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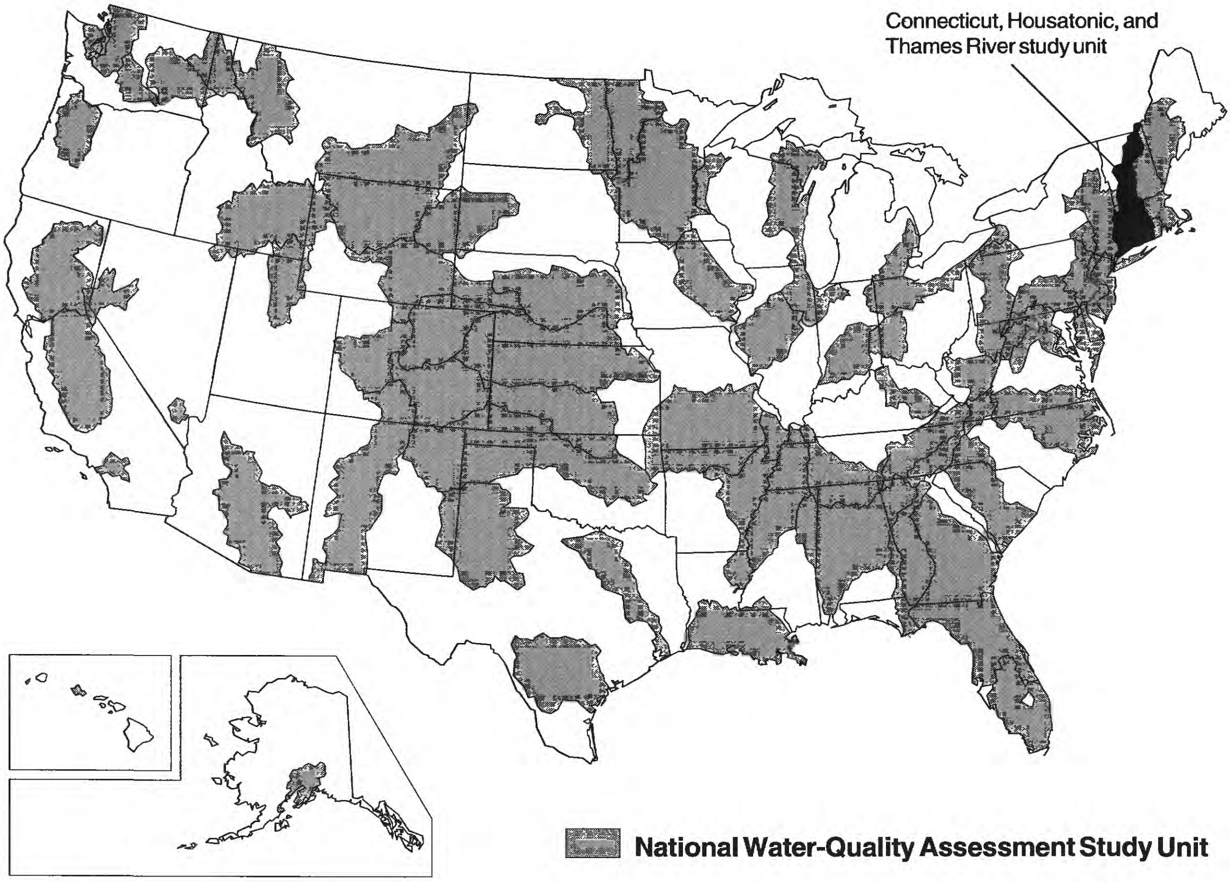
National Water-Quality Assessment Program

Natural and Human Factors Affecting Shallow Water Quality in Surficial Aquifers in the Connecticut, Housatonic, and Thames River Basins

Water-Resources Investigations Report 98-4042



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Natural and Human Factors Affecting Shallow Water Quality in Surficial Aquifers in the Connecticut, Housatonic, and Thames River Basins

By STEPHEN J. GRADY *and* JOHN R. MULLANEY

U.S. Geological Survey
Water-Resources Investigations Report 98-4042

NATIONAL WATER-QUALITY ASSESSMENT PROGRAM

Marlborough, Massachusetts
1998

U.S. DEPARTMENT OF THE INTERIOR
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FOREWORD

The mission of the U.S. Geological Survey (USGS) is to assess the quantity and quality of the earth resources of the Nation and to provide information that will assist resource managers and policymakers at Federal, State, and local levels in making sound decisions. Assessment of water-quality conditions and trends is an important part of this overall mission.

