PRELIMINARY APPRAISAL OF THE EFFECTS OF LAND USE ON WATER QUALITY IN STRATIFIED-DRIFT AQUIFERS IN CONNECTICUT

PRELIMINARY APPRAISAL OF THE EFFECTS OF LAND USE ON WATER QUALITY IN

STRATIFIED-DRIFT AQUIFERS IN CONNECTICUT

U.S. GEOLOGICAL SURVEY TOXIC WASTE--GROUND-WATER CONTAMINATION PROGRAM

By Stephen J. Grady and Martha Fisher Weaver

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 87-4005

Hartford, Connecticut

1988

CONTENTS

ILLUSTRATIONS

[Plates are in pocket]

TABLES

FACTORS FOR CONVERTING INCH-POUND UNITS TO INTERNATIONAL

SYSTEM (METRIC) UNITS

Inch-pound units	Multiplied by	Are converted to Metric units
	Length	
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square foot (ft^2)	0.09294	square meter (m^2)
square mile (mi^2)	2.59	square kilometer (km^2)
	Flow	
foot per day (ft/d)	0.3048	meter per day (m/d)
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)
	Hydraulic units	
hydraulic conductivity in foot per day (ft/d)	0.3048	hydraulic conductivity in meter per day (m/d)
hydraulic gradient in foot per mile (ft/mi)	0.1894	hydraulic gradient in meter per kilometer (m/km)
inch per year (in/yr)	25.4	millimeter per year (mm/yr)
	Temperature	
degree Fahrenheit (°F)	°C = 5/9 (°F - 32)	degree Celsius (°C)

Sea level

In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Mean Sea Level of 1929."

PRELIMINARY APPRAISAL OF THE EFFECTS OF LAND USE ON WATER QUALITY

IN STRATIFIED-DRIFT AQUIFERS IN CONNECTICUT

by Stephen J. Grady and Martha Fisher Weaver

ABSTRACT

This report describes the hydrogeology, land use, and chemical quality of water in two stratified-drift aquifers in Connecticut, and relates differences in ground-water quality to the principal land uses within the study areas.

The stratified-drift aquifers that underlie 7.9 square miles of the Pootatuck and 12.7 square miles of the Pomperaug River valleys consist primarily of sand and gravel deposits up to 150 feet thick. Average horizontal hydraulic conductivity of the stratified drift ranges from 20 to 170 feet per day, and ground water flows through the aquifers at an average rate of 2 to 3 feet per day. The residence time of ground water is short--from a few years to a few decades--and therefore, recent land uses are expected to affect water quality significantly.

Land use in the study areas is changing from primarily undeveloped or agricultural lands to expanding residential, commercial, and light-industrial uses. Most residential areas are unsewered and are characterized by low to medium-density housing. Agricultural lands are located mostly within the valley flood plains and produce silage corn, hay, and berries. Industrial land uses are limited in extent and are characterized by small, modern, high-technology industries. Commercial land uses include a mixture of retail outlets, trades, and services common to suburban areas. The degree of development is characteristic of much of the northeastern United States outside of the densely populated urban areas.

Water-quality data for 1923-82, that include 127 partial chemical analyses of ground-water samples from 38 wells in the two aquifers, were augmented by sampling during 1985 from 21 new stainless-steel wells for selected major inorganic constituents, trace elements, and organic chemicals. Nonparametric statistical procedures were used to compare the water-quality data from four land-use areas, for the two sampling periods, and between the two aquifers.

Human activities associated with agricultural, residential, and industrial/commercial land uses have affected the quality of water in the stratified-drift aquifers underlying these land-use areas. Statistical comparisons of water-quality data between land-use areas show significant differences at an error probability level of 0.05 (95-percent confidence level) for some water-quality constituents. Apparent relations between land use and ground-water quality include:

(1) Median concentrations of most ground-water constituents are smallest in undeveloped areas.

(2) Ground water in agricultural areas has the largest median sulfate and
     total ammonia plus organic nitrogen concentrations. Agricultural areas
     are also characterized by ground water with significantly greater median
     specific conductance, noncarbonate hardness, carbon dioxide, and magne-
     sium concentrations relative to undeveloped areas. The application of
     fertilizers, lime, and other agricultural chemicals is the most likely
     source of the elevated concentrations of these constituents.

(3) Median concentrations of most major inorganic constituents, excluding
     potassium, sulfate, and total ammonia plus organic nitrogen, are greater
     in ground water in residential areas than in undeveloped and agricultur-
     al areas. Ground water in residential areas has significantly greater
     median specific conductance, hardness, calcium, chloride, magnesium,
     and dissolved solids concentrations relative to ground water in un-
     developed areas. Manganese, nickel, and sodium concentrations in
     residential areas are significantly greater than in agricultural areas.
     Probable sources for the elevated concentrations of the above consti-
     tuents in residential areas include effluent from septic systems and
     leaky sewer lines, road deicing chemicals, and lawn and garden chemicals.

(4) Ground water in industrial/commercial areas has the greatest median
     specific conductance, pH, carbon dioxide, calcium, magnesium, chloride,
     bicarbonate, dissolved solids, boron, and strontium concentrations. The
     following major inorganic constituents are significantly greater in the
     industrial/commercial areas than in undeveloped areas: Specific conduct-
     ance, hardness, carbon dioxide, calcium, magnesium, chloride, and dis-
     solved solids. The median dissolved solids concentration in industrial/
     commercial areas is also significantly greater than in agricultural
     areas. The detection frequency of arsenic, lead, and lithium is signi-
     ficantly greater in ground water from industrial/commercial areas than
     for ground water from one or more of the other land-use areas. Possible
     sources for the elevated constituents include leaks, spills, and dis-
     charges of industrial chemicals and runoff from streets and paved lots
     within industrial/commercial areas.

     Significant differences exist between historical and reconnaissance data
for some constituents. These differences may be artifacts of small sample
size, or inconsistent sampling and analytical methodologies used during the dif-
ferent sampling periods. However, statistical tests show insufficient evidence
of interactions between land use and sampling period. No significant differen-
ces are evident in any of the major inorganic constituents for land-use com-
parisons between the two aquifers. It is likely, therefore, that relations
between land use and ground-water quality that can be demonstrated for one
aquifer may be transferrable to other similar settings.

INTRODUCTION

There is a growing concern for the quality of the Nation's ground-water resources as reports of contaminated wells occur more frequently throughout the country. In some of the worst cases, improper waste-disposal practices have resulted in a host of toxic chemicals that pollute water supplies. The area affected by waste-disposal sites, however, is relatively small with respect to the total ground-water resources. To fully assess the quality of the Nation's ground water and the magnitude and severity of the contamination problem, it is necessary to characterize the cumulative effects from activities associated with more prevalent land-use practices. Accurate data on ground-water quality must be obtained and interpreted in conjunction with detailed information on land use and hydrogeologic conditions. More data are especially needed concerning the distribution and concentration of trace elements and organic chemicals in ground water. With this information, existing relations between ground-water quality and man's activities in various hydrogeologic settings may become apparent.

In 1984, the Toxic Waste--Ground-Water Contamination Program of the U.S. Geological Survey initiated 14 regional ground-water-quality appraisals (Ragone, 1984) in areas that have climatic, hydrogeologic, and land-use characteristics that are representative of large sections of the Nation. These studies are intended to provide a better understanding of the distribution and variation in concentrations of chemical constituents that are indicative of changes in ground-water quality that result from human activities inherent to various types of land use in the individual study areas. Consequently, a comparison of the similarities or differences in the types and levels of ground-water contamination that occur from equivalent land uses within various hydrogeologic and climatic regions may allow extrapolation of the findings of these studies to the balance of the Nation's ground-water resources.

The regional appraisal in Connecticut is a study of the quality of ground water in stratified-drift aquifers characteristic of the glaciated northeastern United States. The area lies within the Northeast Uplands ground-water region (Heath, 1984), which includes most of New England and part of New York. The major aquifers in this region are areally extensive, coarse-grained deposits of stratified drift that principally occur in river valleys. They are primarily unconfined and are comprised of interbedded, unconsolidated sediments that have, in the aggregate, moderate to high transmissivities.

Stratified-drift aquifers in this region are highly susceptible to contamination because they have relatively high permeability, and shallow water tables, are recharged mainly from precipitation that percolates from the land surface, and are hydraulically connected to adjacent surface-water bodies. In addition, the land surface above many of these aquifers is extensively developed because of the flat topography, ease of excavation, and location adjacent to principal rivers. Activities associated with several types of land use prevalent in Connecticut and the northeast have resulted in numerous incidents of ground-water contamination and the perception of widespread water-quality impairment (Miller and others, 1974; Handman and others, 1979; Rolston and others, 1979).

3

The objectives of the regional ground-water-quality appraisal in Connecticut are to: (1) Describe the hydrogeology of selected stratified-drift aquifers and the use by man of the overlying areas, (2) determine the chemistry of water in these stratified-drift aquifers with emphasis on trace elements and organic substances, and (3) identify statistically valid relations between ground-water quality and man's activities that may be extrapolated to similar hydrogeological settings elsewhere.

Purpose and Scope

This report describes the initial or reconnaissance phase of the study. In this phase, all relevant information on hydrogeology, water quality, and land use for two preliminary study areas was assembled and evaluated. Additional hydrogeologic and water-quality data were collected where needed to better describe the system and to characterize ground-water quality, particularly concentrations of trace elements and organic constituents. A statistical analysis of the existing and newly collected data was performed to identify possible relations between land use and ground-water quality.

The hypothetical relations between land use and ground-water quality proposed in this report will be subsequently tested through the collection and statistical analysis of new data gathered in the second phase of this study. Conclusions demonstrated for the initial study areas will be tested in other similar hydrogeologic settings so that they may be included in the broader assessment of the quality of the Nation's ground water.

Methods

It has been necessary to describe the physical system and factors that may influence ground-water quality. The ground-water-flow system has been defined in sufficient detail to determine approximate traveltimes and flow paths of ground water in various parts of the system. Emphasis has been placed on determining the age distribution of the water, because water that is less than 100 years old is most likely to reflect anthropogenic factors.

Land-use data have been compiled from aerial photographs, State and local maps, and field surveys. Although 29 types of land use or land cover can be differentiated in the study areas, this study combines land uses into five major categories: Undeveloped, agricultural, residential, institutional/transportational, and industrial/commercial.

Previously collected water-quality data for the stratified-drift aquifers in the study areas have been compiled. These data have been grouped according to the respective land use that circumscribed the sampling sites or the area immediately upgradient from the sampling sites at the time they were sampled. Numerous deficiencies in the historical data prevent a rigorous statistical analysis of land use and ground-water-quality relations based on these data alone. These deficiencies include small sample size, uneven site distribution, incomplete analyses, and improper or inconsistent well-construction, sampling, and analytical procedures. Additional ground-water sampling has been conducted using new stainless-steel wells constructed in or

4

downgradient from land-use areas of interest. Sample collection and analysis procedures have been selected to provide information on a broad array of water-quality constituents including many trace elements and organic chemicals that are absent or poorly represented in the historical data.

Nonparametric statistical procedures have been used to test for associations between water-quality constituents and four land uses. The basic premise of the study is that man's activities within the selected land-use areas affect the quality of water in the stratified-drift aquifers. The null hypothesis tested states that there is no significant difference in the sample population of each specific constituent of the ground water from any land use. Rejection of the null hypothesis suggests evidence of differences among the populations of ground-water-quality variables that may be characteristic of certain land uses.

Four statistical procedures have been used to test hypothetical relations between ground-water quality and land use. A 0.05 level of significance (95-percent confidence level) has been chosen for all tests to describe the error probability of falsely detecting differences. Simple descriptive statistics (median and interquartile range) were first used to describe the distribution of the sample population of each chemical constituent of ground water from the four land uses (Sokal and Rohlf, 1969; Gilliom and Helsel, 1984; Helsel and Gilliom, 1985). Because water-quality constituents commonly do not have a normal distribution, the median and interquartile range provide a better measure of the sample population distribution than the mean and standard deviation. For this reason, an ANOVA (analysis of variance) of ranked data has been used to compare the distribution of the water-quality variables by land use--one-factor analysis, and by land use and sampling period or land use and aquifer--two-factor analysis (Sokal and Rohlf, 1969; Conover and Iman, 1981; Helsel, 1983). More detailed information about the differences between the sample populations of specific constituents for different land uses indicated by the ANOVA have been identified by Tukey's honest significant difference test (Sokal and Rohlf, 1969; Stoline, 1981). Finally, for constituents with a large percentage of observations below analytical detection limits the frequency of occurrence among the various land uses has been compared using contingency-table analysis (Conover, 1980; Helsel and Ragone, 1984).

Acknowledgments

5

Two areas in western Connecticut underlain by stratified-drift aquifers have been selected for investigation. These aquifers were chosen because: (1) Climatic and hydrogeologic settings are typical of most stratified-drift aquifers of Connecticut and the region; (2) considerable hydrogeologic information, including two-dimensional ground-water-flow models, and some water-quality data are available; (3) most major types of land use are present; (4) point and nonpoint sources of contamination have been inventoried by State agencies; and (5) there are essentially no artificial diversions affecting the inflow and outflow of water and (or) contaminants within the basins in which the aquifers lie. Figure 1 shows the locations of the stratified-drift aquifers in the Pootatuck River and the Pomperaug River valleys.
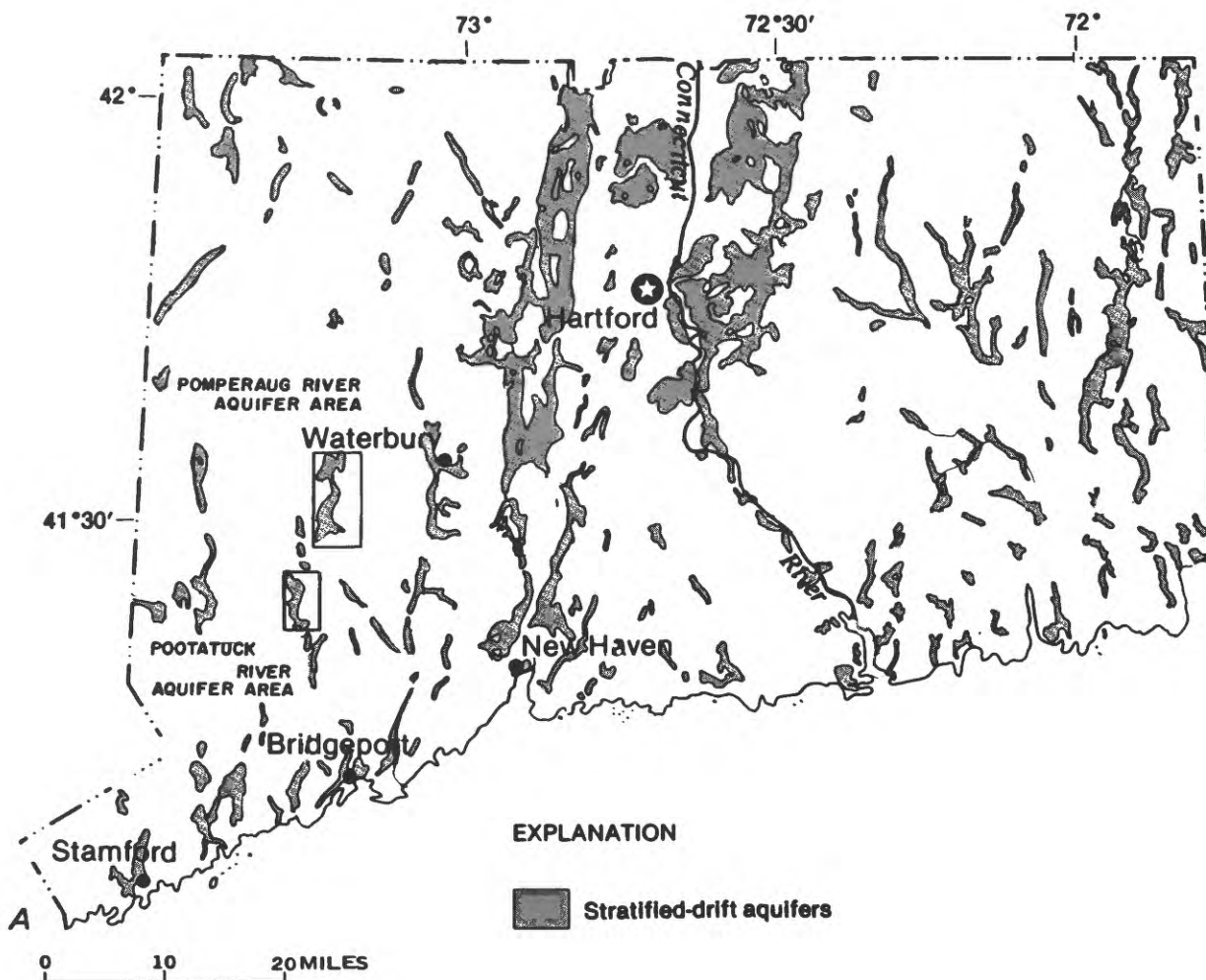
Figure 1.--Location of the Pootatuck and Pomperaug River aquifer areas.

Physical and Climatic Characteristics

The Pootatuck and Pomperaug Rivers drain 26 mi^2 and 79 mi^2 areas, respectively, within the Housatonic River basin. The topography of the study areas is characterized by moderate relief with steep slopes and rolling uplands rising 200 to 700 ft above the valleys.

