DELINEATING RECHARGE AREAS FOR

STRATIFIED-DRIFT AQUIFERS IN CONNECTICUT

WITH GEOLOGIC AND TOPOGRAPHIC MAPS

By Elinor H. Handman

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FACTORS FOR CONVERTING INCH-POUND UNITS TO METRIC UNITS

Multiply inch-pound units	by	To obtain metric units
	Length	
inch (in)	25.40	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
gallon per minute per foot [(gal/min)/ft]	0.2070	liter per second per meter [(L/s)/m]
million gallons per day per square mile ($Mgal/d/mi^2$)	1,460	cubic meter per day per square kilometer ($m^3/d/km^2$)
	Hydraulic Units	
transmissivity, foot squared per day (ft^2/d)	0.0929	meter squared per day (m^2/d)
hydraulic conductivity, foot per day (ft/d)	0.3048	meter per day (m/d)
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)

DELINEATING RECHARGE AREAS FOR STRATIFIED-DRIFT AQUIFERS IN CONNECTICUT WITH GEOLOGIC AND TOPOGRAPHIC MAPS

By Elinor H. Handman

ABSTRACT

In Connecticut, most ground water that is used for municipal and industrial supplies is withdrawn from stratified-drift aquifers. Most of these aquifers are limited in extent and are hydraulically connected to local stream systems. Therefore, the quantity and quality of ground water and surface water are interrelated and use of these resources can be managed collectively. Effective management programs to prevent contamination of ground water require information about the sources of ground-water recharge, the areas where recharge occurs, and the amount of recharge that is derived from each source.

Stratified-drift aquifers are recharged principally by (1) precipitation that infiltrates the land surface overlying the aquifer and percolates downward to the saturated zone, (2) subsurface inflow of ground water from adjacent till-and-bedrock hillsides, and (3) surface water that infiltrates through streambed or lake-bottom sediments by induced recharge. Infiltration of surface water commonly occurs where pumping wells lower the water table sufficiently to reverse the normal hydraulic gradient between the aquifer and a nearby surface-water body to which it is hydraulically connected.

In most parts of Connecticut surface-water and ground-water drainage divides coincide and are found in till-covered bedrock uplands bordering stratified-drift aquifers. Where this is the case, areas that contribute recharge under natural conditions and under conditions of development can be estimated with geologic and topographic maps. The area of stratified drift in which precipitation infiltrates downward to an aquifer along a valley reach of interest may generally be delineated on published geologic or water-resource maps cited in the report. The area of adjacent till-and-bedrock hillsides from which water drains laterally to the aquifer may be delineated on topographic maps by drawing lines from the ends of the aquifer to the nearest drainage divide.

Large stratified-drift aquifers that extend across surface-water drainage divides underlie most of north-central Connecticut and parts of the Quinnipiac and Farmington River basins. Definition of recharge areas for these aquifers is complicated and requires additional hydrologic information.

INTRODUCTION

Stratified-drift aquifers are the major source of large quantities of ground water for public supply in Connecticut. Many towns in Connecticut are developing and implementing plans for water-quality management of these aquifers as part of a national program to address nonpoint sources of contamination--Section 208 of the Clean Water Act (Public Law 92-500). Effective programs to prevent deterioration of ground-water quality in stratified-drift aquifers require information on the sources of recharge, the areas in which recharge occurs, and the amount of recharge that is derived from each source. Connecticut's 15 Regional Planning Agencies, under the direction of the State "208" program (Connecticut Areawide Waste Treatment Management Planning Board), require information on recharge in order to manage the water quality of aquifers that are used for public supply or have been identified as future sources for public supply.

Purpose and Scope

This report (1) reviews information on the occurence of ground water with respect to recharge of stratified-drift aquifers and (2) outlines methods for estimating the extent of areas that contribute recharge to the aquifers. Studies conducted by the U.S. Geological Survey, in cooperation with the Connecticut Department of Environmental Protection, provide information about the hydrology of stratified-drift aquifers in different parts of the State; the results, published as Connecticut Water Resources Bulletins, are listed in the Selected References.

The first part of this report contains general hydrologic information on Connecticut's aquifers. It will help the reader to understand the processes of recharge and discharge in stream-aquifer systems. The second part of the report describes how an understanding of recharge and discharge can be applied to estimate the extent of areas that contribute recharge to stratified-drift aquifers using geologic and topographic maps. The methods are applicable to most stratified-drift aquifers in Connecticut and throughout the Northeastern United States. A glossary of technical terms is included at the end of this report.

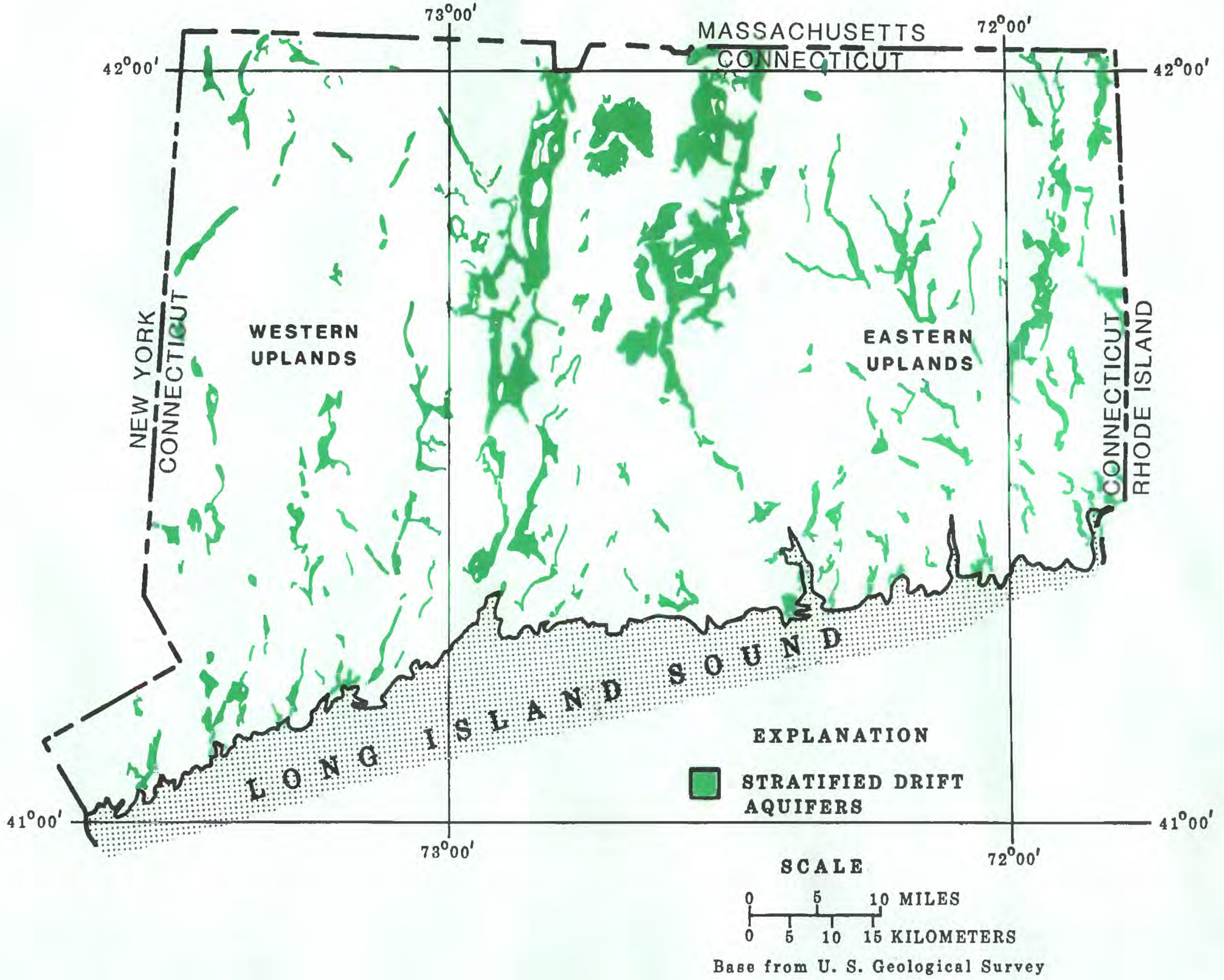


Figure 1.--Distribution of major stratified-drift aquifers in Connecticut (modified from Meade, 1978)

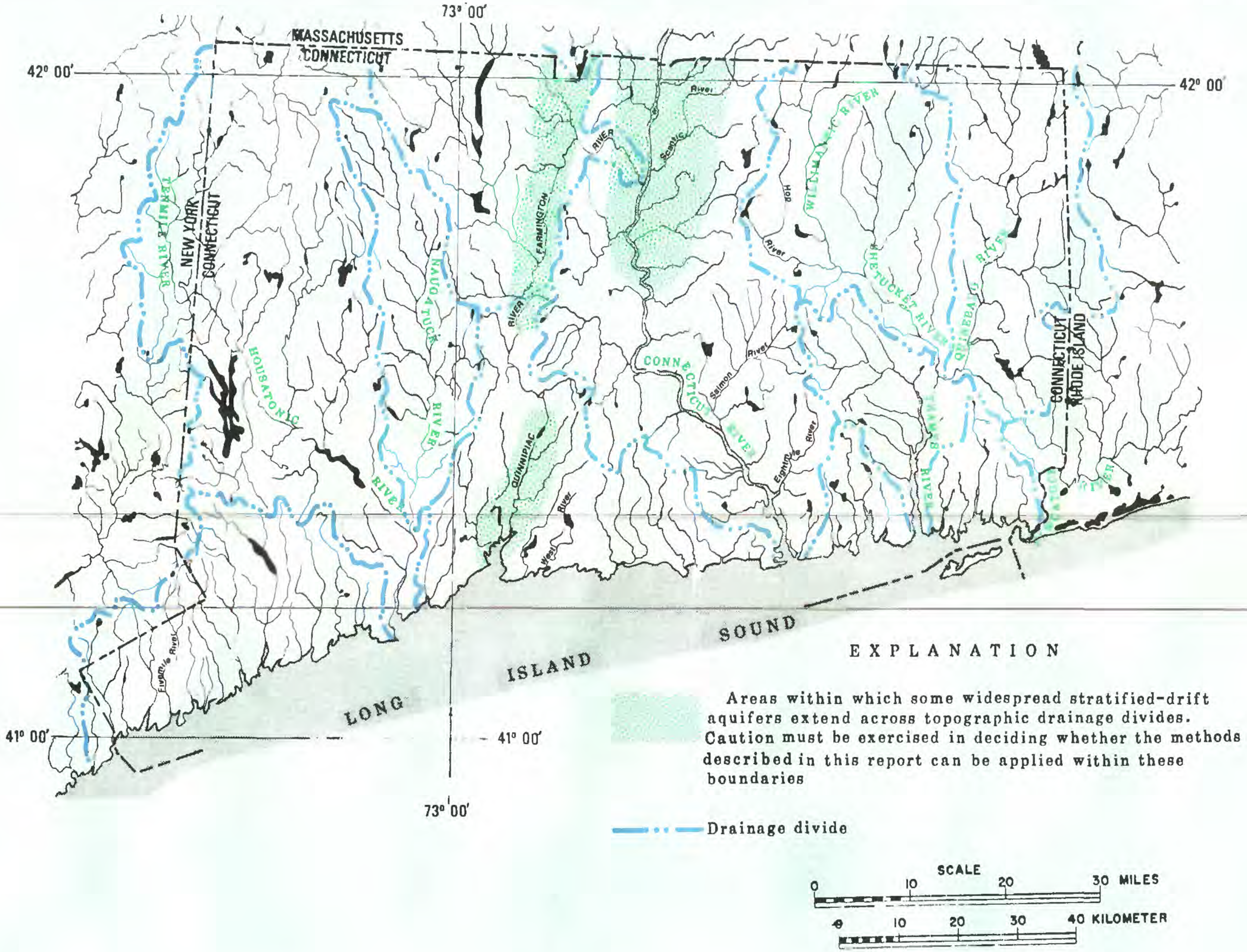


Figure 2.--Principal streams and major drainage-basin boundaries in Connecticut.