One of the greatest challenges faced by water-resources scientists is acquiring reliable information that will guide the use and protection of the Nation's water resources. That challenge is being addressed by Federal, State, interstate, and local water-resource agencies and by many academic institutions. These organizations are collecting water-quality data for a host of purposes that include: compliance with permits and water-supply standards; development of remediation plans for specific contamination problems; operational decisions on industrial, wastewater, or water-supply facilities; and research on factors that affect water quality. An additional need for water-quality information is to provide a basis on which regional- and national-level policy decisions can be based. Wise decisions must be based on sound information. As a society we need to know whether certain types of water-quality problems are isolated or ubiquitous, whether there are significant differences in conditions among regions, whether the conditions are changing over time, and why these conditions change from place to place and over time. The information can be used to help determine the efficacy of existing water-quality policies and to help analysts determine the need for and likely consequences of new policies.

To address these needs, the U.S. Congress appropriated funds in 1986 for the USGS to begin a pilot program in seven project areas to develop and refine the National Water-Quality Assessment (NAWQA) Program. In 1991, the USGS began full implementation of the program. The NAWQA Program builds upon an existing base of water-quality studies of the USGS, as well as those of other Federal, State, and local agencies. The objectives of the NAWQA Program are to:

- Describe current water-quality conditions for a large part of the Nation's freshwater streams, rivers, and aquifers.
- Describe how water quality is changing over time.
- Improve understanding of the primary natural and human factors that affect water-quality conditions.

This information will help support the development and evaluation of management, regulatory, and monitoring decisions by other Federal, State, and local agencies to protect, use, and enhance water resources.

The goals of the NAWQA Program are being achieved through ongoing and proposed investigations of 59 of the Nation's most important river basins and aquifer systems, which are referred to as study units. These study units are distributed throughout the Nation and cover a diversity of hydrogeologic settings. More than two-thirds of the Nation's freshwater use occurs within the 59 study units and more than two-thirds of the people served by public water-supply systems live within their boundaries.

National synthesis of data analysis, based on aggregation of comparable information obtained from the study units, is a major component of the program. This effort focuses on selected water-quality topics using nationally consistent information. Comparative studies will explain differences and similarities in observed water-quality conditions among study areas and will identify changes and trends and their causes. The first topics addressed by the national synthesis are pesticides, nutrients, volatile organic compounds, and aquatic biology. Discussions on these and other water-quality topics will be published in periodic summaries of the quality of the Nation's ground and surface water as the information becomes available.

This report is an element of the comprehensive body of information developed as part of the NAWQA Program. The program depends heavily on the advice, cooperation, and information from many Federal, State, interstate, Tribal, and local agencies and the public. The assistance and suggestions of all are greatly appreciated.

Robert M. Hirsch

Robert M. Hirsch
Chief Hydrologist

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CONVERSION FACTORS

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
	Area	
square mile (mi^2)	2.590	square kilometer
	Flow rate	
gallon per minute (gal/min)	0.06309	liter per second
	Mass	
pound, avoirdupois (lb)	0.4536	kilogram

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:
°F = (1.8 × °C) + 32

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:
°C = (°F - 32) / 1.8

VERTICAL DATUM

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 Sea Level Datum of 1929.

Altitude, as used in this report, refers to distance above or below sea level.

WATER-QUALITY UNITS

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25°C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L), picocuries per liter (pCi/L).