Connecticut's climate is strongly influenced by dry continental air masses that are frequently displaced by humid maritime air masses and periodic storms. Precipitation in the study areas, as elsewhere in Connecticut, is evenly distributed throughout the year. Between 1941 and 1970, annual precipitation ranged from 38 to 52 in. at stations across the State. At two stations in or near the study areas, (Sawpit Hill, Woodbury and Stevenson Dam, Monroe) precipitation averaged 43 and 47 in/yr, respectively, for this period. About half the precipitation is returned to the atmosphere by evapotranspiration (Wilson and others, 1974). Moisture loss from evapotranspiration generally exceeds precipitation in late spring and summer, resulting in reduced runoff and decreased storage in lakes, ponds, swamps, and aquifers.

Because precipitation is relatively evenly distributed throughout the year, and topographic relief is moderate, the water table fluctuates only a few feet and generally resembles a subdued reflection of the topography. Surface- and ground-water drainage divides commonly coincide, and all surface-and ground-water flow within a basin is derived from the precipitation. Ground water discharges primarily to streams and swamps, but some is lost to the atmosphere through evapotranspiration. Ground-water recharge from precipitation does not occur evenly throughout the basin, but is about three times higher in areas underlain by stratified drift than in areas underlain by till or bedrock (Haeni, 1978; Mazzaferro, 1986a). The general pattern of ground-water circulation is away from upland drainage divides toward points of discharge in adjacent valleys.

Hydrogeology

As the last continental glacier retreated from Connecticut about 15,000 years ago, meltwaters carried off much of the debris that had been eroded and transported by the ice, and deposited it largely in valleys that were drainageways for the glacial meltwater streams. These stratified-drift deposits are composed of interbedded layers of sand, gravel, silt, and clay. Although the texture of stratified drift often is highly variable, areally and with depth, it is commonly mapped on the basis of average grain size, and subdivided into coarse-grained deposits and fine-grained deposits. Coarse-grained stratified-drift deposits, that have a saturated thickness greater than 40 ft, are areally extensive, and (or) are hydraulically connected to a major surface-water body, yield moderate to large quantities of water to wells and are the principal aquifers in Connecticut and much of the glaciated Northeast.

The stratified-drift deposits that underlie approximately 7.9 mi^2 of the Pootatuck River valley and about 12.7 mi^2 of the Pomperaug River valley (fig. 2) are composed predominantly of sand and gravel, with lesser amounts of silt and clay. The valleys trend generally north to south and are bounded on the east and west by till-covered bedrock hills. Till is a nonstratified and largely unsorted mixture of silt, clay, sand, gravel, and boulders that was

7

EXPLANATION

Stratified-drift aquifer

SCALE

0 1 2 3 4 5 MILES
0 1 2 3 4 5 KILOMETERS

73°15'

Weekeepeemee River

Nonewaug River

WOODBURY

LITCHFIELD CO.
NEW HAVEN CO.

41°30'

SOUTHBURY

84

Housatonic River

Pomperaug River

84

NEW HAVEN CO.
FAIRFIELD CO.

NEWTOWN

41°22'30"

Pootatuck River

Geology modified from Wilson and
others, 1974, Haeni, 1978, and
Mazzaferro, 1986a
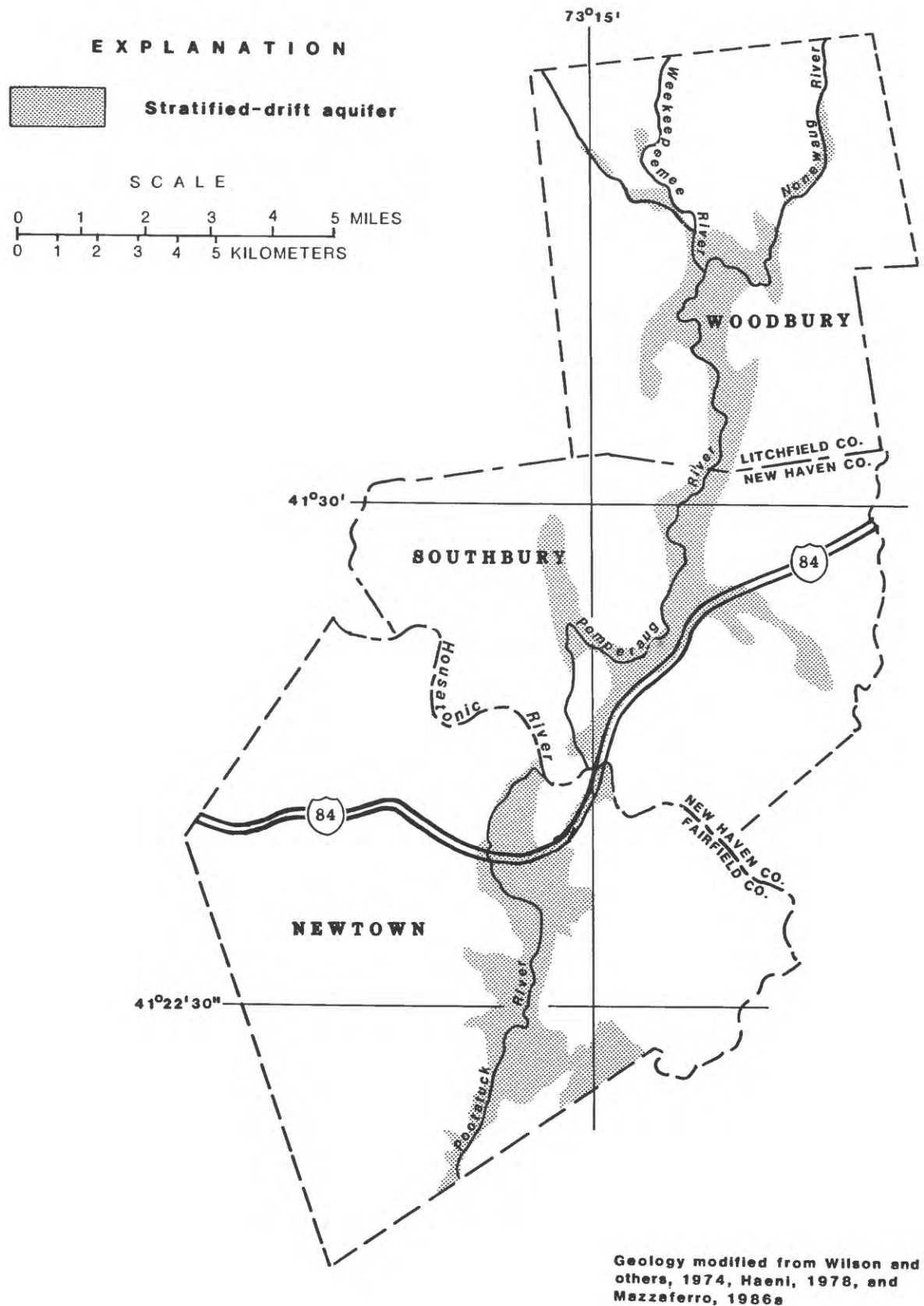
Figure 2.--Location and extent of the stratified-drift aquifers
in the Pootatuck and Pomperaug River areas.

8

carried and deposited directly by the glaciers. This material, characterized by low permeability and compactness, forms a generally thin and discontinuous mantle on the bedrock surface, and serves to restrict ground-water flow between the stratified-drift and underlying bedrock aquifers. The bedrock aquifer beneath the Pootatuck River valley is comprised of fractured crystalline rocks, mostly gneiss and schist, whereas the Pomperaug River valley is underlain by sedimentary rocks, principally arkosic sandstone and siltstone. Figure 3 shows the generalized spatial relations of stratified drift, till, and bedrock in the study areas.

The stratified-drift aquifers in the Pootatuck and Pomperaug River valleys have favorable hydraulic characteristics for yielding large quantities of water to wells (Wilson and others, 1974; Meade, 1978). Haeni (1978) determined that approximately 4.0 Mgal/d could be withdrawn from the Pootatuck aquifer, while Mazzaferro (1986a) estimated that as much as 8.8 Mgal/d are available from the Pomperaug aquifer. Current withdrawals, of 1.5 and 2.0 Mgal/d respectively, are well below the reported potential yields.

Aquifer Characteristics

The movement and fate of chemical species in ground water are strongly influenced by the characteristics of the aquifer. The hydraulic properties of an unconfined aquifer--saturated thickness, hydraulic conductivity, and porosity--control its capacity to transmit, store, and yield water. The relative altitude of the water table determines the direction of horizontal ground-water flow, while hydraulic gradients, hydraulic conductivity, and porosity determine the rate of ground-water movement.

Information on the characteristics of the Pootatuck and Pomperaug aquifers is available from published maps and reports (Meinzer and Stearns, 1929; Grossman and Wilson, 1970; Wilson and others, 1974; Haeni, 1978; and Mazzaferro, 1986a; 1986b), and unpublished data on file at the Connecticut Office of the U.S. Geological Survey. The basic data used to determine aquifer characteristics include: Drillers' or geologists' logs of 116 wells and test holes in the Pootatuck aquifer and 128 wells and test holes in the Pomperaug aquifer; nine seismic-refraction profiles in each area; as well as grain-size analyses, aquifer tests, and water-level measurements in short- and long-term observation wells at selected sites in both areas.

Saturated thickness, the depth from the water table to the bottom of the stratified-drift aquifers, in the Pootatuck and Pomperaug River valleys is shown on plate 1. The thickest deposits of saturated stratified drift occur in the Pomperaug River valley where as much as 150 ft were observed in one location in Woodbury (Mazzaferro, 1986a). The saturated thickness exceeds 80 ft at most places along the center of the Pomperaug River valley, but is less than 40 ft beneath much of the terraced areas along the margins of the valley and within the valleys of tributary streams. In the Pootatuck River valley, the saturated thickness of the stratified drift is less than 80 ft at most places, with the exception of two relatively small areas along the axis of the valley where it is as much as 100 ft in one well (Haeni, 1978). Much of the stratified-drift aquifer underlying the terraced areas on both east and west sides of the Pootatuck River valley is also thinly saturated (generally less than 20 ft).
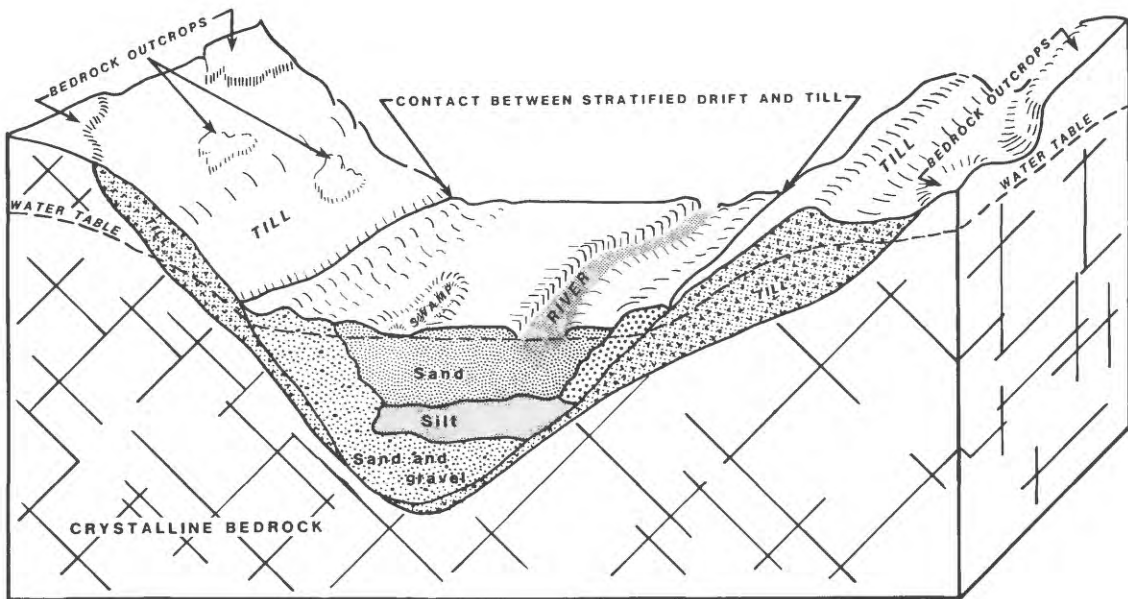
A. Pootatuck River Aquifer Area (from Haeni, 1978)
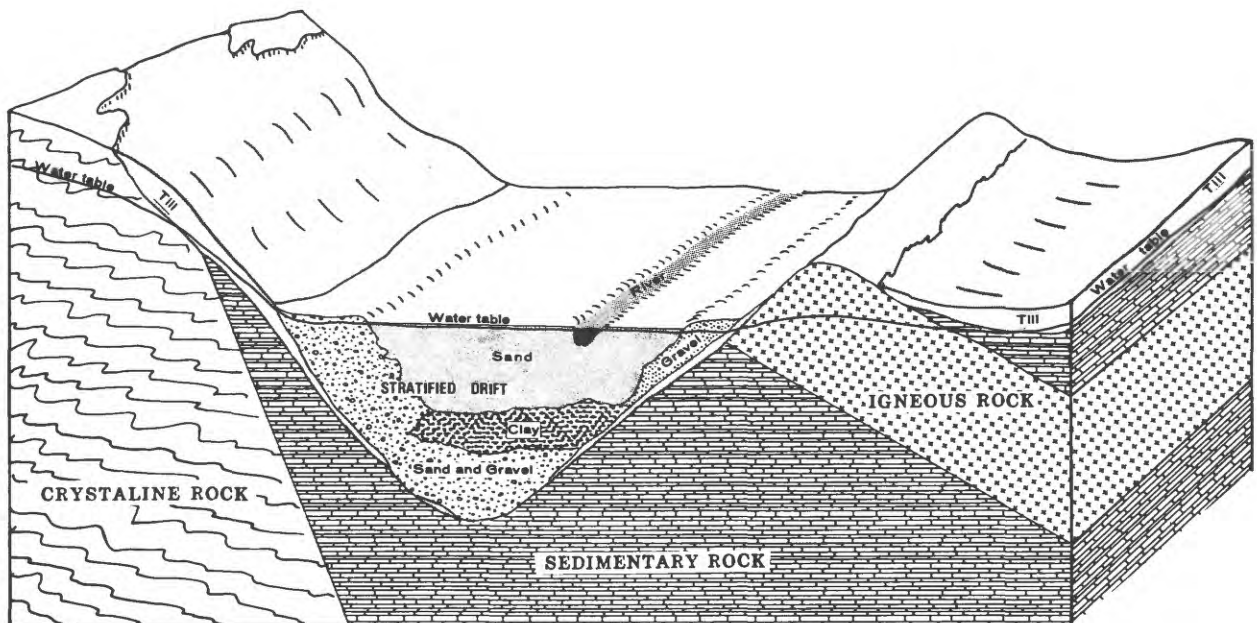
B. Pomperaug River Aquifer Area (from Mazzaferro and others, 1979)

Figure 3.--Idealized spatial relations of stratified-drift, till and bedrock aquifers in the Pootatuck and Pomperaug River areas.

10

The average horizontal hydraulic conductivity of the stratified-drift aquifers, expressed in feet per day, is shown on plate 2. The values shown on plate 2 are those used in ground-water-flow models by Haeni (1978) and Mazzaferro (1986a) to estimate ground-water availability in the Pootatuck and Pomperaug aquifers. A value for horizontal hydraulic conductivity was assigned to each node of the ground-water-flow models developed in the studies (corresponding to areas of 40,000 ft^2 and 250,000 ft^2, respectively) based on data obtained from pumping tests and specific capacities of wells, or on relations between grain-size characteristics of stratified drift in Connecticut and hydraulic conductivity.

For this report, the hydraulic conductivities of the stratified-drift aquifers are grouped in four ranges to better describe the distribution of areas having low (less than 20 ft/d), moderate (20 to 60 ft/d), high (61 to 100 ft/d), and very high (101 to 170 ft/d) average horizontal hydraulic conductivities. Plate 2 shows that the highest hydraulic conductivity values (101 to 170 ft/d) occur in several parts of the Pomperaug River valley, principally in Woodbury. Hydraulic conductivity is greater than 20 ft/d in all of Woodbury reflecting the predominantly coarse-grained texture of the stratified-drift deposits that comprise the northern part of this aquifer. However, much of the aquifer in the central part of Southbury has low hydraulic conductivity reflecting the fine-grained texture of the stratified-drift deposits in this part of the study area. In the Pootatuck River valley, hydraulic conductivity values range from 60 to 100 ft/d in a few relatively small areas in the northern part of the aquifer. The stratified-drift aquifer within the center of the valley generally has hydraulic conductivities 20 to 60 ft/d but is bounded by, and in a few places includes, materials of low hydraulic conductivity.

Porosity values, the percent of the volume of openings or void spaces in the total volume of a soil or rock mass, are necessary to determine average ground-water velocities, but this property has not been measured in previous studies. Specific yield, the ratio of the volume of water that will drain under the influence of gravity to the total volume of aquifer material, has been estimated to be about 0.2 to 0.25 by Wilson and others (1974) and Mazzaferro (1986a) for stratified-drift aquifers in the study area. Because porosity is equal to the sum of specific yield plus specific retention, a value somewhat greater than 0.25 is likely. For this report, porosities of 0.3 and 0.45 are assigned to respective coarse-grained and fine-grained parts of the aquifer. Similar porosity values have been determined for unconsolidated materials of comparable grain size, sorting, and depositional characteristics by Wenzel (1942), Allen and others (1963), Baker and others (1964), Morris and Johnson (1967), and Heath (1980).

Water-table altitudes for the Pootatuck and Pomperaug aquifers, as reported by Haeni (1978) and Mazzaferro (1986a), are shown on plate 3. This plate shows the altitude of the water table for November 1976 in the Pootatuck aquifer and the average altitude of the water table for the period January 1979 through February 1980 in the Pomperaug aquifer. They represent the steady state, average water-table conditions for periods when annual precipitation in Connecticut was somewhat greater than the average for the

11

1941-70 reference period. However, the magnitude of fluctuations of the
water table in most parts of these aquifers is relatively small even for
large variations in recharge. Differences between observed and simulated
mean water levels for a range of recharge conditions were generally less than
a few feet (Haeni, 1978; Mazzaferro, 1986a). Depths to the water table range
from less than 10 ft in much of the central parts of the Pootatuck and
Pomperaug River valleys and their principal tributaries, to greater than
100 ft beneath thick terraces along the valley walls (D. F. Healy, U.S.
Geological Survey, written commun., 1984; Mazzaferro, 1986b).