HYDROGEOLOGIC FRAMEWORK

Principal Water-Bearing Units

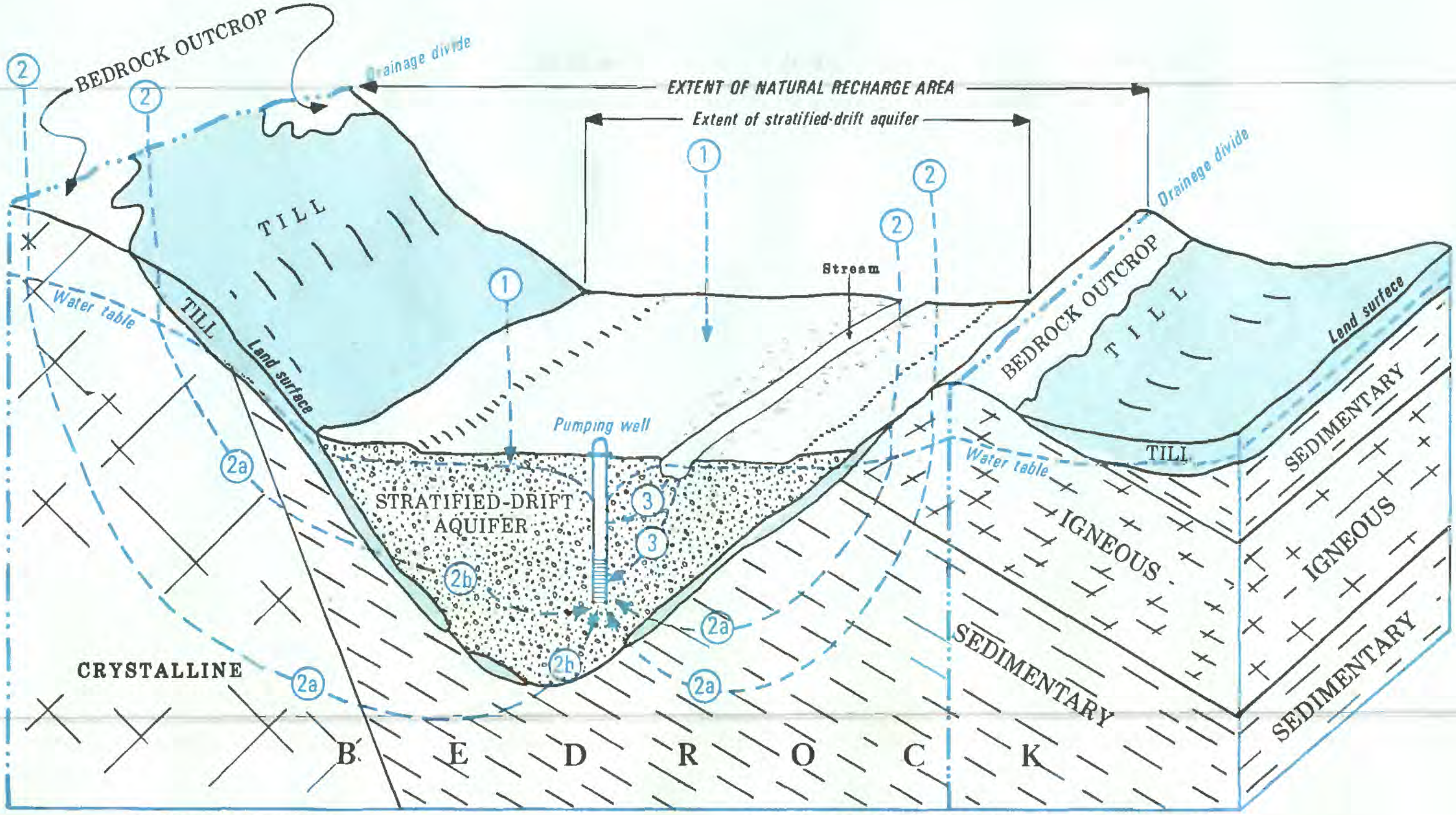
Water in Connecticut is pumped from aquifers composed of unconsolidated sediments and bedrock. Unconsolidated sediments overlie bedrock; water is stored in and transmitted through interconnected pore spaces between the particles of sediment and through the fracture networks in bedrock. The areal distribution of unconsolidated and bedrock aquifers is shown on the State's "Ground Water Availability" map (Meade, 1978). Distribution of stratified-drift aquifers in the State is shown in figure 1. The major streams and stream basins in the State are shown in figure 2. The general spatial relationships among principal aquifers in a typical valley setting in central Connecticut are shown in figure 3.

The two major types of unconsolidated sediments are stratified drift and till. Both are of glacial origin, and both are commonly similar in mineral composition to the underlying or adjacent bedrock from which they predominantly were derived. Coarse-grained stratified drift can be a productive source of ground water. The highest well yields in the State generally are obtained from coarse-grained deposits near major streams. Large saturated thickness, high permeability, and large areal extent of stratified drift also are important criteria favoring development of large supplies.

Till, popularly called "hardpan," yields only small quantities of water and generally supplies water adequate only for domestic use. It forms a widespread discontinuous cover over bedrock throughout most upland areas, and in many areas extends beneath stratified drift in valleys and lowlands. Because shallow wells in till often provide insufficient yields for modern household demands, especially in dry weather, and improperly-located shallow wells are easily contaminated, till has been largely supplanted by bedrock as a domestic-supply source.

Bedrock aquifers are the principal source of water for domestic and commercial users who are not served by public-water supplies. In this report, bedrock is divided into three general types: (1) crystalline rocks (noncarbonate igneous and metamorphic), (2) sedimentary and associated igneous rocks, and (3) carbonate rocks (limestone, dolostone, and marble). Yields from these rock types differ depending on the number, size, and degree of interconnection of fractures or other openings in the saturated zone that are intercepted by a well.

Crystalline bedrock aquifers differ from one another mineralogically, but generally have similar water-yielding properties. Collectively, they comprise the most extensive aquifer in Connecticut. Crystalline bedrock is exposed at the land surface or underlies unconsolidated sediments in the eastern and western parts of the State and sedimentary and associated igneous rocks in the central part.



NATURAL CONDITIONS

Major Sources

(1) Precipitation on the land overlying the aquifer infiltrates the surface and moves vertically downward to the saturated zone.

(2) Subsurface inflow of ground water from adjacent till and bedrock uplands is derived from precipitation that percolates downward to the saturated zone in adjacent deposits 2 and then moves downgradient through pores and fractures in these deposits 2a into the stratified drift 2b.

Minor (not shown)

Vertical movement of water through streambed and unsaturated zone to the water table may occur locally where streams draining uplands flow into stratified-drift deposits in valleys. During floods streams overflow their banks and occupy floodplains, and surface water may infiltrate into the stratified drift.

Sheet runoff from till and bedrock hillsides may infiltrate into stratified drift along valley margins.

CONDITIONS RESULTING FROM HUMAN ACTIVITIES

Major Sources

(3) Induced recharge from surface-water bodies (streams and lakes) occurs where pumping wells reverse the natural hydraulic gradient between the surface-water body and the aquifer and the resulting lower head in the aquifer causes infiltration of surface water through the streambed or lake bottom deposits. Induced recharge of salt water is possible in coastal areas.

Minor (not shown)

Recharge from septic systems, drainage ditches, leaky pipelines, sumps, waste-disposal ponds, and other facilities.

Recharge through injection wells.

Figure 3.--Principal sources of recharge to stratified-drift aquifers and spatial relationships among stratified drift, till, and bedrock in Connecticut.

Sedimentary and igneous rocks underlie a northeast-southwest band through the center of the State. The sedimentary rocks are interlayered with the igneous rocks (fig. 3). Wells have different yields and water-quality characteristics depending on the composition and physical properties of the layers tapped, and the depth and position of the well in the flow system.

The carbonate bedrock is found in the western part of the State, where wells tapping it have slightly higher yields than those tapping crystalline bedrock (Cervione and others, 1972, fig. 46).

Ground water in most unconsolidated aquifers and in many bedrock aquifers is unconfined rather than artesian; therefore, (1) the water table (the top of the saturated zone) fluctuates in response to changes in recharge and discharge, and (2) recharge from precipitation occurs over the entire area underlain by the aquifers.

Recharge in nonurban areas can be estimated as the sum of the components of discharge (primarily ground-water runoff to streams plus underflow) measured during a period in which net storage of ground water does not change. Analyses of ground-water discharge from several basins in southern New England and Long Island, summarized in Cervione and others (1972) and Mazzaferro and others (1979), provide estimates of long-term average recharge to stratified drift and till and bedrock. Such estimates are conservative from a water-supply viewpoint for two reasons. If the water table is lowered by development (1) additional water will infiltrate from streams, and (2) ground water that is normally returned to the atmosphere by deep-rooted plants or by evaporation in swampy areas and is not included in estimates of recharge, may become available to wells. The long-term ground-water recharge from precipitation is much greater--about three times as much--in stratified-drift areas than in till-and-bedrock areas. The difference is a result of the higher infiltration capacity of soils developed on stratified drift, the higher hydraulic conductivity of stratified drift, and the gentler slopes, which reduce surface runoff in stratified-drift areas.

Ground-Water Storage and Circulation

In the saturated zone below the water table, the open pores or fractures in unconsolidated and bedrock aquifers are completely filled with water. Stratified drift and till have more open spaces in which ground water can be stored than fractured bedrock and, where saturated, they contain significantly more water per unit volume. The greatest quantities of ground water, therefore, are stored in areas that have the thickest saturated deposits of stratified drift and till. However, the potential yields of water to wells depend on additional factors (Mazzaferro and others, 1979, p. 35-60).

Ground water stored in unconsolidated and bedrock aquifers constantly flows from areas of recharge to sites of discharge, such as wells or streams (fig. 3). The lengths of ground-water-flow systems are controlled by the hydrogeologic setting, and minor flow systems may exist at shallow depth within major systems of circulation (fig. 4)(also see Toth, 1963). However, in most of Connecticut, every flow system is restricted to the topographic basin drained by a major perennial stream because the major topographic divides are generally in upland areas where the water table is relatively shallow and slopes toward nearby streams. All ground and surface water within the basin is derived from precipitation on the basin and is discharged within the basin or at the basin's outlet by streamflow or underflow. There is no evidence that regional flow systems exist at depth to transfer water across the topographically defined basin divides. Ground-water divides in till and bedrock thus coincide with the topographically defined surface-water drainage divides; they do not migrate significantly in response to a stress imposed on one side of the divide or the other because in these low-permeability materials only small stresses with localized effects are generally feasible. Recharge from precipitation occurs over the entire basin, although the amounts may differ from one place to another.

In some localities within Connecticut, topographic divides cross extensive areas of stratified drift; there, ground-water divides may not coincide with topographic divides. These areas are shown in figure 2 and discussed in this report under "Complex Settings" and "Delineation of Recharge Areas."

Ground water can move vertically and horizontally from one water-bearing unit to another. The direction of movement is a function of head distribution. In upland areas, water generally moves downward through unconsolidated materials into the underlying bedrock, and, in most valley areas, it moves laterally and upward from adjacent and underlying bedrock into unconsolidated materials. Under natural conditions, ground water generally discharges into streams, lakes, wetlands, and the ocean, and a significant amount of ground water may be discharged to the atmosphere by evapotranspiration. At some locations, surface water may move into aquifers in response to heads lowered by pumping (induced recharge).

Ground-water flow is limited by the depth to which interconnected open spaces or fractures are present in the bedrock. In the crystalline bedrock, at depths greater than 300 feet below the bedrock surface, fractures are few and the rock is relatively impervious. A ground-water-flow system that is typical of major valleys in eastern and western Connecticut, and the general pattern of circulation from areas of inflow to areas of outflow, are shown in figure 4.

A quantitative expression of ground-water recharge and discharge under natural conditions is given in the following equation of Schicht and Walton (1961, p. 10-11):

$$G_r = (G_{ro} + G_{et} + U) \pm S,$$

where:
- G_r = Ground-water recharge or inflow
- G_{ro} = Ground water runoff
- G_{et} = Ground-water evapotranspiration
- U = Underflow