ABBREVIATIONS

ANOVA	analysis of variance
BTEX	benzene, toluene, ethylbenzene, and total xylenes
DAR	desethylatrazine to atrazine ratio
DO	dissolved oxygen
DOC	dissolved organic carbon
EDB	ethylene dibromide
GC/MS	gas chromatography/mass spectrometry
GIS	geographic information system
GLM	general linear models
HA	health advisory
HPLC	high performance liquid chromatography
MCL	maximum contaminant level
MCLG	maximum contaminant level goal
MDL	method detection level
MRL	minimum reporting level
MTBE	Methyl *tert*-butyl ether
N	nitrogen
NAWQA	National Water-Quality Assessment Program
NWQL	National Water Quality Laboratory
P	phosphorus
PVC	polyvinyl chloride
QA/QC	quality assurance/quality control
SMCL	secondary maximum contaminant level
TRI	toxics release inventory
USEPA	U.S. Environmental Protection Agency
USGS	United States Geological Survey
VOC	volatile organic compound

Natural and Human Factors Affecting Shallow Water Quality in Surficial Aquifers in the Connecticut, Housatonic, and Thames River Basins

By Stephen J. Grady and John R. Mullaney

Abstract

The quality of shallow ground water in the Connecticut, Housatonic, and Thames River Basins in New England and eastern New York is affected by natural factors related to regional variations in the lithologic composition of surficial aquifers, and by human activities related to land use. Ground-water samples from 120 monitoring wells screened in the uppermost parts of surficial aquifers were collected from 1992 to 1995 and analyzed for 177 water-quality variables. Nonparametric statistical procedures were used to compare the concentrations or frequency of detections of 22 continuous (or slightly censored) and 54 censored water-quality variables. These procedures indicate significant differences in the sample populations of 32 of the 76 variables compared for four aquifer-lithologic-composition and three land-use categories.

Surficial aquifers in the study area were classified into crystalline, arkosic, calcareous, or carbonate categories based on the areal distribution of bedrock units of similar mineralogical composition and the direction and extent of glacial and meltwater transport of sediments composing the surficial aquifers. The effects of aquifer-lithologic composition on ground-water quality were evidenced by significant differences in the concentrations or frequency of detection for 18 of 27 naturally occurring water-quality variables in water samples from the four surficial aquifers.

In general, water type (very fresh, slightly acidic) in the crystalline aquifers differs from water types (fresh, slightly alkaline) in the carbonate, calcareous, and arkosic surficial aquifers. Calcium and bicarbonate were the dominant ions in most waters from the surficial aquifers, but their prevalence diminishes from 100 percent of all water samples from carbonate aquifers to 60 percent of water samples from crystalline aquifers. Sulfate and chloride replaced bicarbonate as the principal anion, and sodium was more prevalent than calcium in some water samples from crystalline aquifers, even in natural, undeveloped settings.

Concentrations and detection frequencies were lowest for most inorganic constituents in samples from crystalline aquifers and were typically highest in samples from carbonate aquifers. Specific conductance and pH measurements, as well as concentrations of dissolved solids, calcium, hardness as calcium carbonate ($CaCO_3$), bicarbonate, and alkalinity were significantly lower in water samples from crystalline aquifers than from all three of the other surficial aquifers. Magnesium concentrations were three to six times higher in waters from the carbonate aquifers than other surficial aquifers, reflecting the dissolution of dolomite, while water samples from calcareous and arkosic aquifers were more representative of calcite dissolution. Detections of fluoride and orthophosphate, concentrations of silica, sodium, sulfate, nitrite plus nitrate, bromide, and dissolved oxygen (DO), plus water temperatures were significantly higher in water samples from the arkosic aquifers relative to one or more of the other surficial aquifers.

Natural water-quality problems associated with some or all surficial aquifers include elevated concentrations of iron and manganese that exceed the respective U.S. Environmental Protection Agency's Secondary Maximum Contaminant Levels (SMCL) of 300 and 50 micrograms per liter (µg/L), pH values less than the 6.5 lower limit of the SMCL, and radon-222 activities exceeding the 300 picocuries per liter proposed Maximum Contaminant Level (MCL).

Effects of human activities on shallow ground-water quality are related to undeveloped (forested), agricultural, and urban land use, are widespread, and are largely consistent for similar land uses across the study area. Eighteen continuous (or slightly censored) and 8 censored water-quality variables show statistically significant differences for comparisons of sample populations by land use.