Plate 3 shows that the general direction of horizontal ground-water move-
ment is to the north in the Pootatuck River valley, and to the south in the
Pomperaug River valley. Because the cross-sectional area of these aquifers
is severely restricted in the lower reach of each valley, the volume of
ground water leaving the aquifers as underflow is considered to be negli-
gible. Flow is directed down tributary valleys and laterally from the valley
sides, toward the valley axis. Ground water ultimately discharges to the
main channel of the Pootatuck and Pomperaug Rivers, or is evapotranspired in
areas where the water table is about 5 to 8 ft below the land surface (Haeni,
1978; Mazzaferro, 1986a). The dominant component of ground-water flow is
horizontal, although vertical flow components exist locally, particularly
near discharge areas.

The altitude of the water table in the Pootatuck aquifer (pl. 3) drops
from 400 ft near the Newtown-Monroe town boundary to 240 ft where interstate
highway I-84 crosses the Pootatuck River; this 160 ft drop occurs along a
linear distance of about 21,500 ft. The hydraulic gradient along sections of
the axis of the valley range from 11 to 42 ft/mi and average approximately
37 ft/mi over this distance. Hydraulic gradients are steeper along the sides
of the valley and down the tributary valleys, ranging from 26 to more than
400 ft/mi in some locations. The larger gradients reflect the increased
slope of the water table in areas of greater topographic relief and (or) the
lower permeability of materials underlying the margins of the valley.

In the Pomperaug River valley, the altitude of the water table drops
from 250 ft near the confluence of the Nonewaug and Weekeepeemee Rivers in
Woodbury, to 170 ft near the confluence of Bullet Creek and the Pomperaug
River in Southbury. This decline in water-table altitude occurs over a
linear distance of about 29,900 ft along the axis of the valley. The average
hydraulic gradient is approximately 16 ft/mi, with individual sections of the
valley having gradients that range from 5.3 to 21 ft/mi. Hydraulic gradients
are much steeper, from 37 to about 700 ft/mi, along the sides of the valley
and in the tributary areas. The lowest gradients, as evidenced by the more
widely spaced water-table contours on plate 3, are found in Woodbury, reflect-
ing the more permeable, coarse-grained materials in that part of the aquifer.

Ground-Water Velocity and Residence Time

The average linear velocity of ground water flowing through the strati-
fied-drift aquifers can be estimated from aquifer characteristics and
hydraulic gradients using the equation:

$$\overline{v} = \frac{\overline{Kh}}{n}\frac{dh}{dl}$$

where,

$\overline{v}$ is the average linear velocity of horizontal ground-water flow, in
feet per day;

$\overline{Kh}$ is the average hydraulic conductivity of the horizontal component of
ground-water flow, in feet per day;

dh/dl is the unit change in head (water-table altitude) per unit length of
flow, that is, the hydraulic gradient, in feet per feet; and

n   is the porosity, dimensionless (estimated as either 0.3 or 0.45 on
the basis of grain size of the stratified-drift aquifers).

It should be noted that velocity estimates computed by this method may
have large errors that stem from uncertainties in the estimated hydraulic
conductivity and porosity values, combined with the errors associated with
the determination of hydraulic gradients (Freeze and Cherry, 1979). However,
with proper consideration of these limitations, ground-water velocities com-
puted by this method are useful for estimating the period of time required
for water to move through the aquifer. This residence time, while not pre-
cise, can be used to evaluate which past and present land-use practices may
affect the ground-water quality.

Average ground-water velocities have been computed for the Pootatuck and
Pomperaug aquifers by overlaying the hydraulic conductivity and water-table
maps, determining the hydraulic gradient along flow paths through each respec-
tive area of hydraulic conductivity shown on plate 2, and inserting the vari-
ables into the linear velocity equation. Ground-water velocities along the
axis of the Pootatuck River valley computed by this method range from less
than 0.01 to about 1.6 ft/d; whereas, velocities for flow directed down tri-
butaries and from the valley sides range from 0.2 to about 10 ft/d and average
about 2 ft/d. In the Pomperaug River valley, estimates of ground-water velo-
city along the axis of the valley are somewhat lower, ranging from 0.1 to
about 0.7 ft/d, a reflection of the lower down-valley hydraulic gradient in
this area. However, flow directed down the tributaries and from the sides of
the Pomperaug Valley varies from 0.6 to about 9 ft/d, and averages approxi-
mately 3 ft/d.

The time-of-travel for water moving through sections of the aquifers has
been estimated using the ground-water velocities and the linear distance along
flow lines through areas of the aquifers with different hydraulic conduc-
tivities. These calculations indicate that in certain parts of the Pootatuck
and Pomperaug aquifers, ground water may reside in the aquifer for periods of
about 1 to as many as 45 years. However, because most of the ground water

discharges to the trunk streams within a few hundred to several thousand feet of the aquifer boundaries, and down-valley underflow is thought to be minimal, most ground water in the Pootatuck and Pomperaug River valley aquifers is less than 2 decades old. This conclusion is important when considering the effects of land use on the quality of the ground water, because for those contaminants that move through the aquifer at the same rate as the ground water, only the impacts of relatively recent land-use practices should be observed. However, the movement of those contaminants that have a tendency to sorb onto porous media may be greatly retarded relative to the bulk motion of ground-water flow.

LAND USE

To evaluate the effects of land use on the quality of the ground water, it is necessary to know the current pattern of land use and history of development in the study area, as well as the type of human activities associated with each land use. In Connecticut, the most comprehensive source of land-use information is the 1970 land-use inventory (Connecticut Office of Policy and Management, 1970). This survey is based upon the interpretation of aerial photographs taken in 1970, and is compiled on colored mylar maps at 1:24,000 scale.

The 1970 statewide land-use inventory used the SLUCONN (Standard Land Use Classification System for Connecticut) prepared by the Connecticut Land Use Standardization Committee (1966). There are 69 land-use and land-cover categories in this classification system developed from the Standard Land Use Coding Manual published by the U.S. Urban Renewal Administration, Housing and Home Finance Agency, and Bureau of Public Roads (1965). For a land use to have been included in the 1970 inventory, it must exceed a minimum area, usually 5 or 10 acres. Therefore, those land uses shown are broadly distributed and areally extensive, and may be considered as nonpoint sources, or as a composite of small point sources of chemical contaminants that may enter the saturated zone.

The major land uses in the Pootatuck and Pomperaug areas in 1985 are mapped on plate 4. Changes in land use over time were evaluated based on the comparison of aerial photographs taken in 1965 and 1980, the 1970 State inventory, local land-use maps available from the municipalities (Town of Woodbury, 1975; Southbury Planning Commission, 1977; Newtown Planning and Zoning Commission, 1981; Woodbury Zoning Commission, 1982), and 1985 field observations. Because ground-water residence time is relatively short, it is unlikely that present (1986) water-quality conditions would reflect land use prior to 1965. Table 1 summarizes the principal land-use categories and the approximate percentage of each area they occupy.

The prevalence of undeveloped land in both study areas reflects the still largely rural nature of much of Connecticut. Most of the land included in this category is covered by noncommercial, eastern hardwood forest and occurs largely in the upland areas beyond the stratified-drift aquifer boundaries. A significant part of the Pootatuck aquifer, however, remains undeveloped and forest covered due to public ownership and private wildlife

14

Table 1.-- Land use in the study areas

[Percentages are for the 20-square-mile Pootatuck area and 31-square-mile Pomeraug area shown on plate 4]

Land-use category	Approximate percentage	
	Pootatuck area	Pomperaug area
RESIDENTIAL:		
(1) less than 1 family per acre	10.4	7.5
(2) 1 to 2 families per acre	7.3	3.0
(3) greater than 2 families per acre	.9	2.6
Subtotal	18.6	13.1
INDUSTRIAL/COMMERCIAL:	2.0	1.6
AGRICULTURAL:	11.6	15.5
INSTITUTIONAL:	1.3	.5
TRANSPORTATION:	1.7	1.0
WASTE DISPOSAL:	.3	.2
UNDEVELOPED:		
(1) Active and inactive gravel pits	1.7	1.9
(2) Wetlands	1.8	1.2
(3) Ponds and reservoirs	.5	.8
(4) Shrub, brush, and inactive farmlands	8.6	10.2
(5) Commercial forest production	0	.6
(6) Noncommercial forest and woodlands	51.9	53.3
Subtotal	64.5	68.0

management. The quality of ground water beneath such areas should be largely unaffected by human practices, with the possible exception of atmospheric desposition and inflow from upgradient developed areas.

Agriculture, once the predominant land use in the study areas, continues to be practiced on a large percentage of the area underlain by stratified drift. Agricultural lands are located almost exclusively within the valley flood plains or terraces, or extend to adjacent gently sloping hillsides. The principal crops are silage corn, hay, and berries with lesser areas devoted to pasture and vegetable production. Golf courses and athletic fields, comprising a relatively minor percentage of the areas, are included in this category because agricultural chemicals are applied to them.

Nitrogen and phosphorous fertilizers are the principal chemicals applied to these agricultural lands. Application rates of soluble nitrogen typically range from 175 to 200 pounds per acre per year for silage corn and hay. Lesser amounts of soluble phosphorous and potash (potassium carbonate), 80 to 100 pounds per acre per year, usually are applied. Borax (sodium borate) and lime (calcium magnesium oxide) are commonly used for weed control and to counter soil acidity. Cultivated fields (silage corn, berries, vegetables) generally are treated annually with a variety of herbicides, most commonly atrazine, and less often with specific insecticides. Ground water in agricultural areas, therefore, may have elevated nutrient concentrations as well as trace levels of pesticides.

The most prevalent change in land use in the study areas between 1965 and 1985 has been residential development on previously agricultural or undeveloped lands. Residential development is expanding in both study areas, so that it presently occupies a greater percentage of land in the Pootatuck area, and nearly so in the Pomperaug area, than does agriculture. The density of houses remains relatively low, however, because most residential areas have lot sizes of 1 acre or larger. In these areas, individual wells provide water supplies, and disposal of domestic wastes is through onsite septic systems. In the more densely populated areas surrounding the commercial cores of the towns of Newtown, Southbury, and Woodbury, and in recently developed high population density condominium or retirement villages, public water supplies and sewer service are commonly available.

A wide variety of potential ground-water contaminants may be introduced from residential areas. Effluent from septic tanks and leaky sewer lines contains large concentrations of nutrient species as well as numerous other chemical constituents including metals and organic compounds. Application of deicing chemicals on residential streets can produce elevated concentrations of chloride, sodium, and calcium in underlying ground water. Use of lawn fertilizers and chemicals, as well as increased loads of animal wastes from pets, are additional sources of nutrients and pesticides.

Other types of land use occupy only relatively small percentages of the study areas, but these include important potential sources of ground-water contamination. Industrial areas often may introduce a variety of contaminants through spills, leakage, or disposal of materials and by-products of the industrial processes. In the study areas, the extent of industrial land use

is limited and the types of industry tend to be small, high-technology plants for the production of electrical components, metal plating, or food processing. The types of potential contaminants that may be introduced from these areas include organic solvents, a variety of metals, and inorganic constituents.

Commercial areas include a variety of retail outlets, trades and services, and related transportation facilities common to suburban areas. Leaks, spills, and disposal of chemicals from gasoline and fuel oil outlets; dry cleaning establishments; automobile repair shops; and printing, photographic processing and other similar facilities; road salting; and infiltration of runoff from street and parking lots are possible sources of organic solvents, hydrocarbons, metals, and inorganic contaminants.

Institutional land use, churches, hospitals, and schools, is probably not an important contribution to ground-water contamination. However, if the institution is served by a large septic system rather than sewered, or if maintenance of adjacent grounds includes heavy application of lawn chemicals, the effects on ground-water quality may be similar to those in high-density residential areas. The transportation land-use category includes primarily the interstate highway corridor that transects each of the study areas and local airport facilities. Road salting, spills, and highway runoff are the most likely factors that could affect ground-water quality.

Waste-disposal areas are included as a land-use category in table 1. Although occupying only a fraction of 1 percent of the study areas, significant ground-water contamination is probable in the vicinity of these areas. Waste-disposal areas, including landfills and sewage-treatment plants, are considered to be point sources of contamination and are not the subject of this study. However, in surveying the effects of human activities upon ground water, all known sources of contaminants must be considered. Because the focus of this study is on the effects of nonpoint sources of pollutants upon the ground-water quality, it is important that monitoring wells not intercept contaminant plumes derived from point sources. An inventory of point sources of contaminants in the Pootatuck and Pomperaug areas (plate 5) by the Connecticut Department of Environmental Protection (1984a, b) includes: 7 road salt-storage piles; 4 fuel or chemical spills; 7 multiple-dwelling onsite septic systems; 4 sewage-treatment plants; 13 landfills; and 6 industrial wastewater or cooling-water discharges.

Plate 5 also shows the location of public-supply wells and the distribution of water and sewer services within the two study areas. This information defines where ground water is likely to receive widespread septic discharges and indicates where imported, treated waters may be ultimately discharged to the aquifer through household septic systems, lawn and garden irrigation, or leakage from water mains, distribution lines, or sewer lines.

The principal land uses and recent land-use changes in the Pootatuck and Pomperaug River areas are typical of large parts of Connecticut and southern New England located in close proximity to major cities and along major transportation corridors. The stage of development for these areas can be considered midway in the transition from rural, agricultural-dominant land use with significant forest cover, to suburban high-density residential land use

or urbanization. Presently, both areas are experiencing expanding residential and commercial development with increasing population densities, deforestation, and conversion of agricultural lands. The 1980 population densities of the towns of Newtown, Southbury, and Woodbury were 316, 346, and 189 persons per square mile, respectively (Connecticut Office of the Secretary of State, 1982). The population density of towns in Connecticut ranges from less than 100 persons per square mile for rural areas of the northwestern and eastern parts of the State, to more than 5,000 persons per square mile within the principal cities of Hartford, New Haven, New Britain, and Bridgeport.

The study areas, therefore, provide a good opportunity to evaluate the effects of a variety of land uses, including both the older, less-intensive rural land uses and the more recent land uses that typify expanding development, on the quality of ground water within relatively small, hydrologically uniform basins. Comparison of the nature, magnitude, and extent of ground-water degradation in such areas to that observed in similar studies of more highly developed and populated areas along the eastern seaboard or elsewhere in the Nation, may provide insight on the scope and severity of water-quality problems that are associated with the varying degrees of intensity of man's activities.

WATER QUALITY

In addition to a basic understanding of the hydrogeologic system and an accurate characterization of land use, appropriate water-quality data are needed to identify relations between land use and ground-water quality. A sufficently large number of samples from sites that accurately reflect the land-use areas of interest are needed for a valid statistical analysis of the differences in the chemical quality of ground water associated with each land use. Also, the analyses should ideally include all or most water-quality constituents that originate from anthropogenic sources. Finally, the methods used to collect and analyze the water-quality samples should be comparable, to prevent introducing bias or magnifying the natural variability in sample populations.

Water-quality data analyzed for this study represent two different time periods--historical data gathered during previous investigations and reconnaissance data collected during this study. The number, type, strengths, and weaknesses of water-quality data for each period are described in this section of the report. The data are also evaluated as to their suitability for assessing the impacts of land use on ground-water quality.

Availability of Historical Data

Some ground-water quality data have been collected during prior studies in both the Pootatuck and Pomperaug areas. Most of the data were collected by the U.S. Geological Survey, however, a few analyses were performed by the Connecticut Department of Health Services laboratory or by private laboratories. The historical data have been reviewed to evaluate their areal and temporal distribution, completeness of analytical determinations, reliablity

with respect to sampling and analytical methodology, and applicability to the objective of the study--the determination of the effects of land use on ground-water quality.

The locations of all wells in the Pootatuck and Pomperaug areas where water-quality data have been collected in the past are shown on plate 4 with the land-use information. Water-quality data for these sites were considered to represent the land-use category in which the site was located, or the land use immediately upgradient of the site. Those sites located near known point sources of contamination were not included in the data analysis. The remaining sites considered useful for this study include 14 wells in the stratified-drift aquifer in the Pootatuck area and 24 stratified-drift wells in the Pomperaug area.

The historical ground-water-quality data for the Pootatuck and Pomperaug aquifers include a limited array of water-quality parameters. Ground-water-quality samples were collected as early as 1923, although most samples were collected between 1976 and 1982. The number and type of chemical constituents analyzed reflect the objectives and scope of the earlier studies and the analytical capabilities of the laboratories. Therefore, the number of values reported for any specific constituent included in the 127 historical ground-water analyses varies from as many as 84 to as few as 1.

Only 11 constituents, the major ions plus nitrate and iron, were measured in the earliest wells sampled, M 25 and M 31, as reported by Meinzer and Stearns (1929). These data are considered useful as indicators of historical background conditions. Most samples collected during the 1960's for the lower Housatonic River basin study (Wilson and others, 1974) were analyzed only for the major inorganic constituents, but some trace element determinations were performed. During later investigations by Haeni (1978) and Mazzaferro (1986a), ground water was analyzed for major inorganic constituents, nutrient species, and selected trace elements. Few observations have been made for organic constituents. Other than total organic carbon, no organic species were determined in the Pootatuck samples. In the Pomperaug area, 10 wells have been sampled for either total organohalide concentrations or for several specific organohalide compounds. Three analyses included MBAS (methylene blue active substance) determinations.