(G_{ro}, G_{et} and U) = Ground-water discharge or outflow

- S = Change in ground-water storage

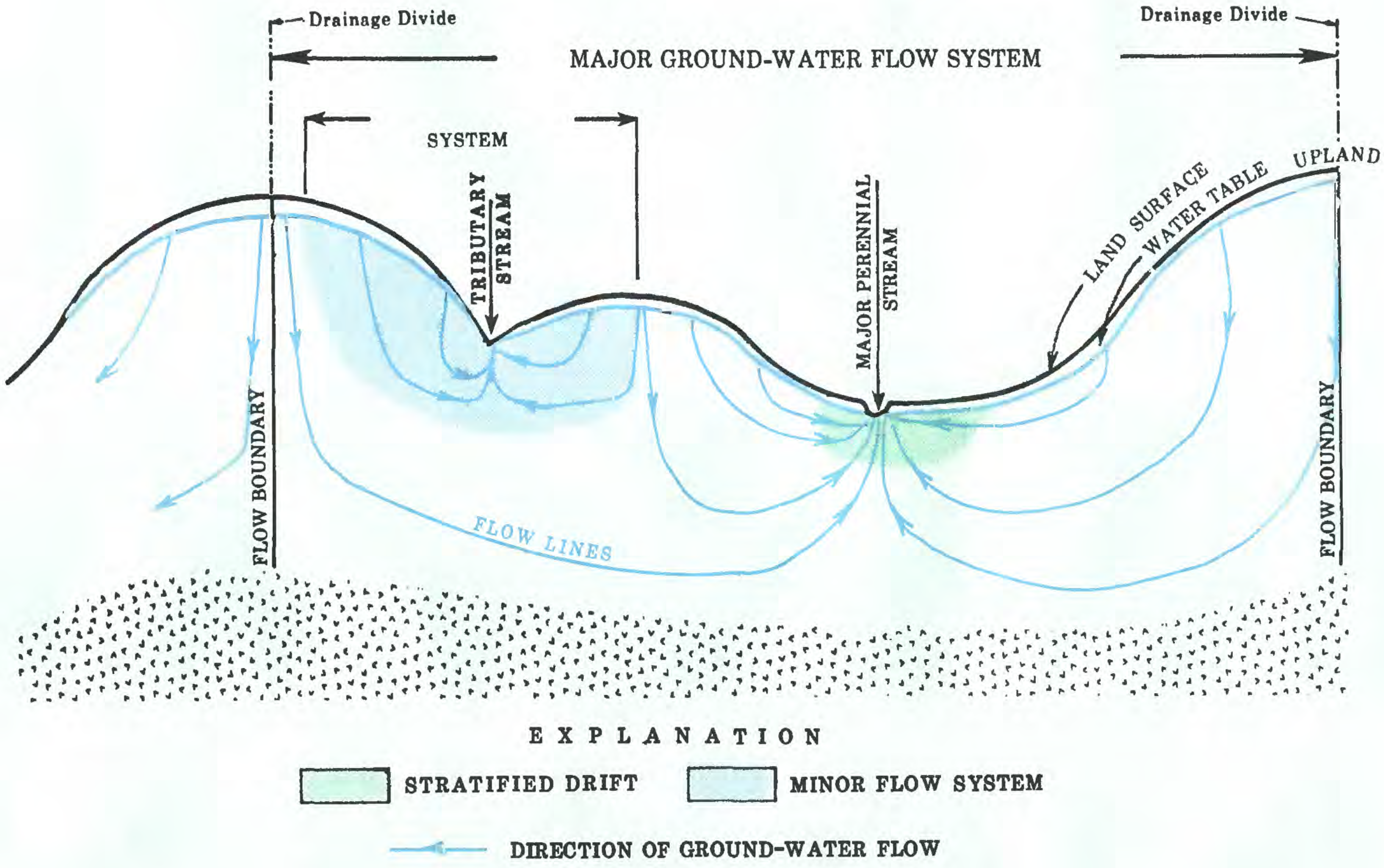


Figure 4.--Schematic diagram of ground-water circulation in stratified drift and bedrock in Connecticut. [Adapted from Cervione and others (1972).]

The components of the equation may differ in amount and rate from one part of the State to another, and from one part of a basin to another, and all vary with time. The diversity is a result of differences in hydrologic, geologic, climatologic, ecologic, and topographic factors. In general, ground water recharge under natural conditions is derived from precipitation and occurs mainly during the nongrowing season (October through April), whereas ground-water discharge consists mainly of ground-water runoff to streams and underflow, including direct discharge to Long Island Sound.

Stratified-Drift Aquifers

Stratified-drift aquifers are composed of different proportions of sand, gravel, silt, and clay, deposited in layers. The quantity of water that can be withdrawn on a temporary or sustained basis from a stratified-drift aquifer depends principally on (1) the hydraulic properties of the aquifer, (2) the location and position of the hydraulic boundaries, (3) the quantity and variability of natural recharge and discharge, and (4) the quantity of water that can be induced to infiltrate from adjacent streams and lakes (induced recharge). Ground-water availability from stratified-drift aquifers in Connecticut is summarized in terms of well yields by Meade (1978) and is discussed in detail in several hydrologic studies (Ryder and others, 1970; Cervione and others, 1972; Wilson and others, 1974; Mazzaferro and others, 1979; Haeni, 1978).

Aquifer Classification

Basic Settings.--Stratified-drift aquifers suitable for delineating recharge area with geologic and topographic maps can be classified according to their physical settings, the most common of which are listed in table 1. The categories for physical setting are approximate; more than one may be applicable for a given aquifer.

Table 1.--Physical settings of stratified-drift aquifers in Connecticut

Physical setting of aquifer	Typical location	Lateral boundaries	Area of drainage basin of largest contiguous stream at downstream edge of aquifer (square miles)
Small headwater basin	Eastern and western uplands 1/	Till and bedrock uplands	Less than 10
Stream-aquifer system			
Intermediate	Statewide, mainly uplands	Till and bedrock	10 - 500
Major	Adjacent to major streams	Till and bedrock; major stream	Greater than 500 2/
Coastal basin	Southern coast	Till and bedrock; Long Island Sound or estuary	Variable: Less than 10 to greater than 500

1/ Eastern and western uplands are shown in figure 1.

2/ Major streams include Connecticut, Housatonic, Thames, and lower reaches of Shetucket, Quinebaug, and Farmington Rivers as shown in figure 2.

The following assumptions apply to the physical settings listed in table 1:

(1) Ground-water drainage divides coincide with surface-water divides and remain approximately coincident when the aquifer is developed. Regional ground-water-flow systems that could transfer water across these topographically-defined divides are considered to be absent in this study.

(2) The cones-of-depression produced by pumping wells that tap the stratified-drift aquifer may reach streams and lower water levels across small and intermediate streams, but the stress imposed by pumping is not considered great enough to produce drawdown on the other side of major streams.

(3) Interbedded and adjacent coarse-grained and fine-grained statified drift are hydraulically interconnected and are considered to be a continuous aquifer for the purposes of recharge-area delineation.

Limitations.--Recharge areas of aquifers that fit the basic physical settings in table 1 can be estimated using topographic, and geologic, or hydrogeologic maps collectively. The assumptions listed must be met in order to use maps to delineate reliably (1) the aquifer area that is recharged directly from precipitation, (2) the adjacent uplands from which ground water flows into the aquifer, and (3) the drainage areas of streams that are likely to be sources of induced recharge if the aquifer is developed. The accuracy of the resultant delineations is limited by how closely the field situation matches the assumed conditions and by the availability and accuracy of the source maps.

Complex Settings.--A few stratified-drift aquifers do not fit into the classification scheme shown in table 1 or do not reasonably meet the stated assumptions. For example, in some areas, surface-water and ground-water drainage divides probably are not coincident. In such cases, the extent of the ground-water-flow system is unknown and recharge areas cannot be determined using the methods described in this report. These conditions are most prevalent in north-central Connecticut (Connecticut River basin) and in parts of the Farmington and Quinnipiac River basins--about 10 percent of the State (fig. 2). Complex situations are discussed in the section titled "Delineation of Recharge Areas."

Recharge

Natural recharge.--Natural recharge to a stratified-drift aquifer is derived primarily from (1) precipitation over the aquifer (area A, fig. 5) that percolates to the saturated zone, and (2) inflow from the adjacent till-and-bedrock uplands (areas labeled D, fig. 5). Minor sources of recharge may include floodwater from streams; leakage from streams draining till and bedrock that may occur for short distances where the streams begin to flow across stratified drift; septic drain fields, leaking water and sewer lines, storm drains, catchment basins, and ditches; and sheet runoff from hillsides adjacent to the aquifer. The total contribution from these sources is probably small, and they are not discussed further in this report. However, minor sources may have intermittent or local significance. The major and minor sources of recharge are listed in figure 3. Variations in the amount and distribution of precipitation can change the quantity and distribution of recharge from these sources.

The amount of recharge from precipitation can be estimated by measuring the ground-water discharge over a period during which ground-water storage remains fairly constant and there is no other source of recharge. Studies on Long Island (Pluhowski and Kantrowitz, 1964, p. 38) indicate that recharge to areas entirely underlain by stratified drift is about 96 percent of the total runoff. For Connecticut, where mean annual runoff ranges from 20 to 28 inches (0.93 to 1.3 $Mgal/d/mi^2$), the mean annual recharge from precipitation on the stratified drift probably ranges from 19 to 25 inches (0.89 to 1.2 $Mgal/d/mi^2$). For distribution of mean annual precipitation and runoff in Connecticut, see Cervione (1982).

Ground water in upstream areas of till and bedrock (areas labeled C, fig. 5) discharges into streams above where the streams flow into the stratified drift. Ground water in the adjacent area of till and bedrock (areas labeled D, fig. 5) flows into the stratified-drift aquifers before it is discharged. On an annual basis (assuming storage changes are neligible), the amount of ground-water inflow to the stratified-drift aquifer from the till-and-bedrock upland will be at least equivalent to the estimated natural recharge to these till-and-bedrock areas; the long-term mean annual recharge to till and bedrock is estimated to be about 7 inches (0.33 $Mgal/d/mi^2$) by Holzer (1973) and Cervione and others (1972). The amount entering stratified drift from these till and bedrock areas will be greater because most storm runoff flowing overland also will infiltrate the stratified drift.

Where induced recharge from streams is small or nonexistent, well yields are sustained primarily by natural recharge. Withdrawal from such areas of quantities of ground water greater than the mean annual recharge will result in a net decrease in storage marked by declining ground-water levels.

Induced Recharge.--Under natural conditions in Connecticut, ground water usually moves from a stratified-drift aquifer, upward through the stream-bottom deposits, and into the stream. However, the water-table gradient may be reversed under pumping conditions, and water from the stream may then infiltrate the aquifer and flow toward the center of pumping.

Where induced recharge from the stream is the principal source of water, well yields may be limited by the available streamflow. Decreased streamflow resulting from pumping ground water may also affect surface-water quality or interfere with water rights of downstream users unless the pumped water is returned to the stream without any change in its quality.

Most areas favorable for the installation of high-capacity wells in stratified-drift aquifers are near streams. Consequently, much of the water pumped from wells adjacent to the streams may be derived from induced recharge. The amount of induced recharge depends on the vertical hydraulic conductivity and thickness of the streambed materials, the area of the streambed through which water infiltrates, the viscosity of the water (which is temperature dependent), the average head difference between stream and the aquifer, and the available quantity of water in the stream.

During periods of low streamflow, less water is available for induced recharge to aquifers. Low flows of unregulated streams are a function of both drainage area and geology, as described by Thomas (1966). Small

Table 2.--Low flows of selected streams in Connecticut
[Flows are in cubic feet per second]

USGS station No.	Stream and location	Drainage area (square miles)	Period of record	Mean flow for period of record	Low Flow 1/ 30-day, 2-year	7-day, 10-year
01119500	Willimantic River near South Coventry	122	1931-82	211	33	14
01120500	Safford Brook near Woodstock Valley	4.15	1950-81	8	0.3	0
01121000	Mount Hope River near Warrenville	28.6	1940-81	50	3.2	0.8
01123000	Little River near Hanover	30.4	1951-81	56	7.8	4.6
01187300	Hubbard River near West Hartland	19.9	1956-81	39	1.8	.4
01187400	Valley Brook near West Hartland	7.33	1940-72	14	.7	.2
01192600	S. Branch Salmon Brook at Buckingham	.94	1960-76	1.6	.6	.3
01192650	Roaring Brook at Hopewell	24.3	1961-71	34	7.7	4.3
01193800	Hemlock Valley Brook near Hadlyme	2.62	1960-76	5.3	.4	.2
01198500	Blackberry River at Canaan	45.9	1949-71	74	9.5	3.0
01199200	Guinea Brook at Ellsworth	3.50	1960-81	6.9	.2	0
01203000	Shepaug River near Roxbury	132	1930-71	236	13	5.3
01204000	Pomperaug River at Southbury	75.0	1932-81	127	14	5.8
01206400	Leadmine Brook near Harwinton	19.6	1960-73	38	1.8	.5

1/ Low flow data are for reference period April 1, 1941 to March 31, 1971. Commonly used indices of lowest mean flow are the lowest mean flow for 30 consecutive days with an average recurrence interval of 2 years (30-day, 2-year low flow) and the lowest mean flow for 7 consecutive days with a recurrence interval of 10 years (7-day, 10-year low flow). In Connecticut the 30-day, 2-year low flow is equivalent to the flow equaled or exceeded 90 percent of the time, on the average. The 7-day, 10-year low flow is equivalent to the flow equaled or exceeded 99.2 percent of the time.

streams draining till-and-bedrock areas of less than 1 mi^2 become dry almost every summer; streams draining 1 to 10 mi^2 may dry up in very dry years, and even larger streams, unless they are regulated, can be significantly affected under extremely dry conditions, such as during the 1960's drought. For examples of mean and low flows of Connecticut streams, see table 2.

DELINEATION OF RECHARGE AREAS

Procedure

The general procedure for delineating recharge areas with geologic and topographic maps is shown in figure 5 and discussed below.

Step 1: The first step is to identify the physical setting of the aquifer as a small headwater basin, intermediate or major stream-aquifer system, or coastal basin using the descriptive information in table 1. If the aquifer does not fit any of these settings, the method may not be applicable. The examples shown in figure 5 are a small headwater basin and a valley segment of an intermediate stream-aquifer system.

Step 2: Determine the areal extent of the aquifer and delineate the boundaries (area A in fig. 5). This area is recharged in part by precipitation that falls on it and percolates downward to the water table.

The areal extent of stratified-drift deposits can be readily determined from 1:24,000-scale surficial geologic maps that are available for most parts of the State (see table 4 and figure 13 in back of this report) and from 1:48,000-scale maps in the series of water-resources inventories of Connecticut published by the State as Connecticut Water Resources Bulletins and referenced in this report. Stratified-drift areas can be obtained from either of these sources, depending on map availability and working scale requirements, and transferred to topographic base maps of appropriate scale. For recharge-area delineation, the areal extent of the aquifer is considered to be the same as the extent of the stratified-drift deposit, although some hydrologic studies (Hayes, 1978; Southeastern Connecticut Regional Planning Agency, 1978) limit the stratified-drift aquifer to saturated deposits only. The differences in area generally are small.

