
29. Water resources inventory of Connecticut, part 9, Farmington River basin, Connecticut, F. P. Haeni, E. H. Handman, and M. P. Thomas, in preparation.
30. Hydrogeologic data for the lower Connecticut River basin, Connecticut, J. W. Bingham, L. A. Weiss, and F. D. Paine, 1975.
31. Water resources inventory of Connecticut, part 10, lower Connecticut River basin, Connecticut, L. A. Weiss, J. W. Bingham, and M. P. Thomas, 1982.
32. Hydrogeologic data for South-Central Connecticut, F. P. Haeni and H. R. Anderson, 1980.
33. Hydrogeologic data for southwest Connecticut, J. W. Bingham, D. K. McKeegan, and Robert Potterton, 1982.
34. A method for estimating the 7-day, 10-year low flow of streams in Connecticut, M. A. Cervione, Jr., R. L. Melvin, and K. A. Cyr, 1982.
35. Streamflow information for Connecticut with applications to land-use planning, M. A. Cervione, Jr., 1982.

Connecticut Department of Environmental Protection Bulletins

1. Gazetteer of natural drainage areas of streams and water bodies within the State of Connecticut; M. P. Thomas, 1972.
*2. Time of travel of a dye in the Quinnipiac River, Connecticut; M. A. Cervione, Jr., 1972.