Review of the historical ground-water-quality data revealed a number of deficiencies or inadequacies that inhibit the use of that data for detecting the effects of land use on ground-water quality.

1. The analyses are generally restricted to the major properties and inorganic chemical constituents. Data for trace metals and other minor elements are limited, and only sparse data are available for organic compounds.

2. The data were collected over a 50-year period and reflect variable hydrologic and land-use conditions, as well as changes in sampling and analytical techniques.

3. The distribution of sampled wells is biased because of the emphasis on defining coarse-grained, highly transmissive aquifer areas, study area and model-boundary constraints, accessibility, and other siting criteria used during previous investigations.

4. A variety of well-construction techniques and materials have been used and some wells sampled have construction characteristics that may affect the reliable determination of the concentration of certain chemical constituents. The types of wells previously sampled include: Old, shallow, fieldstone-lined, hand-dug wells; deep, large-diameter, steel-cased, screened and gravel-packed public-supply wells; and variable depth, small-diameter, observation wells with slotted or screened PVC (polyvinyl chloride) solvent-cemented casing. A considerable literature has developed outlining the possible effects of well-construction materials on water-quality samples (Pettyjohn and others, 1981; Barcelona and others, 1983; Gillham and others, 1983).

5. The sampling methods, equipment, and preservation techniques are unknown, inconsistent, or improper by present standards. For example, ground-water samples analyzed for volatile organic compounds and other pressure-sensitive species were collected with peristaltic pumps, high-yield electric turbine pumps or other pumping equipment known to cause degassing (Gibb and others, 1981; Claassen, 1982; Barcelona and others, 1983; 1984; Gillham and others, 1983).

6. The analytical methods used by various laboratories (U.S. Geological Survey, Connecticut Department of Health Services, and private laboratories) and the detection limits they report are not consistent for several constituents.

Because of these problems and the uncertainty of linking historical water-quality data to particular land uses, additional sampling and analyses were needed to develop hypothetical relations between land use and ground-water quality.

Reconnaissance Sampling

A sampling program was developed and implemented to obtain additional water-quality data for this study. The available time and funding resources and the reconnaissance nature of the program, limited the additional ground-water sampling to 21 sites. Careful consideration was given to locating sites where hydrogeologic factors indicated the sampled ground water would be from areas of well-defined land use. The 21 sites were allocated among four land uses: Seven in or immediately downgradient of residential areas, six each in agricultural and mixed light-industrial/commercial areas, and two in undeveloped areas. The selection of sites was not a random process, but is consistent with the objective of obtaining data to support the development of hypotheses relating ground-water quality to land-use practices. Testing of developed hypotheses by random and statistically significant sampling is the objective of a later phase of this study.

A primary emphasis of the reconnaissance sampling is to determine the concentrations of trace elements and organic compounds. Type 304 stainless-steel casing and screens were selected for well-construction materials based on available ground-water-quality data and prior studies of construction materials. The nominal composition of the type 304 alloy is 74 percent iron, 18 percent chromium, and 8 percent nickel (Johnson Division, Signal Environmental Systems, Inc., written commun., 1984). While leaching of these metals may occur after long exposure to very corrosive conditions, ground water in the study areas is generally non-agressive, with low dissolved solids, and samples were collected within 1 month of installation of the wells. Consequently, the likelihood of introducing dissolved metals to the ground-water samples from the stainless steel casing or screen is considered negligible.

Flush-joint, 2-in. diameter stainless-steel casing and screened well points were obtained in 5- and 2-ft lengths, respectively, to facilitate handling, cleaning, and installation. Screens were of wire-wound, continuous-slot (0.008 or 0.010-in. openings) construction. All sections of pipe and screen were thoroughly cleaned with ALCONOX [1] detergent followed by rinsing in flowing tap water, a 1:10 acetone-deionized water solution, and finally with deionized water. Sections were then air-dried and stored in polyethylene tubing to prevent contamination. Once placed in the ground, the wells were developed by pumping with a peristaltic pump until the discharged water seemed to be clear of any suspended sediment. However, in some wells, small amounts of suspended clay and silt were still present in the water at the time of sampling.

The 21 new wells were placed in the upper part of the saturated zone by drilling with a hollow-stem auger to depths of generally 5 to 10 ft below the water table and driving the stainless-steel well point and casing an additional several feet into the undisturbed aquifer. The annulus around the casing was filled with aquifer materials that reached the surface on the augers. To avoid introducing materials that might affect the water quality, no cements, grouts, or drilling fluids were used. Most wells are less than 20 ft deep, but one well (WY 51) that penetrates a thick unsaturated zone within a terrace deposit is 46 ft deep.

Careful attention has been given to sampling methods, particularly with respect to the volatile organic chemical compounds. Because these compounds tend to degas when exposed to the atmosphere, they are difficult to accurately sample. Presently, there is no generally accepted best method for the collection of volatile species, however, Barcelona and others (1984) rank positive displacement bladder pumps as superior for most applications. A pump of this type, (the Geotech Model No. 0500 small diameter well pump) constructed of stainless steel and Teflon with a Teflon-lined discharge tube, has been used for this study. A portable oilless air compressor was used to pressurize the pump.

---

[1] Use of trade names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

Prior to sampling a well, the exterior of the pump and several feet of the discharge and gas lines were washed with ALCONOX and rinsed with deionized water. Several volumes of a 1:10 acetone-deionized water solution were circulated through the pump and discharge line, followed by additional volumes of deionized water. The pump was then lowered to the well screen and three to five well volumes were removed from the casing to flush any stagnant water from the well. A flow-through chamber was connected to the discharge line, and the water was monitored for temperature, pH, specific conductance, and dissolved oxygen. All parameters were allowed to stablize before samples were collected.

Samples for volatile organic chemical determinations were collected by inserting the discharge line into the bottom of a baked glass vial with Silicone/Teflon septum top, and allowing the vial to fill to overflowing while extracting the discharge tube and sealing the vial. This procedure generally required several attempts before the vial could be capped without entraining an air bubble. It is possible that some loss of volatile compounds may have occurred during this procedure. All other sample aliquots have been collected using standard procedures outlined in Goerlitz and Brown (1972); Wood (1976); Skougstad and others (1979); and Claassen (1982).

EFFECTS OF LAND USE ON WATER QUALITY

As water moves through the hydrologic cycle, various chemical, physical, and biological processes change its composition. Particles of dust and atmospheric gases dissolve to produce low concentrations of most major inorganic constituents in the precipitation that falls on the land surface. Near saltwater sources, precipitation often contains increased concentrations of sodium and chloride. Industrial and automobile emissions produce elevated levels of nitrate and sulfate and the low pH conditions characteristic of acid rain. The composition of water moving through the soil and unsaturated zone is further modified by evapotranspiration and reactions with the porous media, interstitial water and gases, and organic matter. The duration of the contact between water molecules and earth materials, as well as the solubility, sorptive, and ion-exchange properties of those materials, controls the chemistry of natural waters. For this study, it is assumed that the atmospheric processes and natural geochemical environment are now, and have in the recent past been similar across the study areas, and hence do not introduce a high degree of natural variability to the water-quality data. Consequently, differences in the concentration of chemical constituents that are observed for data grouped by land use, are concluded to be a result of man's activities associated with those land uses, or artifacts of inadequate or misleading data.

Statistical procedures have been applied to water-quality data segregated by land use, by sampling period, and, when the data allowed, by aquifer. When multiple analyses were available for a well, the median value was used in calculating the statistics. Table 2 identifies the wells used for this analysis by land use and sampling period. The locations of all wells where water-quality data have been collected are shown on plate 4.

Table 2.-- Wells in four land-use areas sampled
prior to or during this study

[Well numbers are local identification numbers used in U.S. Geological Survey
 publications. Prefix letters indicate town in which wells are located (NT=
 Newtown, SB=Southbury, WY=Woodbury), except for the letter "M" indicating
 well numbers in a previous system used by Meinzer and Stearns (1929) for two
 wells in Woodbury]

	Land-use areas		
Undeveloped	Agricultural	Residential	Industrial/Commercial

Wells sampled during reconnaissance phase

Undeveloped	Agricultural	Residential	Industrial/Commercial
WY 46	NT 100	NT 98	NT 99
WY 52	SB 34	NT 102	NT 101
	WY 45	SB 36	NT 103
	WY 48	WY 47	SB 35
	WY 49	WY 51	WY 44
	WY 50	WY 54	WY 53
		WY 55	

Wells sampled historically

Undeveloped	Agricultural	Residential	Industrial/Commercial
M 25	NT 62	NT 14	NT 54
M 31	NT 65	NT 56	NT 72
NT 2	NT 71	NT 59	SB 3
NT 12	SB 4	SB 30	SB 27
NT 57	SB 5	WY 11	WY 23
NT 60	SB 25	WY 20	WY 26
NT 63	SB 28	WY 31	WY 35
NT 64	SB 29	WY 33	WY 42
	WY 25	WY 39	WY 43
	WY 27		
	WY 28		
	WY 32		

Major Inorganic Constituents

Median concentrations and interquartile ranges (Gilliom and Helsel, 1984; Helsel and Gilliom, 1985) for the major inorganic constituents and properties, nitrogen species, detergents (methylene blue active substance), and total organic carbon are presented in table 3. Median values for specific conductance, pH, carbon dioxide, calcium, magnesium, chloride, bicarbonate, and dissolved solids are largest in industrial/commercial areas. Median concentra-centrations for hardness and sodium, several nitrogen species, and detergents are largest in residential wells. Median sulfate and total ammonia plus organic nitrogen are largest in agricultural wells. Median concentrations of potassium and total organic carbon are largest in undeveloped areas. Generally, for most of the constituents listed above, median concentrations are largest in the industrial/commercial or residential areas, smaller in the agricultural areas, and least in the undeveloped areas.

Box plots of the distributional characteristics of the specific conductance, dissolved solids, and chloride data for each land use are shown in figure 4. The median values are largest for all three constituents in industrial/commercial areas and smallest in undeveloped areas. The variability in the data, shown by the interquartile range, is generally greatest in the industrial/commercial and residential areas, and smallest in the undeveloped areas. Differences in the median concentrations and interquartile ranges for these constituents between the agricultural and undeveloped areas are not as clearly defined as between the industrial/commercial or residential areas and undeveloped areas.

Because chemical data are usually not normally distributed, analysis of variance on ranked data has been performed to test for significant differences between sample populations (Sokal and Rohlf, 1969; Conover and Iman, 1981; Helsel, 1983; Helsel and Ragone, 1984). The following factors are thought to possibly influence the data: (1) Land use, which is the basic premise of this study; (2) sampling period, because the historical data demonstrate inherent deficiencies not present in the reconnaissance data; and (3) aquifer chemistry, or the possibility that the geochemical environment differs between the Pootatuck and Pomperaug aquifers. One-factor analysis of variance for ranked data segregated by land use has been performed for those constituents in table 3 sampled in four or more wells within a land-use area. Two-factor analysis of variance for ranked data segregated by both land use and sampling period has been performed for those constituents represented in data from both sampling periods (specific conductance, pH, calcium, magnesium, sodium, silica, chloride, sulfate, dissolved solids, ammonia as nitrogen, nitrate plus nitrite as nitrogen, detergents, and total organic carbon). Two-factor analysis of variance has also been performed for data segregated by both land use and aquifer for selected constituents. The limited number of wells in some land-use areas for the Pootatuck aquifer has inhibited this comparison.

Results of the one-factor analysis of variance indicate that significant differences in sample population distribution occur between land-use subgroups for many of the constituents included in table 3. Multiple comparison procedures have been used to determine which land uses differ from one another. Results of the Tukey's honest significant difference test (Sokal and

24

Table 3.--Statistical summary of the combined historical and reconnaissance data on the quality of water in the stratified-drift aquifers beneath four land-use areas

[All constituents are dissolved except as indicated. When multiple analyses are available from one well, the median value is used in calculating the statistic. Dashes indicate insufficient data to calculate statistic. Median values that have the same Tukey's test letter symbols are not significantly different. Asterisk indicates some constituent concentrations below analytical detection limit and therefore statistics estimated using method of Helsel and Gilliom (1985). Units: µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter]

| Constituent or property | Units | Land-use areas | | | | | | | | | | | | | | | |
| | | Undeveloped | | | | Agricultural | | | | Residential | | | | Industrial/Commercial | | | |
		Number of wells	Median	Inter-quartile range	Tukey's test	Number of wells	Median	Inter-quartile range	Tukey's test	Number of wells	Median	Inter-quartile range	Tukey's test	Number of wells	Median	Inter-quartile range	Tukey's test
Specific conductance	µS/cm	8	87	30	B	18	162	126	A	16	220	72	A	15	230	192	A
pH	units	8	6.3	0.6	A	18	6.4	0.9	A	14	6.4	0.7	A	15	6.6	1.2	A
Hardness, as CaCO3	mg/L	7	32	16	B	11	66	69	AB	8	84	31	A	8	82	74	A
Hardness, noncarbonate	mg/L	4	4.5	7	B	11	35	28	A	8	42	19	A	7	40	38	AB
Carbon dioxide	mg/L	5	1.3	3.3	B	11	23	29	A	8	15	20	AB	7	27	25	A
Calcium	mg/L	9	8.6	5.4	B	17	14	16	AB	15	21	16	A	14	26	30	A
Magnesium	mg/L	8	2.8	2.0	B	17	4.5	3.6	A	15	6.4	2.8	A	14	7.3	4.8	A
Sodium	mg/L	7	5.1	2.0	C	16	5.7	3.8	BC	15	11	12	A	14	10	8.2	AB
Potassium	mg/L	5	2.9	1.8	A	10	2.0	2.4	A	8	2.0	2.2	A	7	1.3	4.8	A
Silica, as SiO2	mg/L	5	11	8.4	A	15	12	3.8	A	13	14	3	A	13	14	6	A
Chloride	mg/L	9	5.2	9	B	17	12	16	AB	15	21	26	A	14	23	22	A
Sulfate	mg/L	9	12	11	AB	17	17	7	A	15	13	7	B	13	13	9.5	AB
Bicarbonate	mg/L	7	24	17	A	11	39	59	A	8	44	48	A	7	88	76	A
Fluoride *	mg/L	4	0.10	0	A	10	0.10	0	A	8	0.10	.10	A	6	0.10	0.10	A
Dissolved solids, residue at 180° Celsius	mg/L	9	68	36	C	17	92	62	BC	15	134	94	AB	13	149	106	A
Nitrogen, ammonia as N *	mg/L	6	.05	.03	A	8	.09	.17	A	9	.14	.18	A	7	.05	.05	A
Nitrogen, ammonia as NH4 *	mg/L	6	.06	.09	A	8	.11	.22	A	9	.18	.24	A	7	.01	.08	A
Nitrogen, ammonia plus organic, total as N	mg/L	6	.52	.37	--	3	2.0	6.4	--	3	1.6	5.5	--	3	.34	.24	--
Nitrate plus nitrite, as N *	mg/L	2	--	--	--	14	1.8	2.5	A	12	4.4	5.8	A	11	2.7	2.9	A
Methylene blue active substance *	mg/L	2	--	--	--	7	.03	.04	A	9	.05	.06	A	6	.04	0	A
Carbon, total organic	mg/L	6	2.3	3.5	A	8	1.2	30	A	9	1.3	8.5	A	7	1.4	.6	A
Barium	µg/L	2	--	--	--	13	24	26	A	13	30	34	A	13	30	2.8	A
Boron *	µg/L	2	--	--	--	14	21	16	A	13	30	9.7	A	11	50	35	A
Iron *	µg/L	9	80	180	A	17	100	150	B	15	300	23	B	14	15	152	AB
Manganese *	µg/L	6	270	230	A	17	9.0	19	B	15	42	108	B	14	47	55	A
Nickel *	µg/L	7	4.0	6.5	AB	9	3.0	2.0	B	9	9.0	6.0	B	8	2.0	3.1	B
Strontium	µg/L	2	--	--	--	14	88	50	A	13	90	30	A	12	100	48	A
Tin	µg/L	0	--	--	--	8	100	150	A	6	300	200	A	5	300	200	A
Zinc *	µg/L	7	20	10	A	17	6.0	7.2	A	15	9.0	12	A	14	9.0	24	A

Figure 4.--Specific conductance, dissolved solids, and chloride
concentrations in the stratified-drift aquifer beneath four
land-use areas. Boxes show the interquartile range (25th to
75th percentile) of the data. Bar in middle of box is median.
Vertical lines extend to values within 1.5 times the inter-
quartile range. Outliers (extreme values) are shown as "X"
for concentrations greater than 1.5 to 3.0 times the inter-
quartile range, and as "O" for values that exceed 3.0 times
the interquartile range (Kleiner and Graedel, 1980).

26

Rohlf, 1969; Stoline, 1981) are shown as letters in table 3, designating which land uses are significantly different. For example, specific conductance for agricultural, residential and industrial/commercial areas is not significantly different and is designated by the common letter A. However, specific conductance for undeveloped areas is significantly lower than the other land-use areas and is designated by the letter B. The principal relations demonstrated by this analysis is that residential and industrial/commercial areas have significantly larger median concentrations of most inorganic constituents than undeveloped areas. Agricultural areas have significantly greater median concentrations than undeveloped areas for fewer inorganic constituents than either residential or industrial/commercial areas.

A two-factor analysis of variance between land use and sampling period indicates that significant differences are present in the data from historical and reconnaissance periods for sulfate, detergents, and total organic carbon. Significant differences between land uses are observed in the historical data for sulfate (agricultural higher than undeveloped and residential) and total organic carbon (agricultural higher than undeveloped). Insufficient historical data preclude a valid comparison for detergents. However, no differences between land uses are observed in the reconnaissance data for these constituents. Figure 5 shows the median concentration of the three constituents plotted for each period and land use.