Often the upstream or downstream boundary of a valley segment of interest may not be at the end of a stratified-drift aquifer. For example, a political boundary, project-area limit, or data-collection site may justify considering only a segment of a long, continuous aquifer. The recharge area for an aquifer segment under natural conditions may be estimated in the same manner as for a complete aquifer (fig. 5). However, if large withdrawals occur near the end of the aquifer segment, the cone of depression may cause recharge to be drawn from beyond the end of the segment. A water-table map must be prepared for accurate analysis. For rough estimations, experience and trial calculations indicate that for typical valleys the upstream or downstream limits of recharge area around a well field are unlikely to exceed the following:

Withdrawal from well field, in million gallons per day	Distance from center of well field, in feet
1	1,500
2	2,500
4	3,500

(A.D.Randall, U.S. Geological Survey, written commun., 1983)

Step 3: Delineate the drainage area of the adjacent stream at the point where the stream flows out of the aquifer (area labeled B, fig. 5). This drainage area, exclusive of the stratified drift (area A), contributes water to recharge the stratified drift by subsurface inflow and to discharge of the traversing stream from surface-water and ground-water runoff.

Drainage areas can be delineated by sketching drainage divides on topographic maps. For many sites drainage-area maps prepared by the Connecticut Department of Environmental Protection will be of substantial assistance. Drainage areas for many locations on streams are shown on these maps, available from the Natural Resources Center, Connecticut Department of Environmental Protection, at 1:24,000, quadrangle scale; 1:50,000, county map scale; and 1:125,000, State map scale.

The maps show stream systems and the drainage areas that contribute runoff to them. The drainage divides and areas they encompass are natural; they have not been adjusted for the effects of storm sewers, diversion dams, canals, tunnels, or other manmade hydraulic changes.

Step 4: Delineate the drainage area(s) of all streams that flow into the aquifer upstream from the points where they cross the aquifer boundary. This separates the parts of the till and bedrock uplands that are drained by perennial streams (areas labeled C, fig. 5) from the parts that are not.

The drainage areas are separated by delineating the drainage divides on topographic maps beginning at each point where a stream enters the stratified drift and drawing a line upslope perpendicular to topographic contours on each side of the stream until each line intersects the basin divide defined in step 3. The areas drained by these perennial tributaries contribute runoff to stream(s) traversing the stratified drift aquifer, that are potential sources of induced recharge. In small headwater basins, such areas generally are small and few; however, those of intermediate and major streams are extensive and commonly include several towns within and beyond State boundaries.

Step 5: Identify remaining areas (areas labeled D, fig. 5). These areas are sources of recharge to the stratified drift under natural conditions. Ground water beneath these areas flows downgradient into the stratified-drift aquifer; most surface runoff also reaches the stratified drift and percolates to the saturated zone.

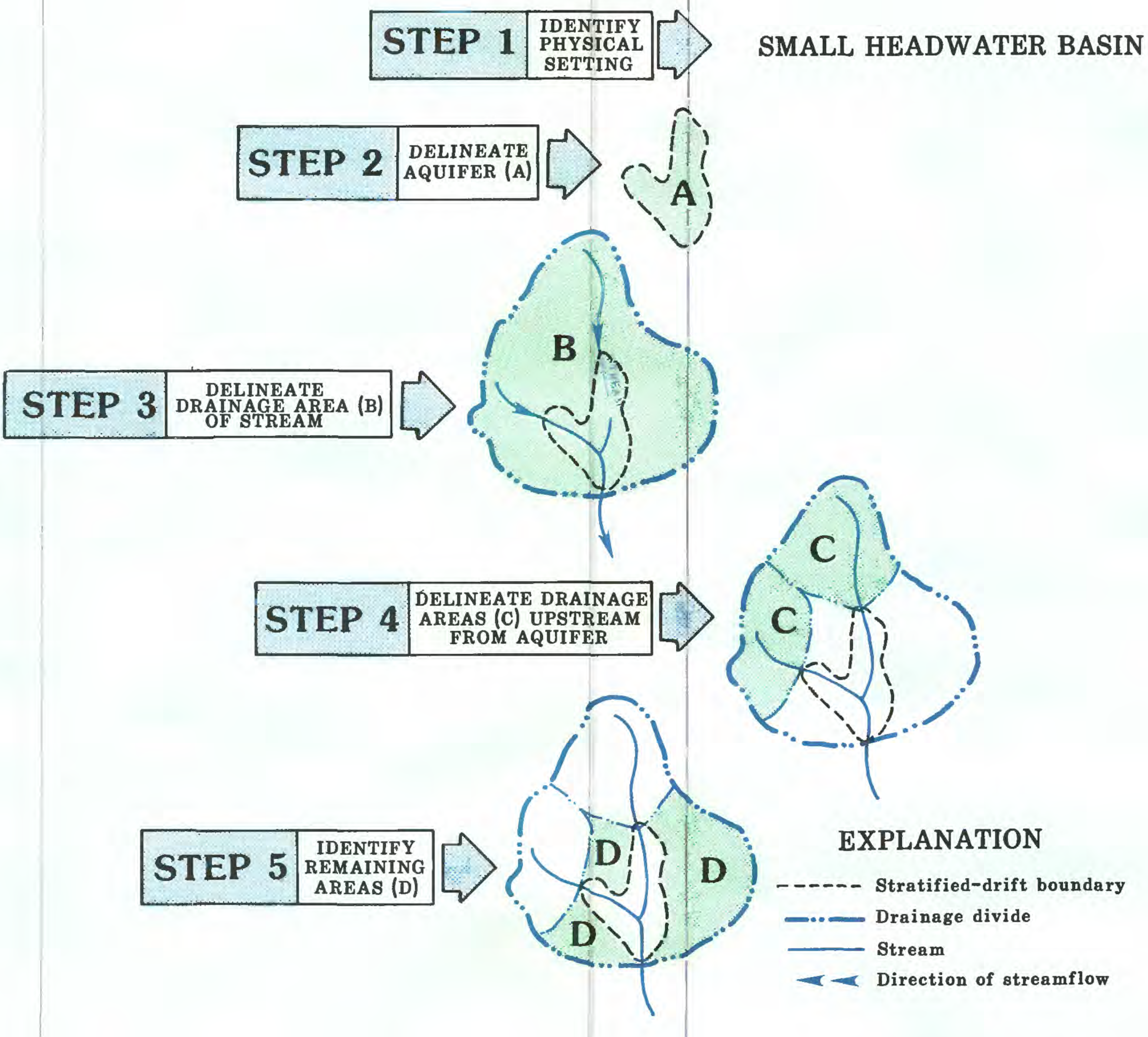
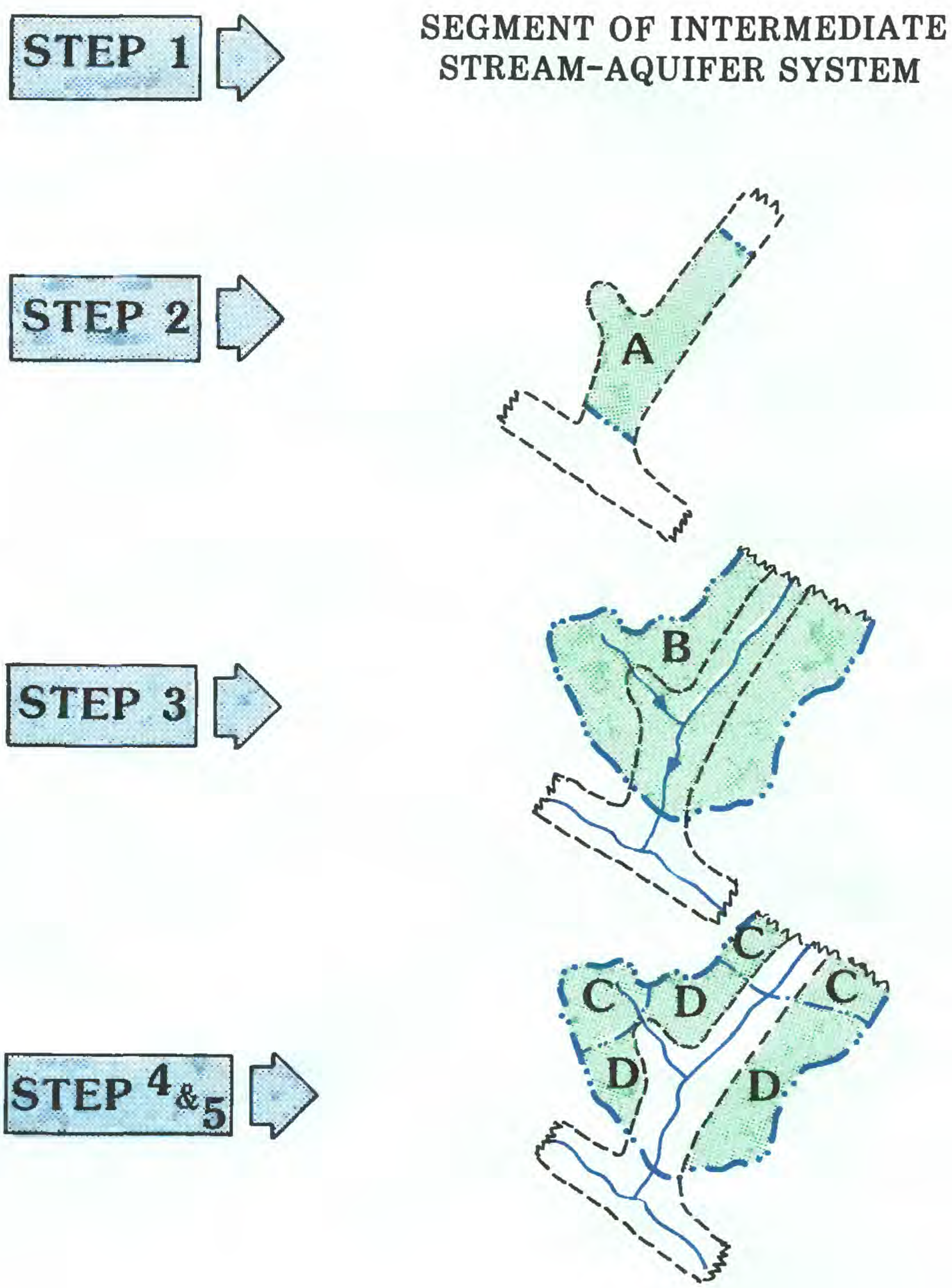


Figure 5.--General procedure for estimating recharge areas.


STEP 1
SEGMENT OF INTERMEDIATE
STREAM-AQUIFER SYSTEM
STEP 2
A
STEP 3
B
STEP 4&5
C
C
D
C
D
D

Steps 1-5 and figure 5 describe the basic procedure for estimating areas from which recharge is derived, or could be derived, for stratified-drift aquifers in Connecticut using geologic and topographic maps. This general method can be followed for aquifers in all basic physical settings (table 1). The number, areal extent, and proportion of recharge areas and the likelihood of significant induced recharge differ from one setting to another, but the procedures remain the same. Examples of applications of the method in a small headwater basin, stream-aquifer systems, and a coastal basin follow.

Examples

Small Headwater Basins

Stratified-drift aquifers in small headwater basins are bounded laterally by till and bedrock uplands and may be hydraulically connected to small streams. The three major sources of recharge or potential recharge to these aquifers are (1) precipitation over the aquifer, (2) inflow from adjacent till and bedrock, and (3) induced recharge from the hydraulically connected streams. Only a limited amount of streamflow generally is available for induced recharge in these basins; it is smallest during late summer and may be absent during droughts. Therefore, aquifers in small basins are recharged primarily by the first two sources, and may not provide adequate sustained yields for large public supplies. However, many aquifers are in less developed parts of the State where contamination sources are absent or scarce, and, consequently, contain good quality water. Therefore, these aquifers may be used for small public supplies. A stratified-drift aquifer in a small headwater basin in the Town of Norfolk is shown in fig. 6. The aquifer is bounded by till and bedrock, and traversed by a small stream, Norfolk Brook. The drainage area of Norfolk Brook upstream from the aquifer is less than 1 mi^2 and streamflow generally is not a sufficient source for large amounts of induced recharge.

The aquifer in the valley of Norfolk Brook is delineated in the surficial geologic map of the Norfolk quadrangle (Warren, 1972), and also on plate B of the water-resources inventory of the upper Housatonic River basin (Cervione and others, 1972). Figure 6.1 shows the extent of the stratified drift adjacent to Norfolk Brook and that part of the deposit where the saturated thickness is 10 feet or more.

Natural drainage divides for Norfolk Brook are given on the 1:24,000 scale drainage-area map of the Norfolk quadrangle (Thomas and White, 1978) and shown in figure 6.2.