Differences in median concentrations of sulfate, detergents, and total organic carbon from the same land use over time might reflect changes in the nature or intensity of land-use activities, or differences in sampling or analytical techniques. However, the "F" statistic generated by the two-factor analysis of variance for the interaction of land use and sampling period was not significant for any of these constituents (Sokal and Rohlf, 1969) and the land-use effects apparently have not changed with time. Examination of the data indicates that small sample populations for all constituents from the undeveloped reconnaissance subgroup and the historical data for detergents and total organic carbon from all land uses is the likely source of these period differences.

Results of the two-factor analysis of variance between land use and aquifer show that no significant difference is evident in any of the major inorganic constituents for land-use comparisons between the Pootatuck and Pomperaug aquifers. This conclusion is important because it affirms the assumption of hydrogeological similarity between the two aquifers, even though differences in bedrock lithology are present. Further, it increases the likelihood that land use--ground-water-quality relations demonstrated within one stratified-drift aquifer may be transferable to other similar settings.

Trace Elements

Median concentrations, interquartile ranges, and results of Tukey's multiple comparison tests for trace elements that occur frequently enough in ground water to calculate the statistics are reported in table 3. When some of the values included in a sample population are below analytical detection limits the statistics are estimated using the method described in Gilliom and
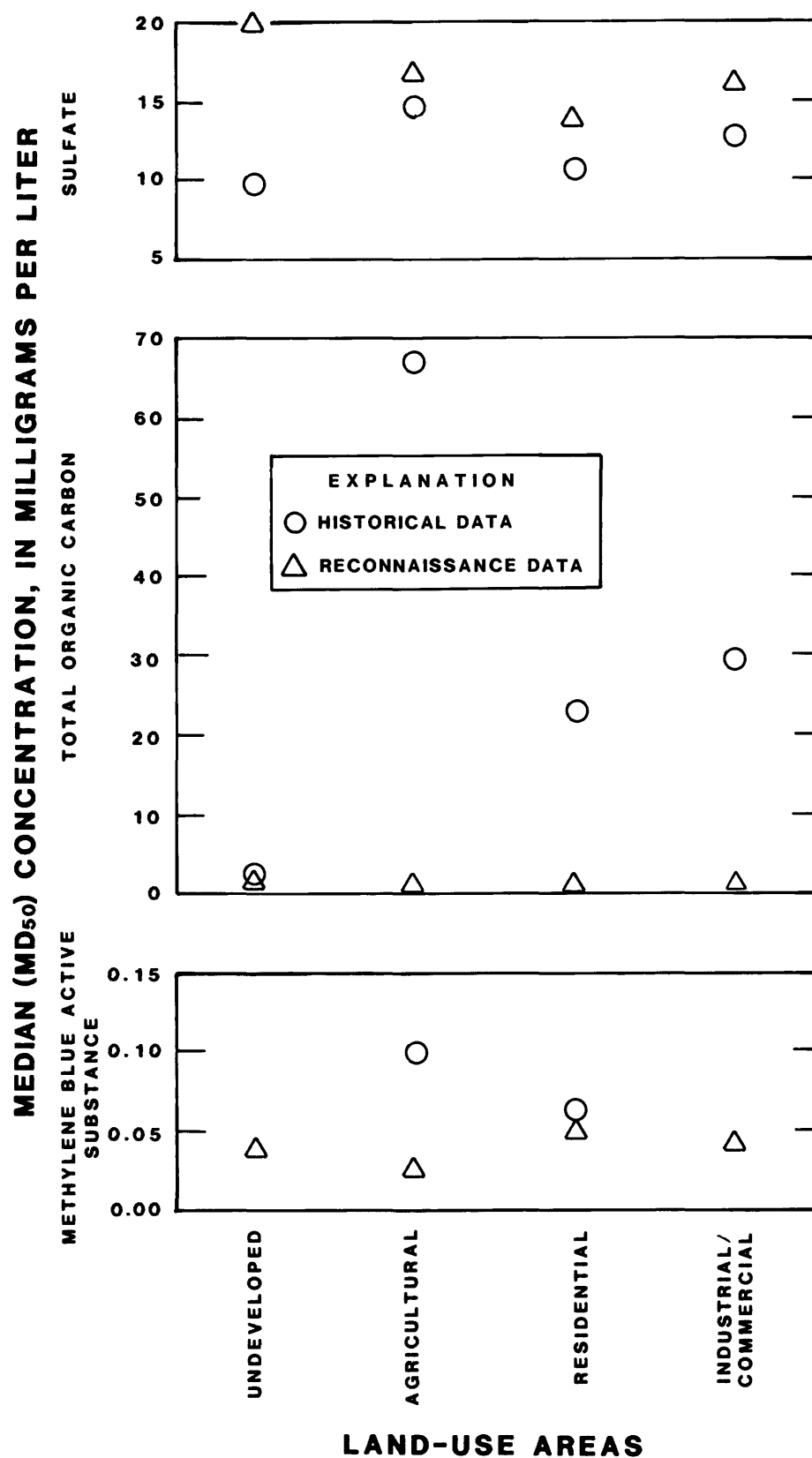
27

Figure 5.--Median concentrations of sulfate, total organic carbon, and detergents (MBAS) in the stratified-drift aquifer beneath four land-use areas compared for historical and reconnaissance data.

Helsel (1984), and Helsel and Gilliom (1985). Median concentrations of five of the eight trace elements included in table 3 are largest in industrial/commercial or residential areas, however, only nickel is statistically significant. Three of the trace constituents (iron, manganese, and zinc) have greatest median concentrations in undeveloped areas. However, these differences generally are not statistically significant, and no clear land-use/water-quality relations are evident. The source of these constituents is thought to be the dissolution of minerals in the aquifer matrix.

When the number of detections is too few to estimate the median and interquartile range, contingency-table analysis has been used to test the significance of the frequency of detection for each land use (Conover, 1980; Helsel and Ragone, 1984). Table 4 identifies the number of wells for each land use that have detectable concentrations of seven trace elements, and similarities or differences in the frequency of detection for various land-use areas from the contingency-table analysis. This analysis has been performed initially for data segrated only by land use. Significant differences in the frequency of detection for different land-use areas are observed in the combined historical and reconnaissance data for arsenic, beryllium, cadmium, lead, and lithium. The frequency of detection of arsenic and beryllium is significantly higher in ground water from industrial/commerical areas relative to agricultural areas. Lithium has been detected more frequently in both agricultural and industrial/commercial areas than in residential areas. However, cadium and lead are ambiguous, with anomalously greater frequency of detection in undeveloped areas.

A two-factor analysis of variance between land use and sampling period has been conducted for all the trace elements included in tables 3 and 4, except tin. Significant differences between sampling periods are identified for arsenic, barium, beryllium, boron, cadmium, lead, nickel, and zinc for some land-use categories. Figures 6 and 7 show the differences between the median concentrations or percentage detected, respectively, of this group of constituents for historical and reconnaissance data segregated by land use. These differences may arise from inadequacies in the sampling methods for the historical data, inconsistent analytical methods, or other circumstances not readily identifiable. They may also represent an artifact of the small sample size when the data are compared by land use and period. They are not, however, an indication of temporal changes in land-use activities, because the two-factor analysis of variance "F" statistic for interactions between land use and period are not significant in each case (Sokal and Rohlf, 1969). One-factor analysis of variance between land uses performed for each period of data separately indicates that significant differences are present in the reconnaissance data for barium (industrial/commercial higher than agricultural), lead (industrial/commercial higher than agricultural and residential), and nickel (residential higher than agricultural and industrial/commercial).

Sufficient data for two-factor analysis of variance between land use and aquifer exist only for iron, manganese, and zinc. Although there is no significant difference between aquifers for zinc, iron and manganese are significantly higher in the Pootatuck aquifer than the Pomperaug aquifer. Because

29

[Trace elements and pesticides are dissolved, volatile organic compounds are total. Dashes indicate insufficient data to calculate statistic; number of detected with same letter for contingency table test are not significantly different. When multiple analyses are available from one well, the median value is used in calculating the statistic. Units are μg/L, micrograms per liter]

Constituent and sampling period	Detection limit (μg/L)	Undeveloped			Agricultural			Residential			Industrial/Commercial			All land uses combined	
		Number of wells where constituent detected	Number of wells	Contingency table test	Number of wells where constituent detected	Number of wells	Contingency table test	Number of wells where constituent detected	Number of wells	Contingency table test	Number of wells where constituent detected	Number of wells	Contingency table test	Number of wells where constituent detected	Total number of wells
TRACE ELEMENTS															
Arsenic: reconnaissance	1	2	2	--	3	6	B	6	7	A	6	6	A	17	21
historical	1	1	5	AB	2	11	B	2	8	AB	4	7	A	9	31
combined	1	3	7	AB	5	17	B	8	15	AB	10	13	A	26	52
Beryllium: reconnaissance	1	0	2	--	0	6	B	1	7	AB	3	6	A	4	21
historical	1	0	0	--	0	8	A	0	6	A	0	6	A	0	20
combined	1	0	2	--	0	14	B	1	13	AB	3	12	A	4	41
Cadmium: reconnaissance	1	0	2	--	0	6	A	0	7	A	0	6	A	0	21
historical	1	5	5	A	3	11	B	3	8	B	5	8	AB	16	32
combined	1	5	7	A	3	17	B	3	15	B	5	14	AB	16	53
Lead: reconnaissance	10	1	2	--	0	6	B	0	7	B	3	6	B	4	21
historical	10	4	4	A	4	4	A	1	3	--	1	4	B	10	15
combined	10	4	6	A	4	10	B	1	10	B	4	10	B	14	36
Lithium: reconnaissance	5	1	2	--	1	6	AB	0	7	B	2	6	B	4	21
historical	5	0	0	--	3	8	A	0	6	B	1	6	B	4	20
combined	5	1	2	--	4	14	A	0	13	B	3	12	B	8	41
Mercury: reconnaissance	0.1	1	2	--	2	6	A	1	7	A	0	6	A	4	21
historical	.1	0	0	--	1	8	A	1	6	A	2	5	A	4	19
combined	.1	1	2	--	3	14	A	2	13	A	2	11	A	8	40
Copper: reconnaissance	10	0	2	--	0	6	A	0	7	A	0	6	A	0	21
historical	10	1	5	A	1	11	A	1	8	A	2	8	A	5	32
combined	10	1	7	A	1	17	A	1	15	A	2	14	A	5	53
VOLATILE ORGANIC COMPOUNDS															
1,1,1-Trichloroethane: reconnaissance	3	0	2	--	0	5	A	0	7	A	0	6	A	0	20
historical	1	0	0	--	2	2	--	1	1	--	3	3	--	6	6
Trichloroethylene: reconnaissance	3	0	2	--	0	5	A	0	7	A	0	6	A	0	20
historical	1	0	0	--	2	2	--	0	1	--	2	3	--	4	6
Tetrachloroethylene: reconnaissance	3	0	2	--	0	5	A	0	7	A	1	6	A	1	20
historical	1	0	0	--	0	2	--	0	0	--	1	3	--	1	5
1,1,2-Tetrachloroethane: reconnaissance	3	0	2	--	0	5	A	0	7	A	0	6	A	0	20
historical	1	0	0	--	0	1	--	0	0	--	1	2	--	1	3
Toluene: reconnaissance	3	0	2	--	0	5	A	0	7	A	0	6	A	0	20
historical	1	0	0	--	0	1	--	0	0	--	1	2	--	1	3

30

Table 4.--Number of wells screened in the stratified-drift aquifer beneath four land-use areas that have concentrations of trace elements, volatile organic compounds, and pesticides that exceed detection limits--continued

[Trace elements and pesticides are dissolved, volatile organic compounds are total. Dashes indicate insufficient data to calculate statistic; number of detected with same letter for contingency table test are not significantly different. When multiple analyses are available from one well, the median value is used in calculating the statistic. Units are µg/L, micrograms per liter]

Land-use areas

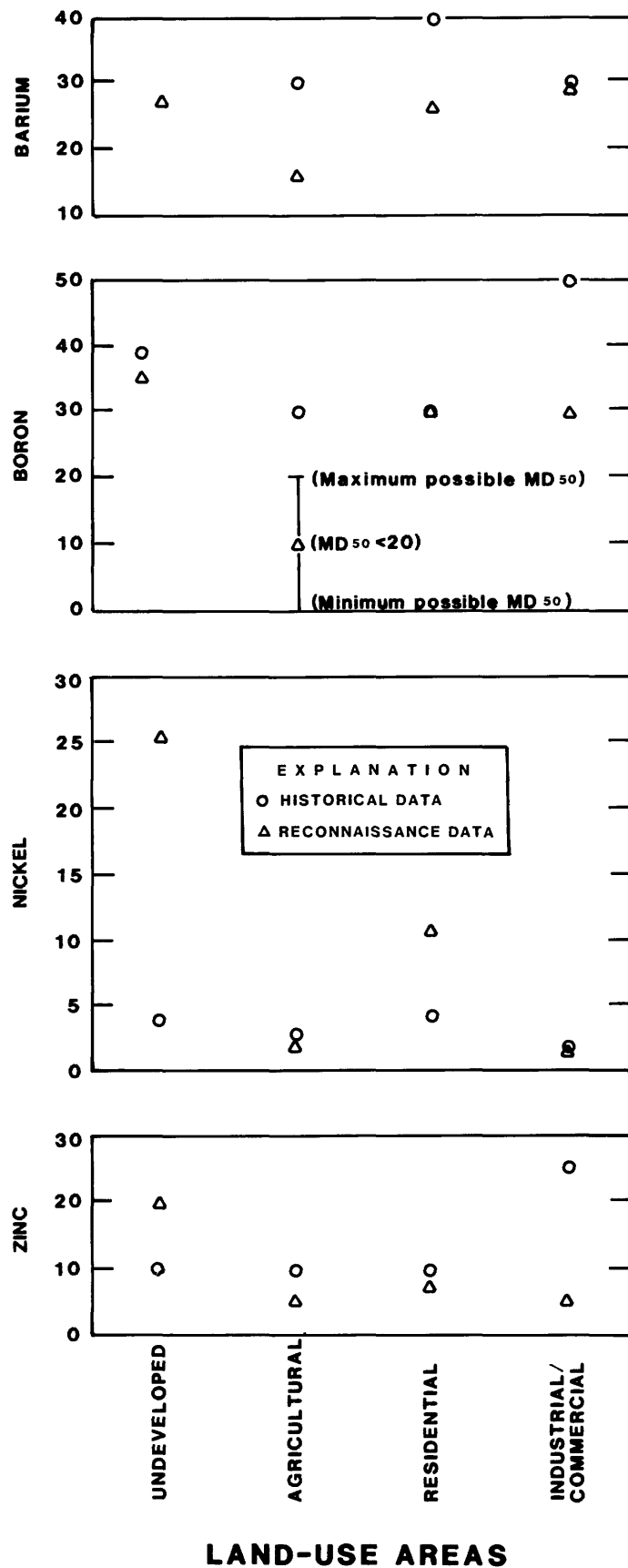| Constituent and sampling period	Detection limit (µg/L)	Undeveloped			Agricultural			Residential			Industrial/Commercial			All land uses combined	
		Number of wells where constituent detected	Number of wells	Contingency table test	Number of wells where constituent detected	Number of wells	Contingency table test	Number of wells where constituent detected	Number of wells	Contingency table test	Number of wells where constituent detected	Number of wells	Contingency table test	Number of wells where constituent detected	Total number of wells
VOLATILE ORGANIC COMPOUNDS															
Bromoform: reconnaissance	3	0	2	--	0	5	A	0	7	A	0	6	A	0	20
historical	0.1	0	0	--	0	0	--	0	0	--	1	3	--	1	3
Chlorodibromomethane: reconnaissance	3	0	2	--	0	5	A	0	7	A	0	6	A	0	20
historical	.1	0	0	--	0	0	--	0	0	--	2	3	--	2	3
Chloroform: reconnaissance	3	0	2	--	0	5	A	0	7	A	0	6	A	0	20
historical	1	0	0	--	2	2	--	0	0	--	1	3	--	3	5
1,1-Dichloroethane: reconnaissance	3	0	2	--	0	5	A	0	7	A	1	6	A	1	20
historical	.1	0	0	--	0	0	--	0	0	--	2	2	--	2	2
1,2-Dichloroethane: reconnaissance	3	0	2	--	0	5	A	0	7	A	0	6	A	0	20
historical	.1	0	0	--	0	0	--	0	0	--	1	2	--	1	2
Dichlorobromomethane: reconnaissance	3	0	2	--	0	5	A	0	7	A	0	6	A	0	20
historical	1	0	0	--	0	2	--	0	0	--	1	3	--	1	5
PESTICIDES															
Diazinon: reconnaissance	.01	0	0	--	0	6	A	1	7	A	0	0	--	1	13
2,4-D: reconnaissance	.01	0	0	--	0	6	A	1	7	A	0	0	--	1	13
2,4,5-T: reconnaissance	.01	0	0	--	0	6	A	1	7	A	0	0	--	1	13
Silvex: reconnaissance	.01	0	0	--	0	6	A	1	7	A	0	0	--	1	13

31

Figure 6.--Median concentrations of barium, boron, nickel, and zinc
in the stratified-drift aquifer beneath four land-use areas
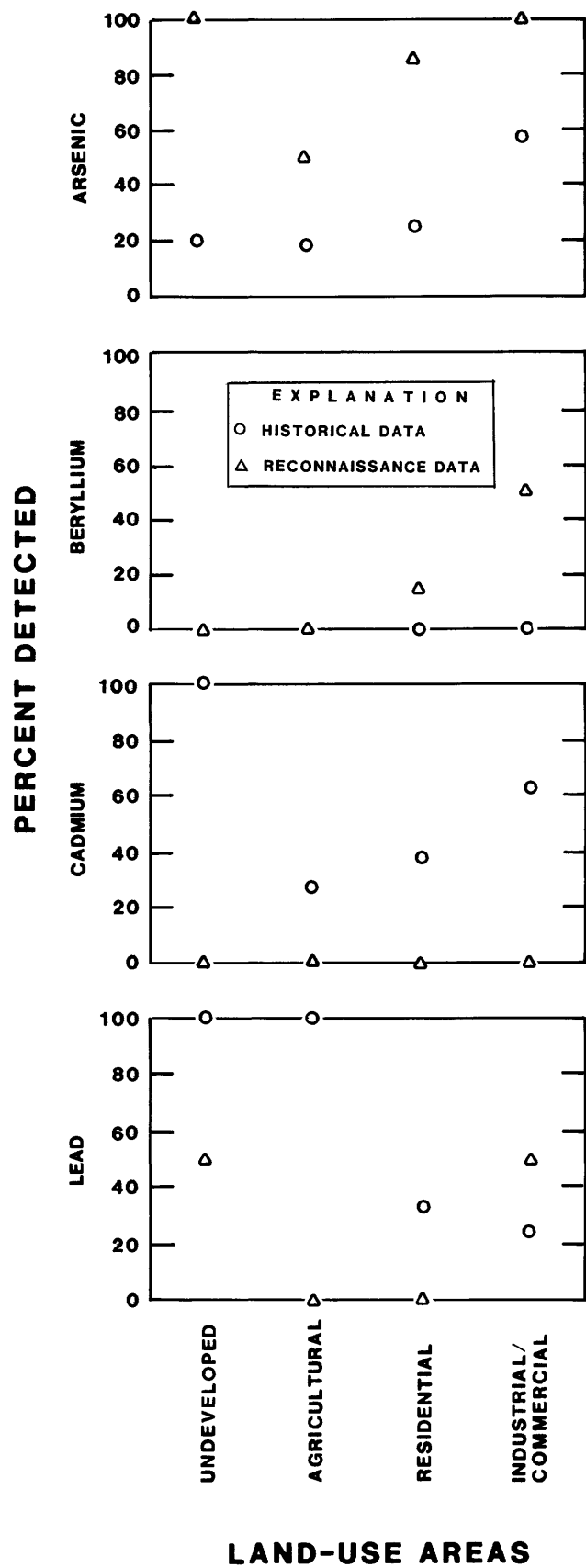compared for historical and reconnaissance data.