The till and bedrock uplands in the drainage basin for Norfolk Brook are separated into (1) those parts that are drained by a perennial stream and are not sources of recharge to the stratified drift under normal conditions (Area C, fig. 6.3) and (2) those parts that are directly in contact with and are sources of recharge to the stratified drift under natural conditions (Area D, fig. 6.3). Norfolk Brook has a small (less than 1 mi^2) drainage area (Area C, fig. 6.3), and as a consequence has little potential to supply water to the aquifer

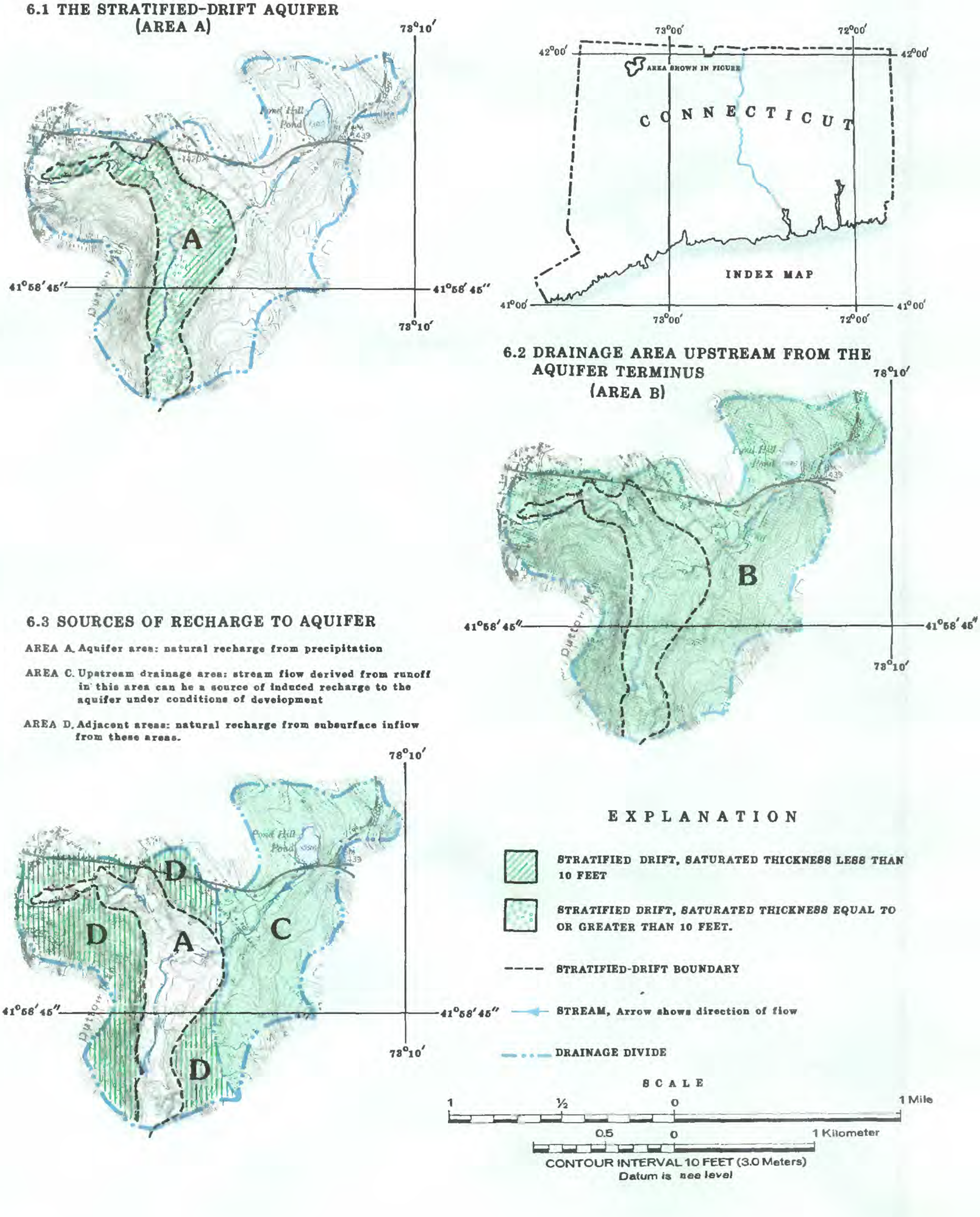


Figure 6.--Recharge-area delineation of an aquifer in a small headwater basin, Norfolk Brook, Connecticut.

by induced recharge. The remaining till and bedrock areas in the drainage basin (Area D, fig. 6.3) contribute recharge to the stratified-drift aquifer by subsurface inflow and infiltration of overland flow along the stratified-drift boundary.

Stream-Aquifer Systems

A stream-aquifer system, as defined in this report, includes a stratified-drift aquifer that is bounded laterally by till-and-bedrock uplands and is hydraulically connected to an intermediate or major stream. An intermediate stream is defined as one that has an upstream drainage area of 10 to 500 mi^2 and a major stream is one that has an upstream drainage area of more than 500 mi^2. The largest Connecticut streams are shown in figure 2 and their drainage areas are given in table 3. A stratified-drift aquifer may extend along both sides of a stream. In some places, such as along the Housatonic River in Derby and Shelton, an aquifer is partially bounded by a stream and the other side of the stream is underlain by till and bedrock.

Recharge to the stratified drift in a stream-aquifer system is derived from the same sources as in a small headwater basin. More ground water may be available for development, however, because the areas are larger and the potential for induced recharge is greater. Aquifers adjacent to intermediate and large streams are directly recharged from precipitation and from subsurface inflow of ground-water. In addition, streamflow is generally large enough to provide significant induced recharge under suitable conditions. The smaller streams draining only 10 to 20 mi^2, however, may have little flow during severe drought or seasonal periods of low flow, particularly if low flows are regulated or water is diverted from the basin.

The stratified drift on one side of a stream may be hydraulically connected both to the stream and to associated stratified-drift deposits across the stream. Consequently, heavy pumping of wells on one side of the stream may not only induce surface water into the aquifer, but may also capture ground water from the far side of the stream. Under nonpumping conditions this ground water would have discharged either to the stream or, by evapotranspiration, to the atmosphere. For this reason, stratified drift on both sides of an intermediate stream is treated as a single aquifer. Conversely, wells developed in stratified-drift aquifers along major rivers (draining 500 mi^2 or more) are less likely to cause ground water from across the river to flow into the wells, especially where the streambed and underlying stratified drift are coarse grained. The following sections on "intermediate streams" and "major streams" give examples of recharge-area delineation for stream-aquifer systems.

Intermediate Streams.--Stratified drift on both sides of an intermediate stream is considered as a single aquifer. First, the extent of the aquifer is delineated using geologic or geohydrologic maps. The aquifer boundary can be the stratified drift-till contact or 10-foot saturated thickness contour.

Table 3.--Drainage areas at selected points on the largest streams in Connecticut
[Includes all streams draining 200 mi^2 or more. Streams are located in figure 2. Drainage areas are from Thomas, 1972.]

Stream	Location	Drainage area (square miles)
Connecticut River	At Mass.-Conn. State line near Thompsonville	9,640
	Below Farmington River at Windsor	10,453
	At mouth, Lynde Point to Griswold Point, at Old Saybrook	11,269
Housatonic River	At Mass.-Conn. State line near Canaan	535
	Below Womenshenuck Brook at Gaylordsville	1,006
	At mouth at Milford Point	1,946
Thames River	Below Yantic River at Norwich	1,366
	At mouth at Eastern Point near Groton	1,478
Shetucket River (head of Thames)	Below Natchaug River at Willimantic	398
	Below Little River at Occum	509
	At State Route 12 above Yantic River at Norwich.	1,269
Quinebaug River	Below French River at Mechanicsville	284
	Below Moosup River near Wauregan	564
	At mouth at Taftville	744
Farmington River	Below East Branch Farmington River near New Hartford	303
	Above Salmon Brook at Tariffville	503
	At mouth at Windsor	607
Naugatuck River	Below Mad River at Waterbury	205
	At mouth at Derby	310
Pawcatuck River	Above Ashaway River at R.I.-Conn. State line	242
	At mouth at Watch Hill	304
West Branch Farmington River	Below Still River at Riverton	217
	Above East Branch Farmington River near New Hartford	238
Willimantic River (head of Shetucket)	Below Hop River near Willimantic	206
	Above Natchaug River at Willimantic	226
Tenmile River	Near Bulls Bridge (Gaylordsville)	203
	At mouth at Bulls Bridge	210

The stratified-drift aquifer in the Yantic River valley in eastern Connecticut is an example of an intermediate stream-aquifer system. The areal extent of the stratified drift, from surficial geologic maps of the Fitchville and Norwich quadrangles (Pessl, 1966; Hanshaw and Snyder, 1962), and where the saturated thickness is less than or greater than 10 feet, from Thomas and others (1968, plate B), are shown in figure 7. The Southeastern Connecticut Regional Planning Agency (1978) limited this aquifer to stratified drift that has a 10-foot or greater saturated thickness, and is west of State Route 52.

Figure 8 shows the aquifer along the Yantic River, its recharge areas, and part of the areas that contribute runoff to Elisha and Susquetonscut Brooks to the north, Bentley Brook and an unnamed brook to the south, and the Yantic River to the west. Drainage areas of the Yantic River and Susquetonscut Brook are too extensive to show in figure 8, and are shown in their entirety at a smaller scale in figure 9. The downstream reaches of the tributary streams in the lower reach of the Yantic River flow across the stratified-drift aquifer. They are hydraulically connected to the aquifer and could be sources of induced recharge under pumping conditions.

Drainage areas for the Yantic River, the principal stream associated with this aquifer, as well as most other intermediate and all major streams that are part of stream-aquifer systems, are much more extensive than the natural recharge areas of the aquifer. Because they are so large, parts of the stream drainage areas are likely to be outside the jurisdiction of local agencies for water-quality management, and, in some cases, are outside of Connecticut.

Major Streams. -- Where a stratified-drift deposit is traversed by a major stream, the deposits on either side, in many cases, can be considered as individual aquifers that are hydraulically separated by the stream. This simplifying assumption can be made because pump tests of wells in stratified-drift aquifers along major rivers in Connecticut have not measurably affected ground-water levels across the stream. However, heavy pumpage of similar aquifers in other States has resulted in ground-water flow beneath streams (A.D. Randall, U.S. Geological Survey, written commun., 1983). Therefore, where average daily withdrawals from closely spaced wells on one bank of a major stream exceed 2,000 gallons per minute, or are known to produce significant drawdowns on the far bank, or occur from gravel beneath a confining layer known to extend beneath the stream, it would be prudent to delineate recharge areas in the same manner as for intermediate streams. At most locations, however, the stratified drift on each side of a stream draining more than 500 mi^2 can be treated as a separate stream-aquifer system and its recharge areas can be delineated separately. The aquifer boundaries are considered to be the stream and the stratified drift-till contact, or another feature such as a saturated-thickness contour.

Stratified-drift deposits bordering the Shepaug Reservoir along the Housatonic River in New Milford are examples of major stream-aquifer systems; their recharge areas were delineated in a previous study using the methods outlined in this report (Hayes, 1978). Although mapped as primarily fine-grained material by Meade (1978), the aquifer is very thick and has a

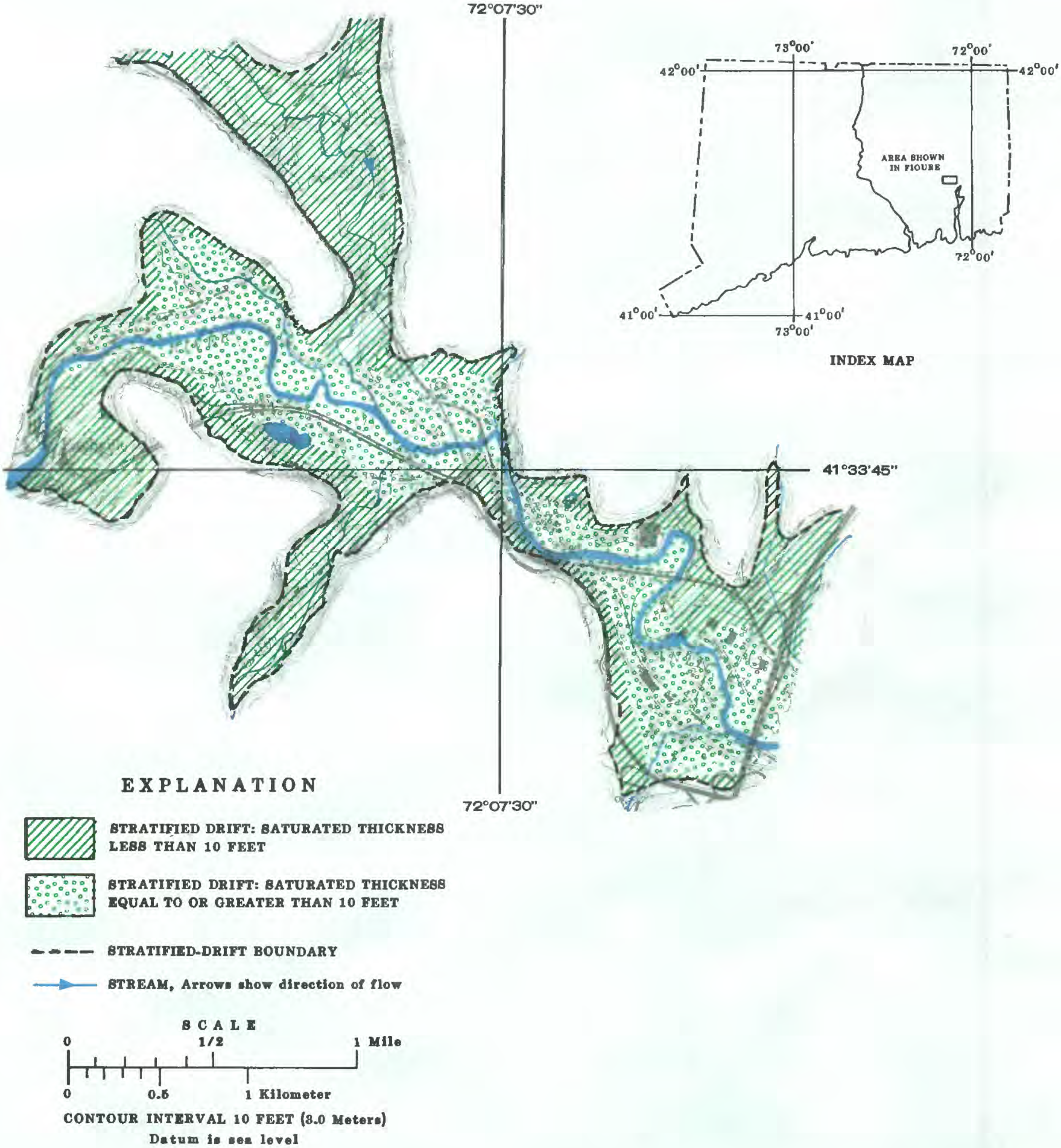


Figure 7.--Recharge-area delineation: Areal extent of the aquifer in an intermediate stream-aquifer system, Yantic River basin, Connecticut.