Figure 7.--Percentage of wells screened in the stratified-drift
aquifer beneath four land-use areas in which arsenic,
beryllium, cadmium, and lead have been detected
compared for historical and reconnaissance data.

differences between land-use areas for iron and manganese are ambiguous (concentrations in undeveloped generally are higher than other land-use areas) and the common occurrence of high concentrations of these elements in ground water throughout the State (Handman and others, 1979, p. 17), no particular relevance is attributed to this observation. It is possible that the Pootatuck aquifer is enriched with iron- and manganese-bearing minerals relative to the Pomperaug aquifer, or that oxidation-reduction conditions are more favorable for the mobilization of these elements in the former than the latter.

Several other trace elements, not included in tables 3 and 4, have been statistically analyzed. These constituents, however, are either detected infrequently (aluminium, chromium, cobalt, germanium, molybdenum, silver, and vanadium), or not at all (antimony, gallium, selenium, and zirconium). The lack of any substantial occurrence of these elements in ground water from all land uses is informative in itself, as land-use activities apparently are not introducing these contaminants into the ground water.

Organic Chemicals

The least data are available for organic chemicals in ground water. Only a few wells in the study areas have been sampled historically for selected volatile organic compounds and none for pesticides. Augmenting the data base for organic constituents was an impetus for the reconnaissance sampling, however, it is difficult to statistically compare historical and reconnaissance data for some of these constituents because of the higher detection limit used by the laboratory for the reconnaissance analyses.

Small sample sizes and the low frequency of detection for volatile organic compounds at concentrations greater than or equal to 3.0 μg/L (micrograms per liter) in the reconnaissance data have allowed only contingency-table analyses to be performed (table 4), and no significant differences between land uses have been observed. However, aside from the detection of trichloroethylene and 1,1,1-trichloroethane in two agricultural wells, and the latter compound in one residential well, all other volatile organic compounds have been detected only in industrial/commercial areas. Considering that nearly 50 percent of the volatile organic compound detections in the historical data are at concentrations less than 3.0 μg/L, it is likely that the reconnaissance analyses failed to detect potential land-use relations that may be evident at lower detection levels. Resampling of reconnaissance wells and analysis of volatile organic compounds at a detection level less than 1.0 μg/L will be conducted during the second phase of this study.

Water from residential and agricultural wells has been analyzed for 26 insecticide and herbicide compounds plus polychlorinated biphenyls and napthalenes. Only the chlorophenoxy-acid herbicides 2,4-D, 2,4,5-T, and silvex, and the insecticide diazinon have been detected (table 4). The herbicides are present in one residential-area well in the Pootatuck area (NT 102), and the insecticide has been detected in a residential-area well in the Pomperaug area (WY 51). The probable source of these compounds in residential areas is the application of lawn and garden chemicals.

Gas chromatography/flame-ionization detection scans have also been run on the 15 reconnaissance samples from undeveloped, residential, and industrial/ commercial areas. This analytical method provides an inexpensive, non-quantitive test for the presence of a large number of organic compounds including priority pollutants, and is used as a tool to direct further sampling efforts. Samples from two residential-area wells (NT 102 and WY 51) have shown positive indications that potentially quantifiable concentrations of unknown organic compounds are present. These wells were resampled for gas chromatography/mass spectrophotometer analyses that identified 1.0 $\mu g/L$ concentrations of the non-priority pollutant compounds, 1-bromo-2-chloro cis-cyclohexane and 2-heptanone, in water from both wells, and 3.0 $\mu g/L$ of 1,2-dichlorobenzene, a priority pollutant insecticide compound, in well WY 51. It is possible, however, that the former compounds are artifacts of external contamination of the samples during storage or analysis at the laboratory.

CONCLUSIONS

This study has found that agricultural, residential, and industrial/ commercial land uses have affected the quality of water in two stratified-drift aquifers in Connecticut. Statistical comparisons of water-quality data show significant differences at the 0.05 error-probability level (95-percent confidence level) in the concentrations, or frequency of detection, for some constituents that are related to land use. Apparent relations between land use and ground-water quality include:

1. The smallest median concentrations of most major inorganic constituents in ground water occur in samples from undeveloped areas. Those few constituents that have the greatest median concentrations in ground water from undeveloped areas, including potassium, total organic carbon, iron, manganese, and zinc are likely derived from natural sources.

2. Ground water in agricultural areas has the largest median sulfate and total ammonia plus organic nitrogen concentrations relative to other land-use areas. Ground water in agricultural areas has significantly greater median specific conductance, noncarbonate hardness, carbon dioxide, and magnesium concentrations than ground water in undeveloped areas. The application of fertilizers, lime, and other agricultural chemicals is the most likely source of elevated concentrations of the above constituents in ground water from agricultural areas. The lowest median concentrations or detection frequencies, have been observed in ground water from agricultural areas for the following constituents: Nitrate plus nitrite, detergents, total organic carbon, and all trace elements except nickel, lead, lithium, and mercury. No pesticides have been detected in ground-water samples from agricultural areas. Trichloroethylene and 1,1,1-trichloroethane have been detected in two wells sampled historically in agricultural areas.

3. Ground water in residential areas has greater median concentrations of all the major inorganic constituents except potassium, sulfate, and total ammonia plus organic nitrogen than ground water in both undeveloped and agricultural areas. The largest median concentrations of the following constituents have been observed in ground water from residential areas: Hardness, sodium, ammonia, nitrate plus nitrite, detergents,

and nickel. Median concentrations of all of the above constituents plus specific conductance, chloride, and dissolved solids are significantly greater in ground water underlying residential areas relative to ground water underlying undeveloped areas. Ground water from residential areas also has significantly greater median concentrations of manganese, nickel, and sodium than ground water from agricultural areas. The pesticides 2,4-D, 2,4,5-T, and silvex, and the volatile organic compound 1,1,1-trichloroethane each have been detected once in samples from wells in residential areas. Effluent from septic systems, infiltration from sewer lines, the application of deicing chemicals to residential streets and sidewalks, and the use of lawn and garden chemicals are probable sources for the elevated concentrations of the above constituents in ground water underlying residential areas.

4. Ground water in industrial/commercial areas has the highest median specific conductance and pH values, and the largest median concentrations of carbon dioxide, calcium, magnesium, chloride, bicarbonate, dissolved solids, boron, and strontium relative to ground water from the other land-use areas. Median concentrations of the following constituents are significantly greater in ground water in industrial/commercial areas than in ground water in undeveloped areas: Specific conductance, hardness, carbon dioxide, calcium, magnesium, chloride, and dissolved solids. The median dissolved solids concentration in ground water from industrial/commercial areas is also significantly greater than in agricultural areas. The frequency of detection of arsenic, beryllium, lead, and lithium is significantly greater for samples from wells in industrial/commercial areas than for ground-water samples from one or more of the other land-use areas for some historical and (or) reconnaissance data. Volatile organic compounds also have been detected more frequently in ground water from industrial/commercial areas. A variety of sources, including leaks, spills, and discharges of industrial chemicals and byproducts, and runoff from streets and paved lots within industrial/commercial areas, may contribute to the elevated concentrations or more frequent detections of the above constituents.

Comparisons of data from different sampling periods show significant differences between data collected historically and data collected for this study with respect to sulfate, detergents, total organic carbon, and for numerous trace elements. Possible explanations for the observed differences include: Small sample sizes for some constituents and some land-use categories; improper historical sampling methods; inconsistent analytical methods between period data, or other unknown circumstances. The possibility that the differences between sampling periods reflect temporal changes in land-use activities is dismissed on the basis of statistical tests for interactions between land use and sampling period. The reconnaissance data collected for this study are considered more reliable than the historical data as new stainless-steel wells and sampling procedures designed to obtain representative samples of the ground water have been used.

Comparison of the data by land use and aquifer shows that there are no significant differences in ground water from similar land uses between the Pootatuck and Pomperaug areas for the following constituents: Specific conductance, pH, calcium, magnesium, sodium, chloride, ammonia, sulfate,

dissolved solids, nickel, and zinc. Only iron and manganese were significantly different between the two aquifers, and these elements probably reflect differences in the natural geochemical environments particular to each aquifer. The lack of significant interaquifer differences in the concentrations of constituents that have demonstrated associations with land use enhances the probability that relations between land use and ground-water quality that can be identified in one aquifer are transferable to other similar settings.

Additional data need to be collected to define more clearly the effects of land use on ground-water quality. Augmenting and balancing the number of wells in each land-use category will help to negate the problems caused by small or disproportionate sample sizes, to minimize the within-sample variability, and to provide a more representative data base from which to compare land-use effects. A better distribution of wells between aquifers will allow a more complete analysis of interaquifer differences and a more accurate appraisal of the influence of hydrogeological factors on water quality. Additional factors, such as the effects of sewering, well depth, within-well variation, and refinements to the land-use classification, should be investigated.

Further studies need to gather information on the distribution of trace elements and organic constituents at low analytical detection limits. Insufficient data for these constituents prevented a more complete appraisal of the effects of land use on ground-water quality.

REFERENCES

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

Baker, J. A., Healy, H. G., and Hackett, O. M., 1964, Geology and ground-
      water conditions in the Wilmington-Reading area, Massachusetts: U.S.
      Geological Survey Water-Supply Paper 1694, 80 p.

Barcelona, M. J., Gibb, J. P., and Miller, R. A., 1983, A guide to the
      selection of materials for monitoring well construction and ground-water
      sampling: Illinois State Water Survey Contract Report 327, 78 p.

Barcelona, M. J., Helfrich, J. A., Garske, E. E., and Gibb, J. P., 1984, A
      laboratory evaluation of ground-water sampling mechanisms: Ground Water
      Monitoring Review, v. 4, no. 2, p. 32-41.

Claassen, H. C., 1982, Guidelines and techniques for obtaining water samples
      that accurately represent the water chemistry of an aquifer: U.S.
      Geological Survey Open-File Report 82-1024, 49 p.

Connecticut Department of Environmental Protection, 1977, Water service area
      maps: Connecticut Department of Environmental Protection, Natural
      Resources Center, 1:24,000 scale unpublished quadrangle maps (on mylar).

----- 1982, Atlas of the public water-supply sources and drainage basins of
      Connecticut: Connecticut Department of Environmental Protection, Natural
      Resources Center, Bulletin 4.

----- 1984a, Leachate and wastewater discharge sources for the Hudson, [and]
      Housatonic River basins: Connecticut Department of Environmental
      Protection, Water Compliance Unit, 1:50,000 scale map.

----- 1984b, Leachate and wastewater discharge sources for the Hudson, [and]
      Housatonic River basins - an inventory: Connecticut Department of
      Environmental Protection, Water Compliance Unit, 31 p.

Connecticut Land Use Standardization Committee, 1966, Standard land use
      classification system for Connecticut.

Connecticut Office of Policy and Management, 1970, Land use inventory:
      Connecticut Office of Policy and Management, Hartford, Connecticut,
      statewide coverage by 1:24,000 scale quadrangle maps.

----- 1978, Sewer service area maps: Connecticut Office of Policy and
      Management, Hartford, Connecticut, 1:24,000 scale unpublished quadrangle
      maps (on mylar).

Connecticut Office of the Secretary of State, 1982, Connecticut State
      register and manual: Hartford, Connecticut, 915 p.

Conover, W. J., 1980, Practical nonparametric statistics (2d ed.):   New York, John Wiley, 493 p.

Conover, W. J., and Iman, R. L., 1981, Rank transformations as a bridge between parametric and nonparametric statistics: American Statistician, v. 35, p. 124-129.

Freeze, R. A., and Cherry, J. A., 1979, Groundwater: Englewood Cliffs, New Jersey, Prentice Hall, Inc., 604 p.

Gibb, J. P., Schuller, R. M., and Griffin, R. A., 1981, Procedures for the collection of representative water quality data from monitoring wells: Illinois State Water and Geological Survey, Cooperative Groundwater Report 7, 61 p.

Gillham, R. W., Robin, M. J. L., Barker, J. F., and Cherry, J. A., 1983, Groundwater monitoring and sample bias: American Petroleum Institute Publication 4367, 206 p.

Gilliom, R. J., and Helsel, D. R., 1984, Estimation of distributional parameters for censored trace-level water-quality data: U.S. Geological Survey Open-File Report 84-729, 25 p.

Goerlitz, D. F., and Brown, E., 1972, Methods for analysis of organic substances in water: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. A3, 40 p.

Grossman, I. G., and Wilson, W. E., 1970, Hydrogeologic data for the lower Housatonic River basin, Connecticut: Connecticut Water Resources Bulletin 20, 50 p.

Haeni, F. P., 1978, Computer modeling of the ground-water availability in the Pootatuck River valley, Newtown, Connecticut, with a section on quality of water by E. H. Handman: U.S. Geological Survey Water-Resources Investigations Report 78-77, 64 p.

Handman, E. H., Grossman, I. G., Bingham, J. W., and Rolston, J. L., 1979, Major sources of ground-water contamination in Connecticut: U.S. Geological Survey Water-Resources Investigations Report 79-1069, 59 p.

Heath, R. C., 1980, Basic elements of ground-water hydrology with reference to conditions in North Carolina: U.S. Geological Survey Water-Resources Investigations Report 80-44, 86 p.

----- 1984, Ground-water regions of the United States: U.S. Geological Survey Water-Supply Paper 2242, 78 p.

Helsel, D. R., 1983, Mine drainage and rock type influences on Eastern Ohio streamwater quality: Water Resources Bulletin, v. 19, p. 881-887.

Helsel, D. R., and Gilliom, R. J., 1985, Estimation of distributional parameters for censored trace-level water-quality data, II.   Verifications and applications: U.S. Geological Survey Open-File Report 85-86, 21 p.

Helsel, D. R., and Ragone, S. E., 1984, Evaluation of regional ground-water quality in relation to land use--U.S. Geological Survey Toxic Waste--Ground-Water Contamination Program: U.S. Geological Survey Water-Resources Investigations Report 84-4217, 33 p.

Kleiner, B., and Graedel, T. E., 1980, Exploratory data analysis in the geophysical sciences: Reviews of Geophysics and Space Physics, v. 18, no. 3, p. 699-717.

Mazzaferro, D. L., 1986a, Ground-water availability and water quality in Southbury and Woodbury, Connecticut: U.S. Geological Survey Water-Resources Investigations Report 84-4221, 105 p.

----- 1986b, Depth to bedrock, depth to the water table, and classification of unconsolidated materials above the water table in stratified-drift areas of part of the Pomperaug River valley, Southbury and Woodbury, Connecticut: U.S. Geological Survey Miscellaneous Investigations Series Map I-1690, scale 1:24,000.

Mazzaferro, D. L., Handman, E. H., and Thomas, M. P., 1979, Water resources inventory of Connecticut, part 8, Quinnipiac River basin: Connecticut Water Resources Bulletin 27, 88 p.

Meade, D. B., 1978, Ground water availability in Connecticut: Connecticut Geological and Natural History Survey, Natural Resources Atlas Series Map, scale 1:125,000.

Meinzer, O. E., and Stearns, N. D., 1929, A study of ground water in the Pomperaug River basin, Connecticut with special reference to intake and discharge: U.S. Geological Survey Water-Supply Paper 597B, p. 73-146.

Miller, D. W., DeLuca, F. A., and Tessier, T. L., 1974, Ground-water contamination in the Northeast States: U.S. Environmental Protection Agency, Environmental Protection Technology Series EPA-660/2-74-056, 325 p.