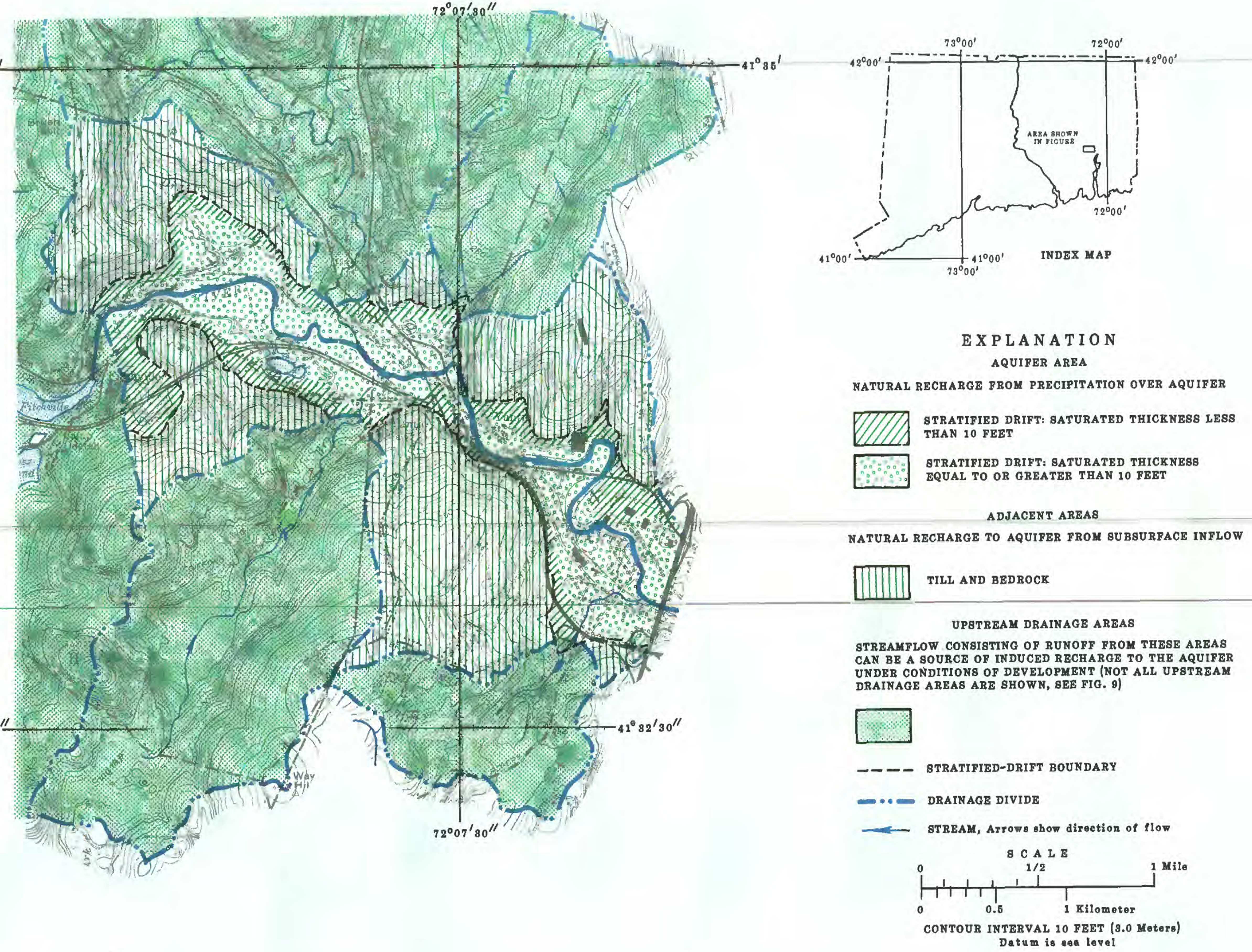


Figure 8.--Recharge-area delineation: Natural recharge areas of the aquifer in an intermediate stream-aquifer system. Yantic River basin. Connecticut.

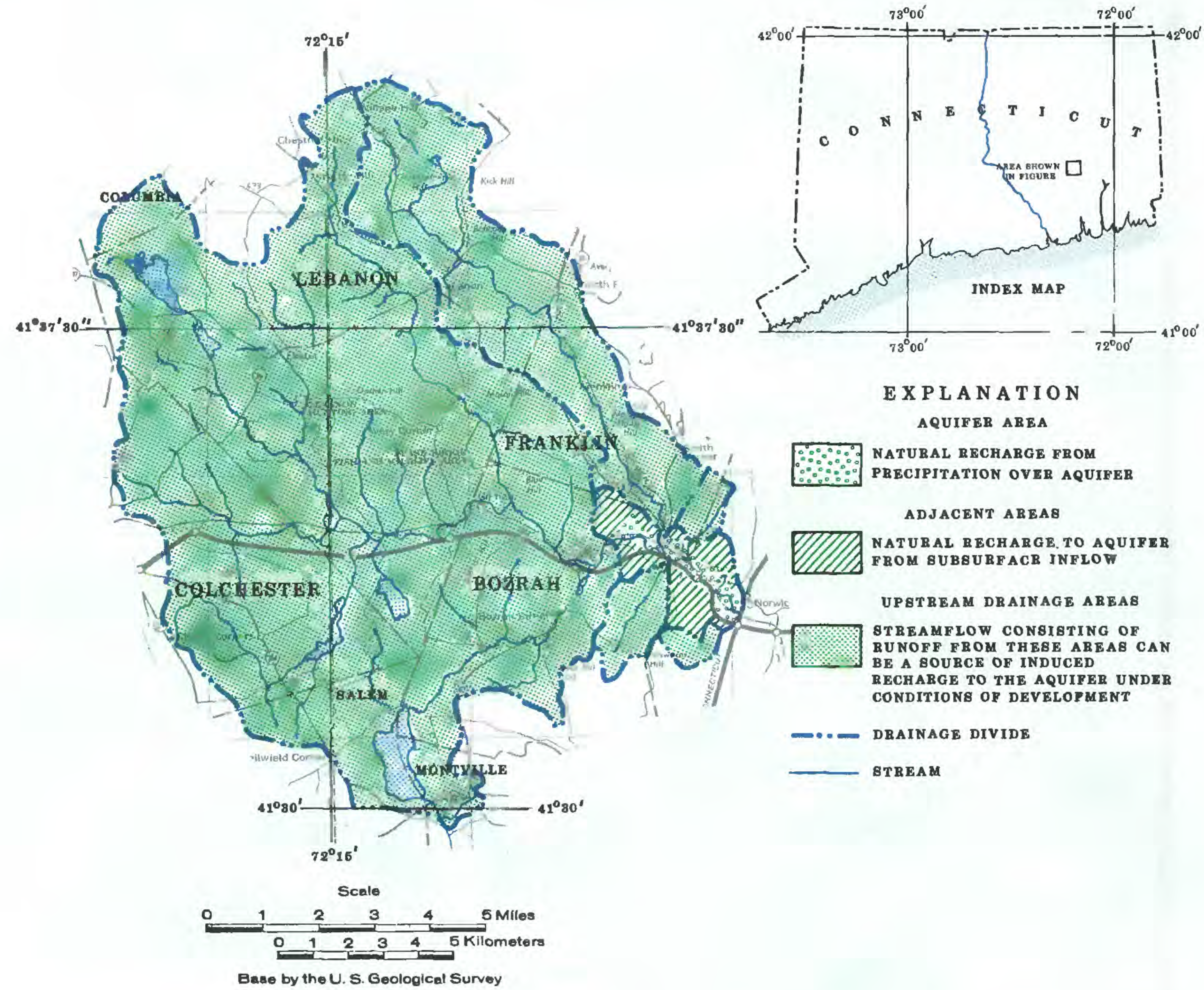


Figure 9.--Recharge-area delineation: Drainage areas of the aquifer in a intermediate stream-aquifer system, Yantic River basin, Connecticut.

transmissivity of 2,000 to 8,000 ft^2/d 1/ (Cervione and others, 1972). The areal extent of the stratified-drift deposits on the east side of the river (Thompson, 1975), and an aquifer boundary based on the saturated thickness and transmissivity of these deposits (Cervione and others, 1972, plate B), are shown in figure 10 along with areas contributing natural recharge to the aquifers from subsurface inflow of ground water.

Pumping of ground water may induce recharge into the upstream (northern) aquifer from the Housatonic, West Aspetuck, and East Aspetuck Rivers. Recharge to the downstream (southern) aquifer might be induced from the Housatonic River and Great Brook. Parts of the drainage areas for these streams are shown in figure 10. The drainage area of the Housatonic River above the Aspetuck River is 1,065 mi^2, of the Aspetuck River at its mouth is 50.6 mi^2, and of Great Brook at its mouth is 4.03 mi^2. These areas are too extensive to be fully delineated in figure 10. Much of the drainage area of the Housatonic River (table 3), lies outside the State.

Coastal Basins

In mapping recharge areas of aquifers in coastal basins, the shoreline contact with saltwater can be considered a boundary. Streams traversing coastal aquifers may be small, as in the Bride Lake area in East Lyme (fig. 11), intermediate, as along Norwalk Harbor, or major, as along the Connecticut River estuary. Figure 11 shows the extent of the stratified drift adjacent to Bride Brook (Goldsmith, 1964) and the thick (saturated thickness equal to or greater than 10 feet) section (Thomas and others, 1968, plate B). Its recharge areas are delineated in figure 12. Runoff from upstream drainage areas discharges into Bride Brook and Beaver Dam Brook north of the aquifer, and an unnamed tributary of Bride Brook to the west. These drainage areas are shown on maps of the Niantic and Old Lyme quadrangles (Thomas, 1975a; 1975b). In this example, drainage areas are delineated upstream from the points where these streams flow across the 10-foot saturated zone of the stratified drift shown in figure 11.

Heavily pumped, closely spaced wells near the coast and along estuaries are likely to induce saltwater intrusion into the aquifer. Where pumped wells disturb the equilibrium between freshwater and salty ground water, the interface moves landward and the wells may eventually yield salty water. Therefore, large public-water supplies are not commonly developed in areas of coastal zone vulnerable to saltwater intrusion. In such cases, it may be necessary to delineate recharge areas for only those parts of coastal aquifers that lie upgradient from the "vulnerable zone."

For example, saltwater intrusion is possible in the southern part of the aquifer along Bride Brook as shown in figure 12. For this reason, the Southeastern Connecticut Regional Planning Agency (1978) excludes

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1/ The unit for transmissivity is cubic foot per day per foot of aquifer thickness. In reduced form this becomes foot squared per day (ft^2/d).