Morris, D. A., and Johnson, A. I., 1967, Summary of hydrologic and physical properties of rock and soil materials, as analyzed by the hydrologic laboratory of the U.S. Geological Survey: U.S. Geological Survey Water-Supply Paper 1839-D, 42 p.

Newtown Planning Zoning Commission, 1981, Newtown, Connecticut - existing land use: 1:14,400 scale map prepared by TPA Services, New Haven, Connecticut.

Pettyjohn, W. A., Dunlap, W. J., Cosby, R. L., and Keeley, J. W., 1981, Sampling ground water for organic contaminants: Ground Water, v. 19, no. 2, p. 180-189.

Ragone, S. E., 1984, U.S. Geological Survey Toxic Waste--Ground-Water Contamination Program--Fiscal Year 1983: U.S. Geological Survey Open-File Report 84-474, 56 p.

Rolston, J. L., Grossman, I. G., Potterton, R. S., Jr., and Handman, E. H., 1979, Places in Connecticut where ground water is known to have deteriorated in quality: U.S. Geological Survey Miscellaneous Field Studies Map MF 981-B, scale 1:125,000.

Skougstad, M. W., Fishman, M. J., Friedman, L. C., Erdmann, D. E., and Duncan, S. S., editors, 1979, Methods for determination of inorganic substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water Resources Investigations, book 5, chap. A1, 626 p.

Sokal, R. R., and Rohlf, F. J., 1969, Biometry: San Francisco, W. H. Freeman, 776 p.

Southbury Planning Commission, 1977, Inventory of land utilization, Town of Southbury, Connecticut: 1:12,000 scale map prepared by Robert S. Bryan and Associates Community Development Services.

Stoline, M. R., 1981, The status of multiple comparisons--simultaneous inference of all pairwise comparisons in one-way ANOVA designs: American Statistician, v. 35, p. 134-141.

Town of Woodbury, 1975, Land use - Town of Woodbury, Connecticut: 1:24,000 scale map based on Land Use Aerial Photo Survey, Central Naugatuck Valley Regional Planning Association, April 1975.

U.S. Urban Renewal Administration, Housing and Home Finance Agency, and Bureau of Public Roads, 1965, Standard land use coding manual, a standard system for identifying and coding land use activities: Washington, D.C., 111 p.

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

Wilson, W. E., Burke, E. L., and Thomas, C. E., Jr., 1974, Water resources inventory of Connecticut, part 5, lower Housatonic River basin: Connecticut Water Resources Bulletin 19, 79 p.

Wood, W. W., 1976, Guidelines for collection and field analysis of ground-water samples for selected unstable constituents: U.S. Geological Survey Techniques of Water Resources Investigations, book 1, chap. D-2, 24 p.

Woodbury Zoning Commission, 1982, Zoning map-Town of Woodbury, Connecticut: 1:24,000 scale map.

EXPLANATION

CONTACT BETWEEN STRATIFIED DRIFT AND
TILL OR BEDROCK

— 40 — LINE OF EQUAL THICKNESS OF SATURATED
STRATIFIED DRIFT—Values shown are 10, 40,
80, and 120 feet

SCALE 1:24,000

CONTOUR INTERVAL 10 FEET (3.0 Meters)
NATIONAL GEODETIC VERTICAL DATUM OF 1929

Base from U.S. Geological Survey
Newtown 1:24,000, 1963, photorevised 1972
Botsford 1:24,000, 1969, photorevised 1984

Hydrogeology modified from Wilson and
others, 1974, and Haeni, 1978

POOTATUCK RIVER AQUIFER AREA

Base from U.S. Geological Survey
Woodbury 1:24,000, 1955, photorevised 1970
Southbury 1:24,000, 1953, photorevised 1972

Hydrogeology modified from Wilson and
others, 1974, and Mazzaferro, 1986a

POMPERAUG RIVER AQUIFER AREA

SATURATED THICKNESS OF STRATIFIED-DRIFT AQUIFERS IN THE POOTATUCK AND POMPERAUG RIVER VALLEYS

EXPLANATION

CONTACT BETWEEN STRATIFIED DRIFT AND
TILL OR BEDROCK

—260— WATER-TABLE CONTOUR--Shows altitude of water
table in the stratified-drift aquifer of the Pootatuck
River valley (November 1976: from Haeni, 1978), and
the average altitude of the water table in the
stratified-drift aquifer of the Pomperaug River
valley (for January 1979 to February 1980: from Mazz-
aferro, 1986a). Dashed where approximately located.
(Contour interval 10 feet.)

HORIZONTAL DIRECTION OF GROUND-WATER
MOVEMENT

SCALE 1:24,000

1   ½   0   1 Mile

1   0.5   0   1 Kilometer

CONTOUR INTERVAL 10 FEET (3.0 Meters)
NATIONAL GEODETIC VERTICAL DATUM OF 1929

Base from U.S. Geological Survey
Newtown 1:24,000, 1963, photorevised 1972
Botsford 1:24,000, 1969, photorevised 1984.

Hydrogeology modified from Wilson and
others, 1974, and Haeni, 1978

POOTATUCK RIVER AQUIFER AREA

Base from U.S. Geological Survey
Woodbury 1:24,000, 1965, photorevised 1970
Southbury 1:24,000, 1963, photorevised 1972

Hydrogeology modified from Wilson and
others, 1974, and Mazzaferro, 1986a

POMPERAUG RIVER AQUIFER AREA

ALTITUDE OF THE WATER TABLE IN THE STRATIFIED-DRIFT AQUIFERS IN THE POOTATUCK AND POMPERAUG RIVER VALLEYS

EXPLANATION

Land use shown for areas greater than 5 or 10 acres, based on 1970 State of Connecticut land-use inventory (Connecticut Office of Policy and Management, 1970). Land-use and land-cover categories have been combined to show the principal land-use categories with respect to potential water-quality impacts. Modifications to 1970 land use based on interpretation of 1965 and 1980 aerial photographs, local land-use sources (Town of Woodbury, 1975; Southbury Planning Commission, 1977; Newtown Planning and Zoning Commission, 1981; and Woodbury Zoning Commission, 1982), and on field surveys conducted in 1985

PRINCIPAL LAND-USE CATEGORIES

Agricultural--Includes active agricultural production (undifferentiated), dairies, athletic fields, golf courses, and cemeteries

Industrial/Commercial--Includes general light manufacturing, and general trades and services

Institutional/Transportation--Includes hospitals, primary and secondary education facilities, churches and monasteries, general cultural and entertainment facilities, airports, and highway right-of-ways over 100 feet wide

Residential--Includes all sewered and unsewered residential areas with housing densities of less than 1 to more than 8 families per acre

Undeveloped--Includes all open lands (inactive agricultural and scrub lands), noncommercial forest and woodlands, commercial forestry production, wetlands and water bodies

HYDROGEOLOGIC INFORMATION

Contact between stratified drift and till or bedrock

O 65 Well sampled prior to or during this study. Number is local identification number used in U.S. Geological Survey publications

SCALE 1:24,000
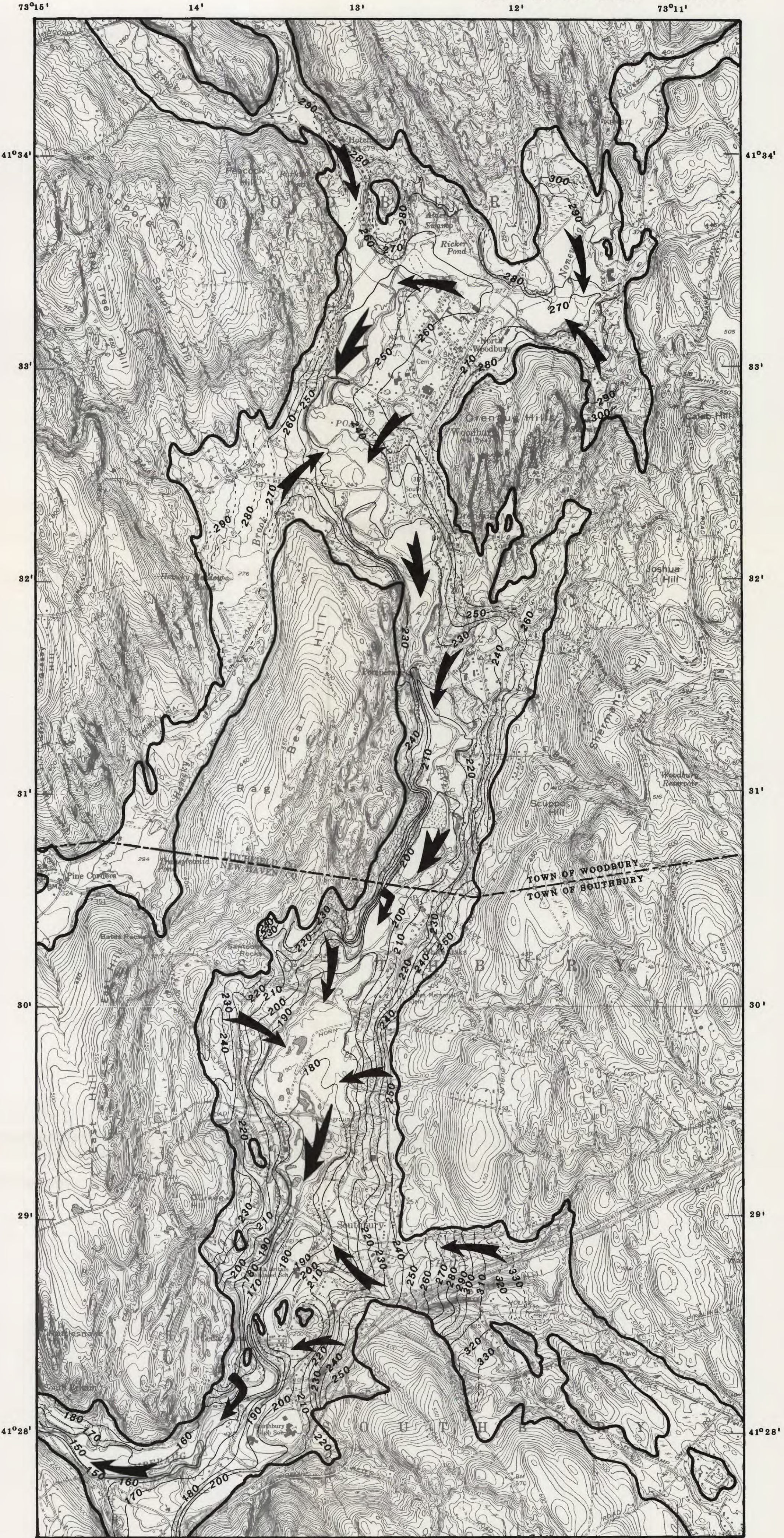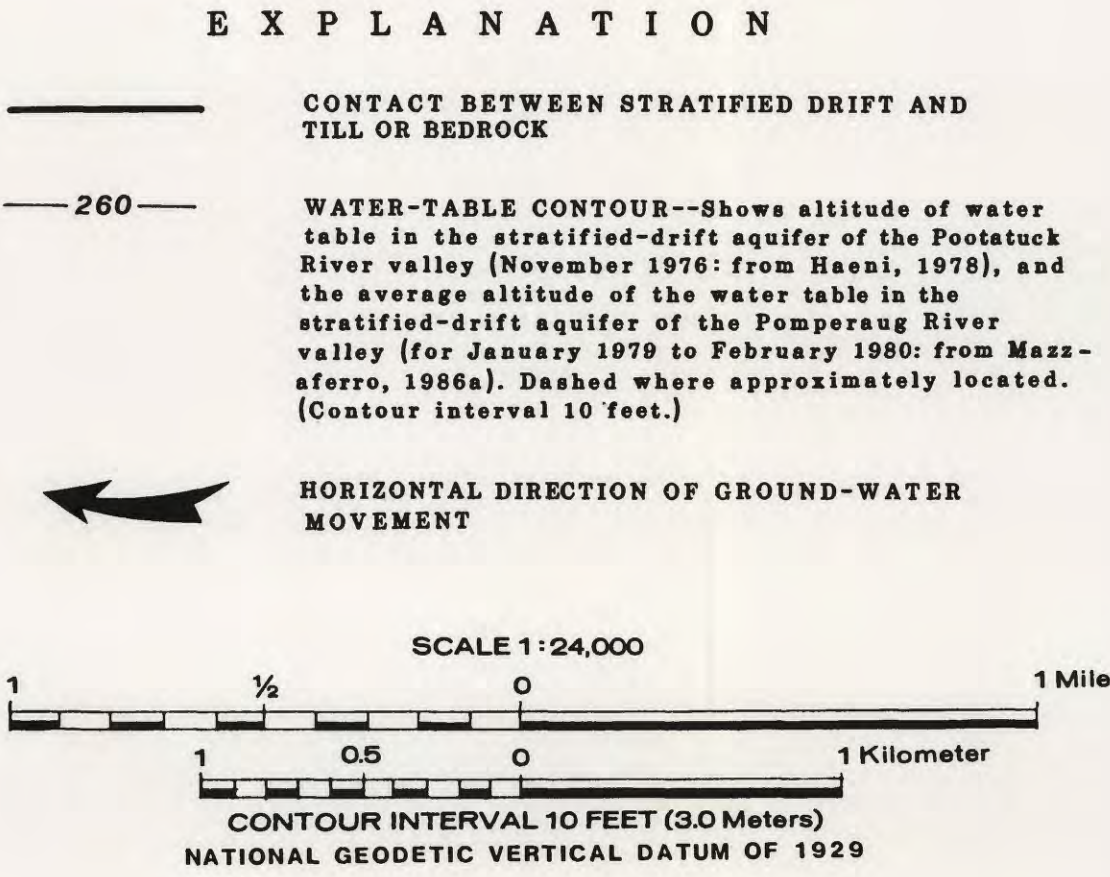
CONTOUR INTERVAL 10 FEET (3.0 METERS)
NATIONAL GEODETIC VERTICAL DATUM OF 1929

Base from U.S. Geological Survey
Newtown 1:24,000, 1963, photorevised 1972
Botsford 1:24,000, 1969, photorevised 1984.

Hydrogeology modified from Wilson and others, 1974, and Haeni, 1978

POOTATUCK RIVER AQUIFER AREA

Base from U.S. Geological Survey
Woodbury 1:24,000, 1955, photorevised 1970
Southbury 1:24,000, 1953, photorevised 1972

Hydrogeology modified from Wilson and others, 1974, and Mazzaferro, 1986a

POMPERAUG RIVER AQUIFER AREA

LAND USE AND LOCATION OF WELLS SAMPLED IN THE POOTATUCK AND POMPERAUG RIVER VALLEYS

EXPLANATION

Contamination point sources indicating locations of known spills, leachate, or wastewater discharges are modified from Connecticut Department of Environmental Protection (1984a, b). Solid symbols indicate active sites, open symbols indicate inactive sites. Water supply sources and service areas from Connecticut Department of Environmental Protection (1977, 1982). Sewer service areas from Connecticut Office of Policy and Management (1978)

— CONTACT BETWEEN STRATIFIED DRIFT AND TILL OR BEDROCK

WATER-AND SEWER-SERVICE AREAS

Public water-supply service area and lines

Sewer service area and lines

POINT SOURCES OF CONTAMINATION

▲ Landfill, M indicates mixed wastes, B indicates bulky wastes

⬟ Sewage treatment plant

● Road salt storage

⬇ Industrial wastewater discharge

⚬⚬ Cooling-water discharge

◊ Spill or leak, P indicates petroleum product, C indicates chemical

◆ Multiple-dwelling onsite septic system

⌀ Public water-supply well

SCALE 1:24,000

1   ½   0   1 Mile

1   0.5   0   1 Kilometer

CONTOUR INTERVAL 10 FEET (3.0 Meters)
NATIONAL GEODETIC VERTICAL DATUM OF 1929

Base from U.S. Geological Survey
Newtown 1:24,000, 1963, photorevised 1972
Botsford 1:24,000, 1969, photorevised 1984.

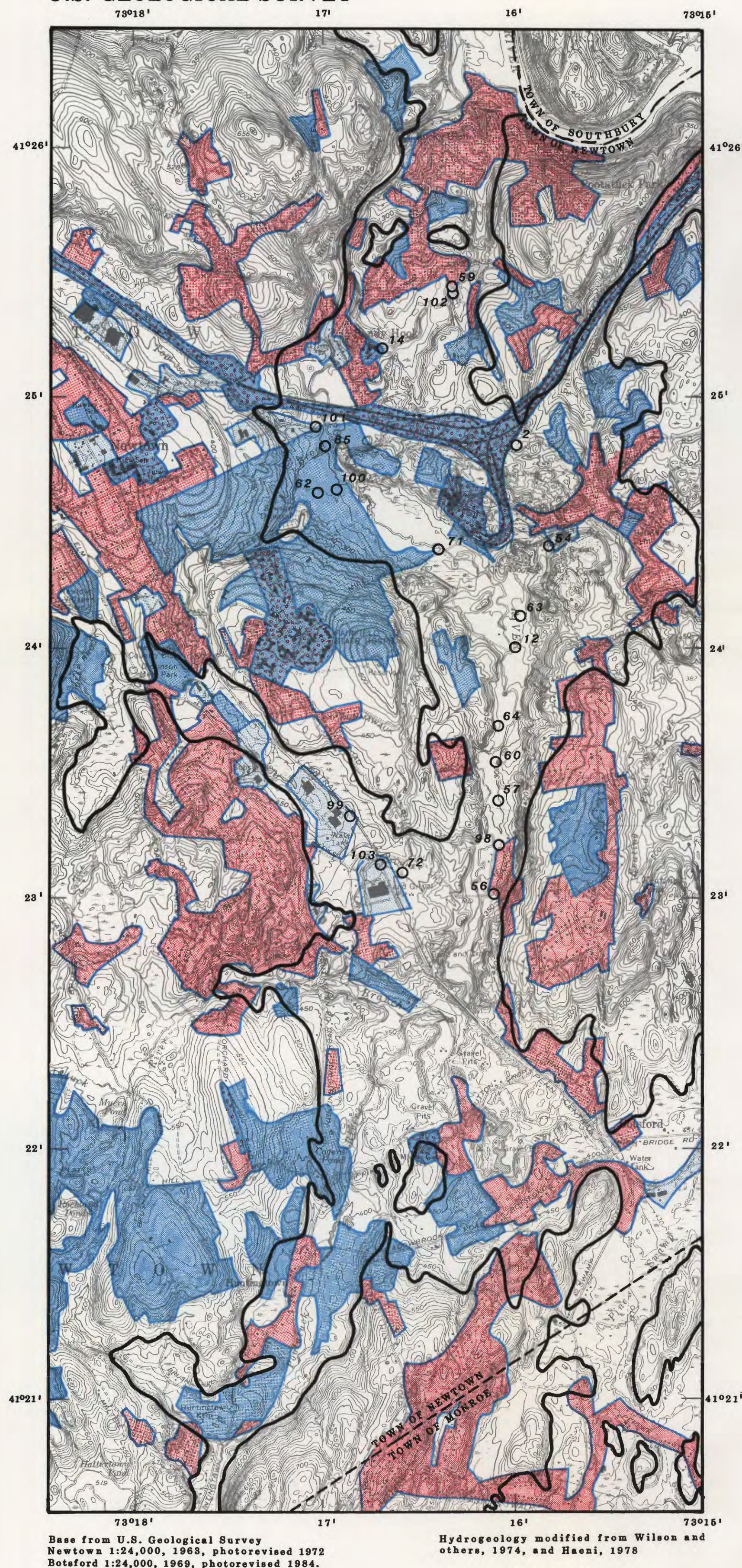Hydrogeology modified from Wilson and others, 1974, and Haeni, 1978.
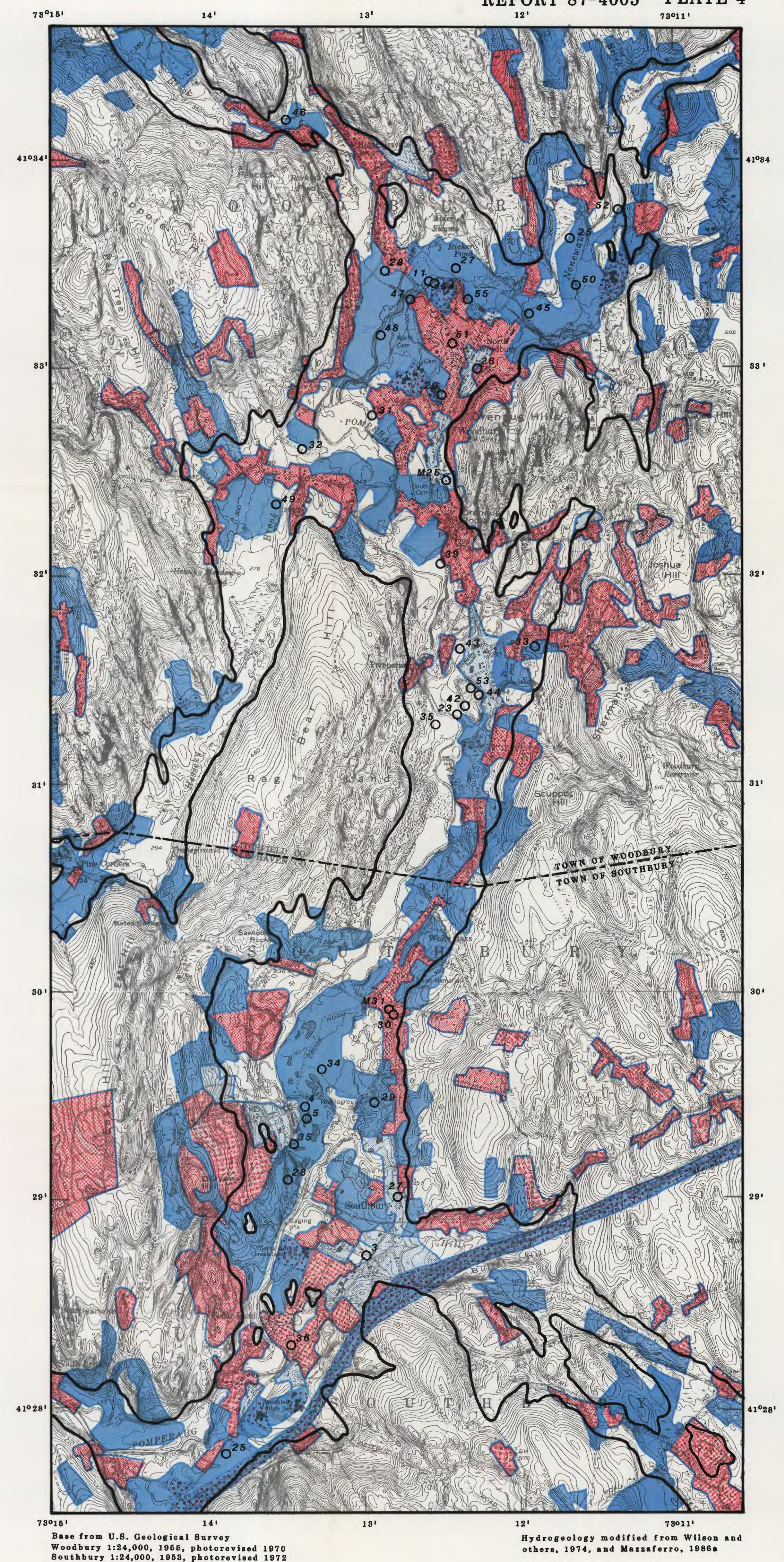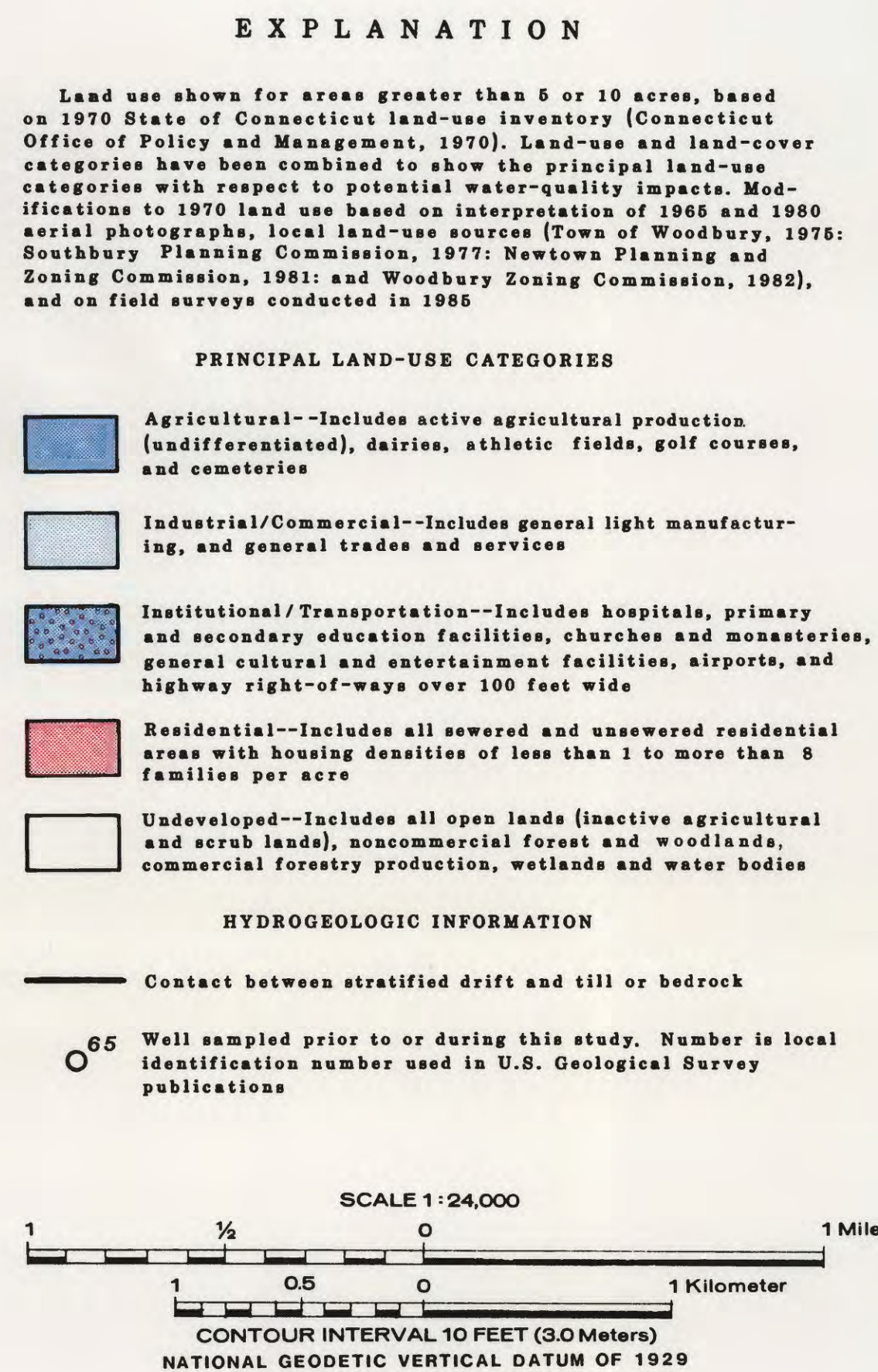
POOTATUCK RIVER AQUIFER AREA

Base from U.S. Geological Survey
Woodbury 1:24,000, 1955, photorevised 1970
Southbury 1:24,000, 1955, photorevised 1972

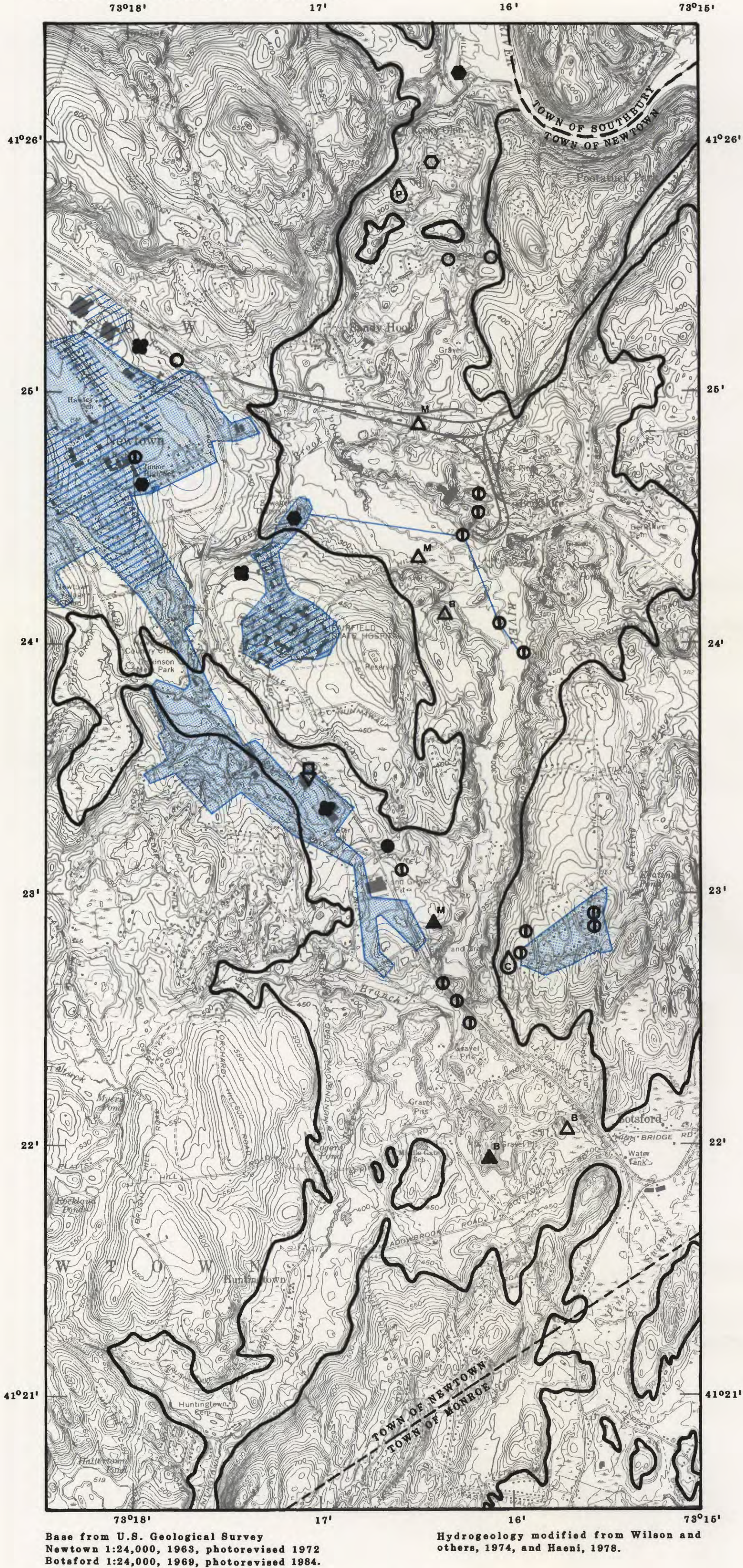Hydrogeology modified from Wilson and others, 1974, and Mazzaferro, 1986a.
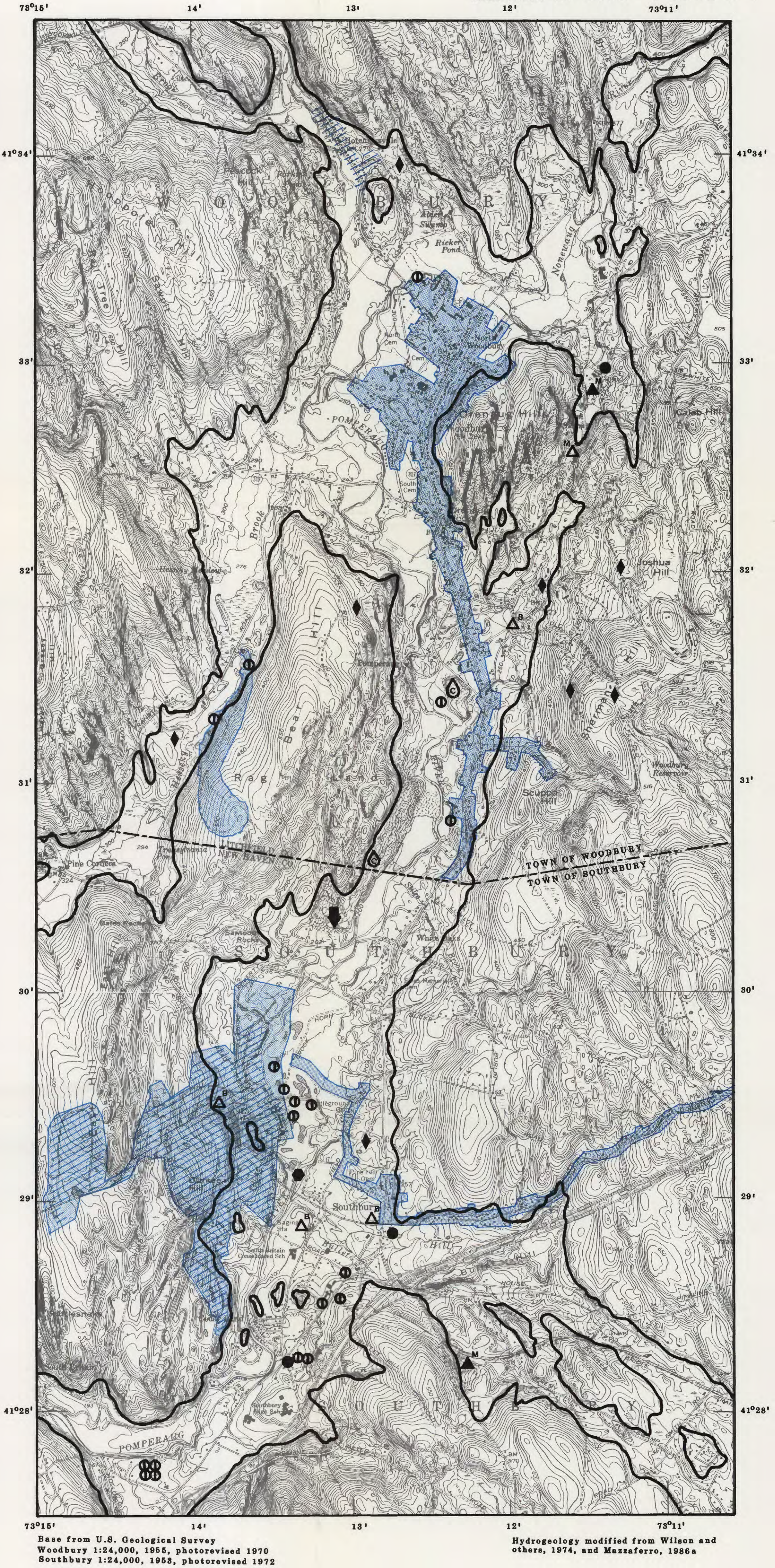
POMPERAUG RIVER AQUIFER AREA

POINT SOURCES OF CONTAMINATION AND WATER-AND SEWER-SERVICE AREAS IN THE POOTATUCK AND POMPERAUG RIVER VALLEYS