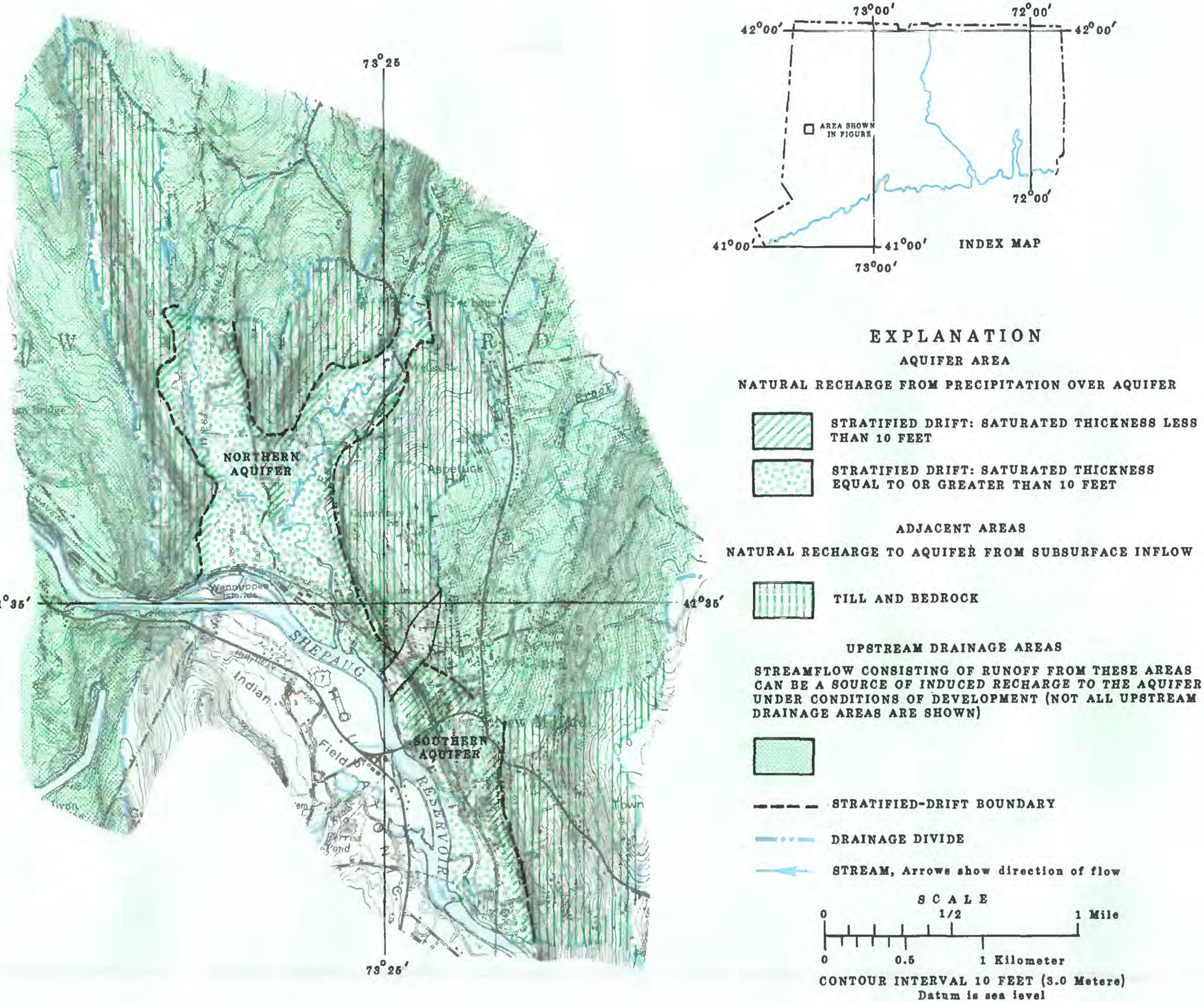
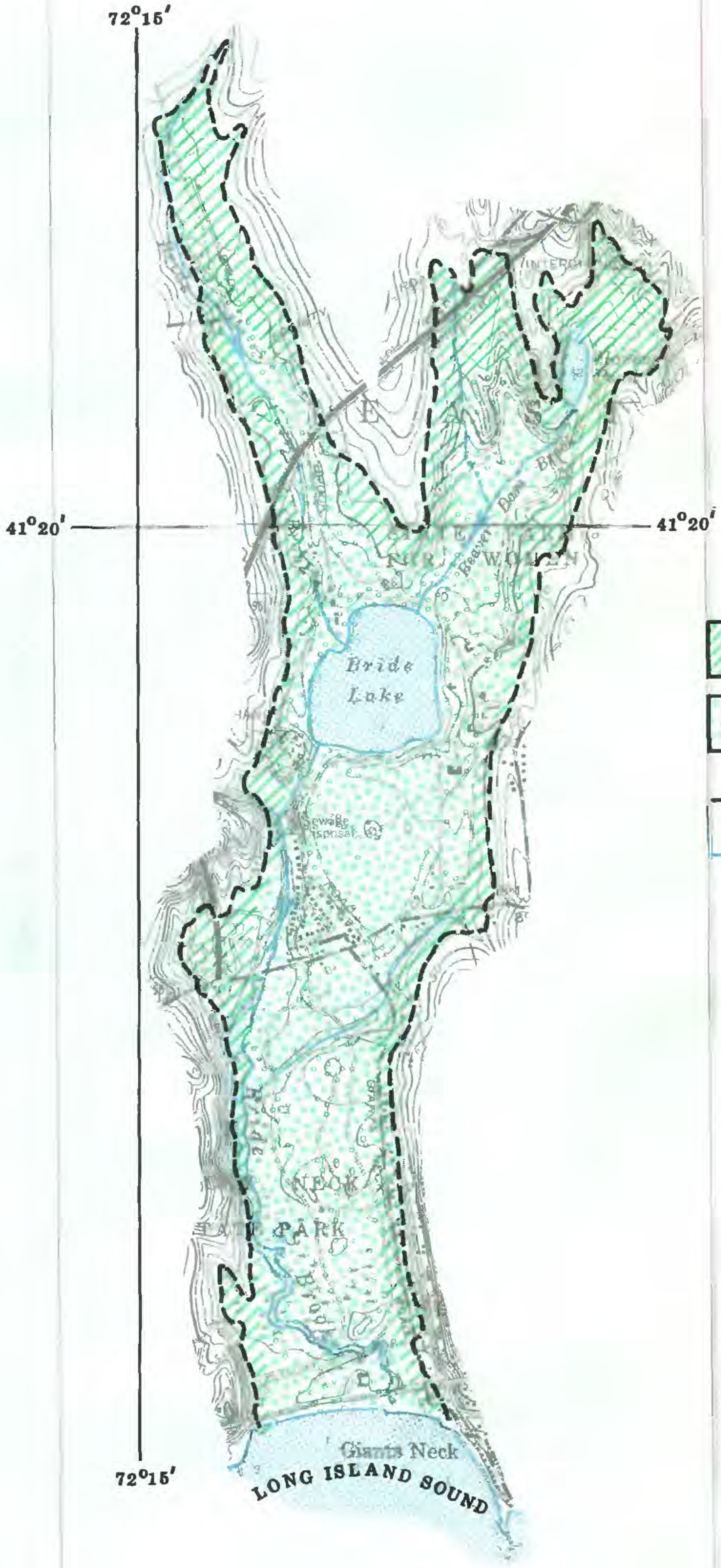
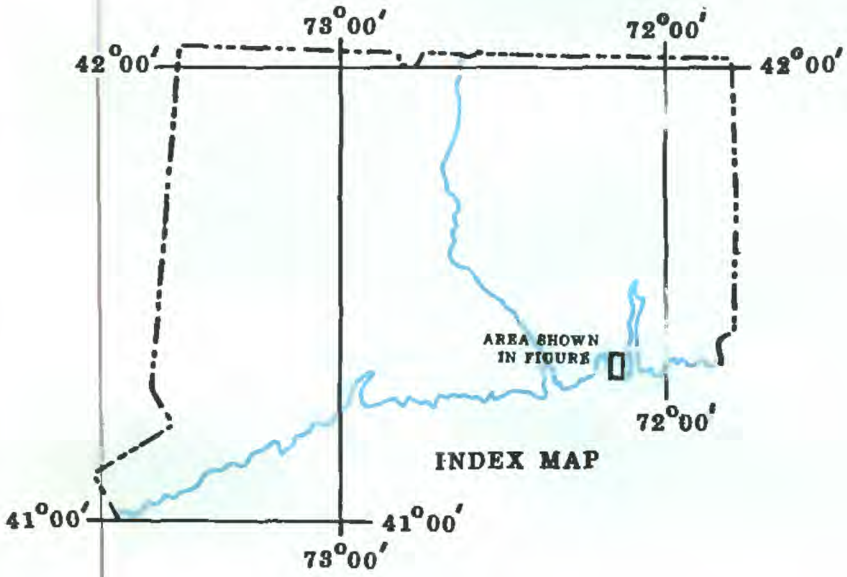


Figure 10.--Recharge-area delineation: Major stream-aquifer system in the Housatonic River basin, Connecticut.





EXPLANATION

STRATIFIED DRIFT: SATURATED THICKNESS LESS THAN 10 FEET

STRATIFIED DRIFT' SATURATED THICKNESS EQUAL TO OR GREATER THAN 10 FEET

STRATIFIED-DRIFT BOUNDARY

STREAM, Arrows show direction of flow

SCALE

0 1/2 1 Mile

0 0.5 1 Kilometer

CONTOUR INTERVAL 10 FEET (3.0 Meters)

Datum is sea level

Figure 11.--Recharge area delineation: Areal extent of aquifer in a coastal basin adjacent to Bride Brook, Connecticut.

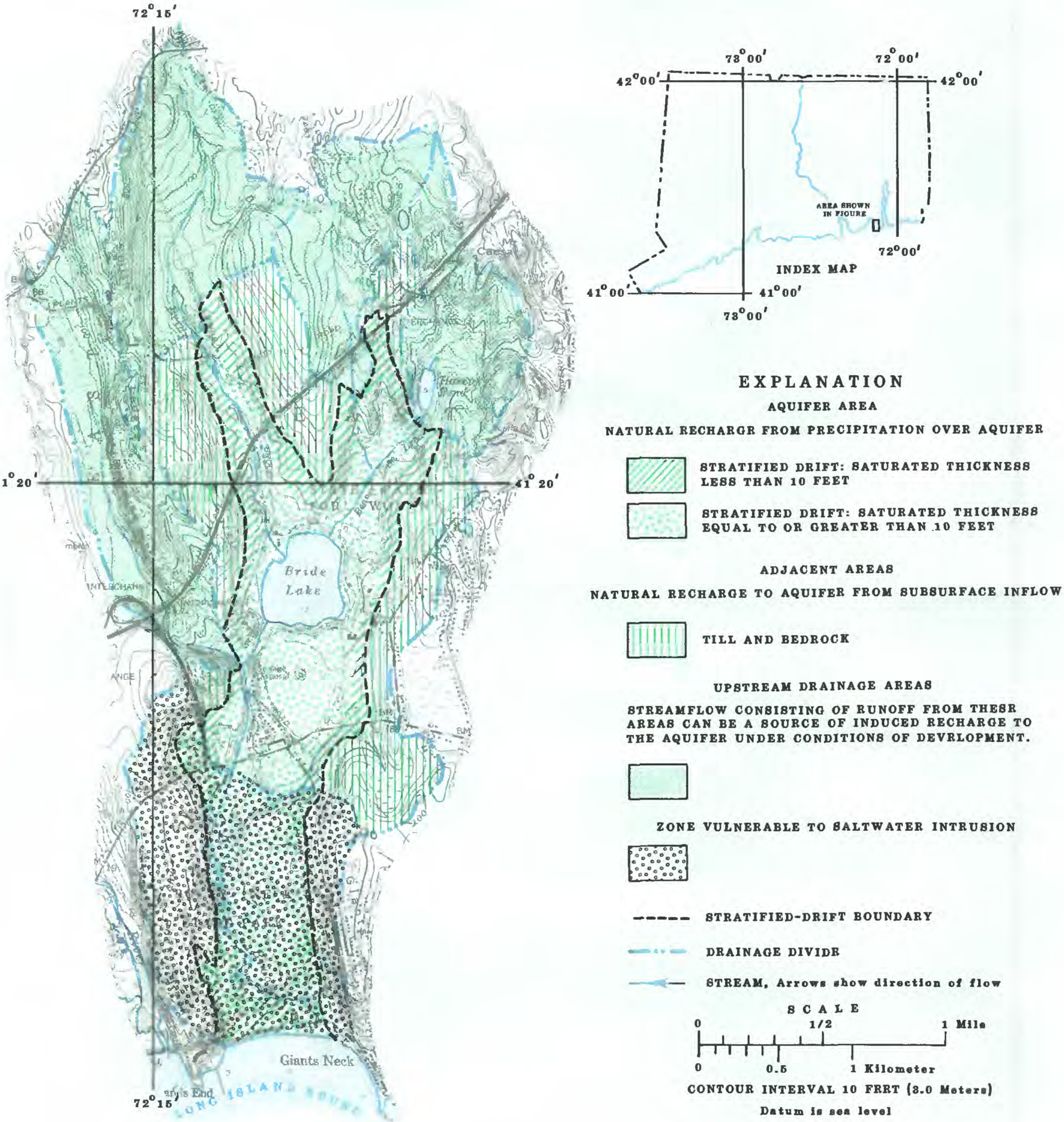


Figure 12.--Recharge-area delineation: Recharge areas of an aquifer in a coastal basin adjacent to Bride Brook, Connecticut.

this part of the aquifer from consideration for large public supplies. The northern part, however, is used for public supply. A 1:125,000-scale map of Connecticut (Rolston and others, 1979) delineates the Connecticut coastal area considered vulnerable to saltwater intrusion. The map can serve as a reference for selecting aquifers in coastal basins, mapping their extent, and delineating their recharge areas.

Complex Settings

In parts of the Connecticut, Farmington, and Quinnipiac River basins (figure 2), and rarely elsewhere, widespread stratified-drift aquifers extend across surface-water drainage divides and coarse-grained deposits commonly border or grade laterally into extensive fine-grained materials of lower hydraulic conductivity. In these areas that constitute about 10 percent of the State, ground-water drainage divides may not coincide with surface-water divides under natural conditions, and are likely to migrate laterally in response to stresses such as pumping. In some locations coarse-grained aquifers underlie the fine-grained stratified drift and the extent of the aquifers may have no relationship with surface drainage divides. In many urbanized areas, diversions by storm sewers, dams, and culverts have altered surface-water drainage. Without knowledge of the configuration of the water table in the stratified drift under present conditions, or under conditions of future development, the positions of ground-water divides and recharge areas cannot be accurately defined.

The U.S. Geological Survey is conducting studies to evaluate the use of ground-water-flow models to estimate areas contributing flow to pumping centers in large stratified-drift aquifers. The method requires approximations of the water-table configuration, boundary conditions, and aquifer characteristics, and the locations and pumping rates of future pumping centers also must be specified.

Use of ground-water flow models has advantages in that the area recharging a pumping center generally constitutes only a small part of the aquifer and water-quality management can focus on this area.

CONCLUSIONS

In order to protect stratified-drift aquifers from contamination, it is necessary to determine land areas that can or may contribute recharge to them. Recharge areas can be delineated for stratified-drift aquifers in most parts of Connecticut using topographic and geologic or hydrogeologic maps. Under natural conditions, recharge to stratified-drift is from (1) precipitation that falls on the area overlying the aquifer and percolates to the saturated zone, and (2) precipitation that falls on adjacent till and bedrock, and either percolates to the saturated zone, and flows laterally into the stratified-drift aquifer, or runs off the surface and recharges the stratified drift at its edge.

Under conditions of development, pumping wells may alter the natural ground-water-flow conditions, inducing surface water from nearby streams and lakes into the aquifer. This induced recharge consists of runoff from the entire upstream drainage area of an adjacent surface-water body and can affect water quality in an aquifer.

In areas where ground-water and surface-water drainage divides do not coincide, and where coarse-grained aquifers underlie fine-grained materials and have little relationship to surface drainage, such as in parts of the Connecticut, Farmington, and Quinnipiac River basins, (see Fig. 2), recharge areas cannot be estimated without additional detailed hydrologic information.

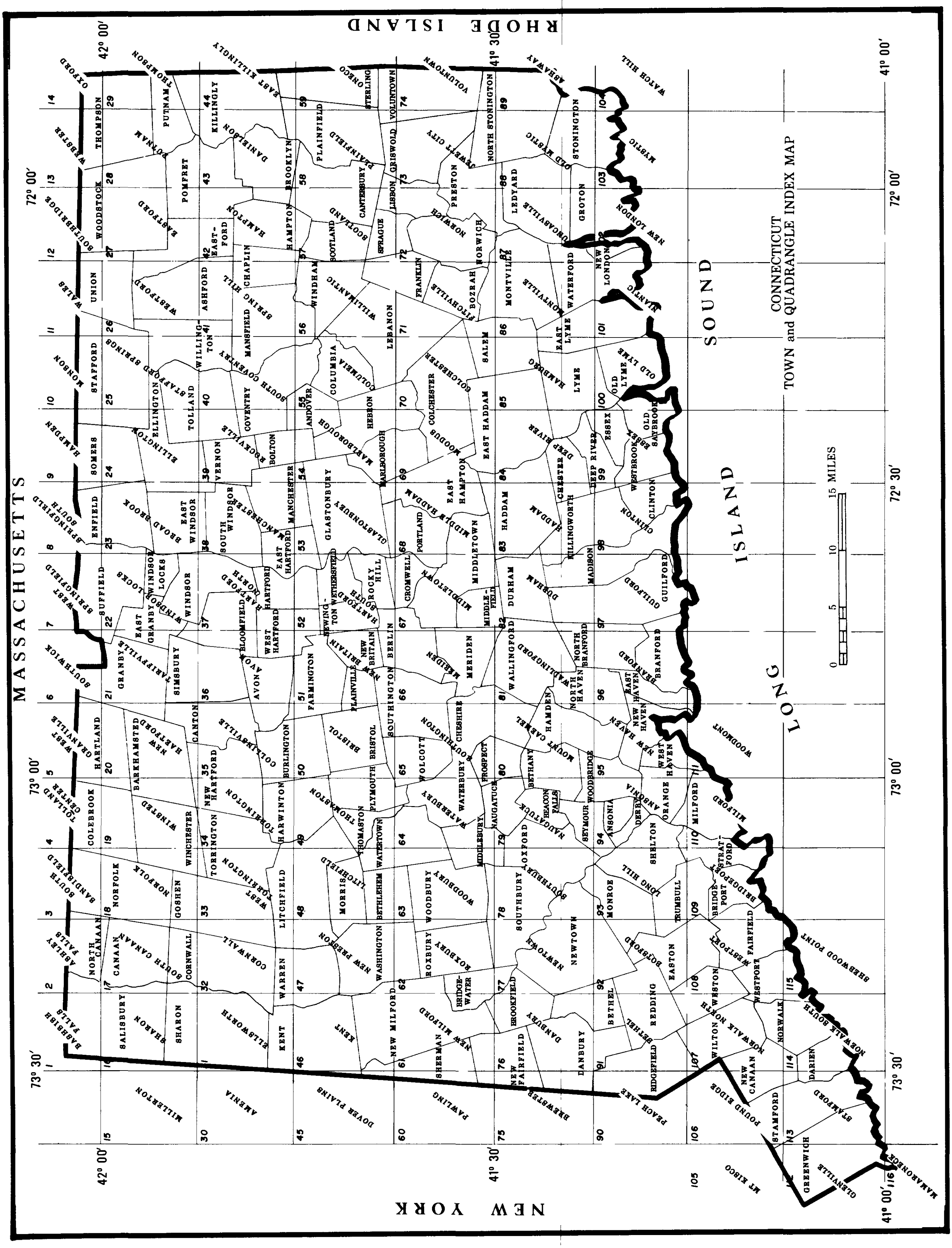


Figure 13.--Towns and quadrangles in Connecticut

Table 4.--Quadrangle maps showing geology, topography, and drainage areas in Connecticut
[Quadrangle locations are in figure 13. A complete listing of pertinent topographic geologic, and hydrologic maps by quadrangle was compiled by Bronson, 1982]

A. Published 1/ and open file 2/ surficial geologic maps

Quadrangle	Map number	Quadrangle	Map number	Quadrangle	Map number
Ansonia	QR23	Jewett City	GQ-1434	Southbridge	Open file
Ashaway	GQ-712	Kent	Open file	Southbury	Open file
Ashley Falls, MA	GQ-936	Litchfield	GQ-848	South Canaan	Open file
Avon	GQ-147	Manchester	GQ-433	Southington	GQ-146
Bashbish Falls, MA	GQ-507	Marlborough	GQ-1504	So. Sandisfield, MA	GQ-1519
Branford	QR14	Meriden	GQ-150	Southwick, MA	GQ-891
Bristol	GQ-145	Milford	QR23	Springfield So., MA	GQ-678
Broad Brook	GQ-434	Monson, MA	GQ-1429	Spring Hill	QR26
Clinton	QR28	Montville	GQ-148	Stafford Springs	GQ-1216
Collinsville	Open file	Moodus	GQ-1205	Tariffville	GQ-798
Cornwall	GQ-1148	Mount Carmel	QR12	Thomaston	GQ-984
Danbury	Open file	Mystic	GQ-940	Torrington	GQ-939
Danielson	GQ-660	Naugatuck	QR35	Uncasville	GQ-138
Deep River	GQ-1370	New Britain	GQ-119	Voluntown	GQ-469
Durham	GQ-756	New Hartford	GQ-1257	Wallingford	QR10
Eastford	GQ-1023	New Haven	QR18	Watch Hill, RI	GQ-410
Ellington	GQ-965	New London	GQ-176	Webster, MA	Open file
Ellsworth	Open file	New Milford	Open file	Westford	GQ-1214
Essex	QR31	New Preston	GQ-782	West Granville, MA	Open file
Fitchville	GQ-485	Niantic	GQ-329	Westport	MF-1295
Glastonbury	GQ-1354	Norfolk	GQ-983	West Springfield, MA	GQ-892
Guilford	QR28	Norwalk South	GQ-718	West Torrington	GQ-727
Haddam	QR36	Norwich	GQ-165	Willimantic	QR39
Hampden, MA	Open file	Old Lyme	QR31	Windsor Locks	GQ-137
Hampton	GQ-468	Oneco, RI	GQ-917	Winsted	GQ-871
Hartford North	GQ-223	Plainfield	GQ-1422	Woodbury	GQ-896
Hartford South	QR20	Roxbury	GQ-611	Woodmont	QR18
		Scotland	GQ-392		

1/ Published separately in the Geologic Quadrangle (GQ) and Miscellaneous Field Studies (MF) series of Geological Survey publications and the Geologic Quadrangle Report (QR) series of State publications and available from:

Connecticut Department of Environmental Protection
Publication Sales
State Office Building, Room 555
Hartford, Connecticut 06115

2/ Open-file maps may be inspected at:

Connecticut Department of Environmental Protection
Natural Resources Center
State Office Building, Room 553
Hartford, Connecticut 06115

B. U.S. Geological Survey topographic maps at a scale of 1:24,000 are available for all parts of the State.

C. Blueprint copies of drainage-area maps for all quadrangles may be obtained from:

Connecticut Department of Environmental Protection
Natural Resources Center
State Office Building, Room 553
Hartford, Connecticut 06115

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GLOSSARY

Aquifer: A geologic formation or unit that can yield usable quantities of water.

Artesian aquifer (confined aquifer): An aquifer overlain by a confining bed and containing water under sufficient pressure to rise above the upper surface of the aquifer.

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

Carbonate rock: Rock composed primarily of calcium and magnesium carbonate minerals.

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

Contamination: The degradation of natural water quality as a result of human activities, to the extent that its usefulness is impaired (Miller and others, 1974, p. 319).

Crystalline rock: Igneous and metamorphic rocks; the most common types in the State are schist, gneiss, and granite.

Drainage basin (drainage area): The whole area or entire tract of country that gathers water and contributes it ultimately to a particular stream channel, lake, reservoir, or other body of water.

Drawdown: The lowering of the water table or other potentiometric surface caused by pumping. It is equal to the difference between the static level and the pumping level.

Estuary: A body of water or zone at the river's mouth in which river water mixes with, and measurably dilutes, sea water.

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

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

Ground water: Water in the saturated zone.

Ground-water discharge: The discharge of water from the saturated zone by 1) natural processes, such as ground-water runoff and ground-water evaporation, and 2) artificial discharge through wells and other manmade structures.

Ground-water recharge: The addition of water to the saturated zone by 1) natural processes, such as infiltration of precipitation, and 2) induced recharge and artificial recharge through basins, sumps, and other manmade structures.

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

Hydraulic conductivity: A measure of the ability of a porous medium to transmit a fluid. The material has a hydraulic conductivity of unit length per unit time if it will transmit in unit time a unit volume of water at the prevailing kinematic viscosity through a cross section of unit area, measured at right angles to the direction of flow, under a hydraulic gradient of unit change in head over unit length of flow path.

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

Induced infiltration: The process by which water in a stream or lake moves into an aquifer by the establishment of a hydraulic gradient from the surface-water body toward a pumping well or wells.

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

Infiltration: Passage of a gas or liquid into or through soil or rock by penetrating pores or small openings.

Point source: Any discernible, confined, and discrete conveyance, such as a pipe, ditch, or channel, from which pollutants are or may be discharged.

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

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

Runoff, total: That part of the precipitation that appears in streams; it includes ground-water and surface-water components. It is the same as streamflow unaffected by artificial diversions, storage, or other works of man in or on the stream channels.

Saltwater intrusion: The movement of saltwater or brackish water into a nearby aquifer, resulting from the pumping of freshwater near the sea.

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

Saturated zone: The subsurface zone in which all open spaces are filled with water under pressure greater than atmospheric.

Sedimentary rock: Rock formed of sediment. The most common types in the State are sandstone, siltstone, and shale.

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

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

Stratified drift: A sorted sediment laid down by or in meltwater from a glacier; includes sand, gravel, silt, and clay deposited in layers.

Stream-aquifer system: An aquifer in hydraulic connection with an adjacent stream.

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

Transmissivity: The rate at which water is transmitted through a unit width of aquifer under a unit hydraulic gradient. Equal to the average hydraulic conductivity times the saturated thickness.

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

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

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

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

Unsaturated zone: The subsurface zone above the water table.

Vulnerable coastal zone: The area along the coast and along estuaries that is susceptible to saltwater intrusion.

Water table: The upper surface of the saturated zone. It is defined by the levels at which water stands in wells that penetrate just deep enough to hold standing water. In wells penetrating to greater depth, the water level will stand above or below the water table if an upward or downward component of ground-water flow exists.