Median concentrations of 15 of the 18 water-quality variables with significant land-use effects were lowest in water samples from monitoring wells in undeveloped areas and highest in samples from urban wells. The median dissolved-solids and chloride concentrations for samples from urban areas were significantly higher than respective medians for agricultural areas and undeveloped areas. Fifteen percent of the samples from urban monitoring wells exceeded the 500 milligrams per liter (mg/L) SMCL for dissolved solids. The median chloride concentration for urban areas was more than twice to nearly ten times higher than medians for agricultural and undeveloped areas, respectively. Calcium, magnesium, hardness as $CaCO_3$, sodium, bicarbonate, alkalinity, DO, sulfate, silica, bromide, and manganese concentrations also were strongly related to land use.

Nitrite plus nitrate concentrations were less than 1.0 mg/L as nitrogen for 95 percent of the samples from undeveloped wells. The median nitrite plus nitrate concentration for ground-water samples from urban areas was 1.1 mg/L and the maximum concentrations was 9.7 mg/L. The median nitrite plus nitrate concentration for samples from agricultural areas was 3.8 mg/L and nearly 13 percent of the samples from monitoring wells in agricultural areas exceeded the 10 mg/L MCL.

Detections of 24 of 85 pesticide compounds (or their metabolites) in samples from one or more of 103 monitoring wells varied significantly by land use. Pesticides were detected more frequently in ground-water samples from agricultural areas than in samples from wells in undeveloped and urban areas. Ninety percent of all pesticide detections were herbicides, with triazine herbicides detected most commonly. Detections of the triazine herbicide atrazine and its metabolite desethylatrazine account for 53 percent of all pesticide detections. Carbamate insecticides comprised more than one-half of the limited insecticide detections, with carbaryl detections most frequent among the carbamates. Ninety-six percent of pesticide concentrations were less than 1.0 μg/L and 41 percent were less than 0.01 μg/L. Only one pesticide detection, atrazine at 3.6 μg/L in one sample from an agricultural well, exceeded a MCL.

The frequency of atrazine, desethylatrazine, metolachlor, and prometon detections varied significantly by land use. Detections of atrazine, desethylatrazine, and metolachlor were significantly more frequent in water samples from agricultural wells than in samples from undeveloped and urban areas. These three herbicide compounds have been used widely in agricultural areas for pre-emergent control of broadleaf weeds in corn fields. Atrazine and metolachlor were the most and the third-most heavily used pesticides in the study area during 1982-85. Undetected or rarely detected in ground-water samples from undeveloped areas and agricultural areas, prometon detections were common (32 percent) in wells from urban areas. Prometon is a nonselective herbicide effectively used for either pre- or post-emergent, perennial broadleaf weed and grass control, and is commonly used on railroad, powerline, pipeline, and roadway right-of-ways.

Detections of 25 of 60 volatile organic compounds (VOCs) in one or more of 86 monitoring wells sampled for these compounds vary by land use. Overall, the frequency of VOC detections was significantly higher in water samples from urban areas and agricultural areas than from undeveloped areas. VOCs were detected in 62 percent of wells in urban areas, 38 percent of wells in agricultural areas, and in only 9 percent of wells in undeveloped areas. Concentrations of VOCs detected in the study area range from less than 0.2 to 300 μg/L and 5 of the 25 compounds detected—benzene, 1,2-dibromoethane, naphthalene, tetrachloroethene, and trichloroethene—exceed MCLs or HAs (health advisories). Eight of the 25 compounds detected are either known, probable, or possible human carcinogens.

Detections of the VOCs methyl *tert*-butyl ether (MTBE), chloroform, tetrachloroethene, and trichloroethene differ significantly by land use. MTBE, the most frequently detected VOC, was found in 40 percent of wells in urban areas, which was significantly more frequent than in undeveloped and agricultural areas. Nearly all MTBE detections in ground water were in Connecticut and Massachusetts where its use as a gasoline additive is required to reduce atmospheric concentrations of carbon monoxide and ozone from automobile emissions. MTBE concentrations ranged from 0.2 to 2.4 μg/L, well below the 20 μg/L lower limit of the draft lifetime HA. Chloroform was the second most frequently detected VOC. Chloroform concentrations of 0.3 to 3.1 μg/L were measured in 32 percent of wells in urban areas. Tetrachloroethene and trichloroethene were detected only in ground-water samples collected from urban areas.

INTRODUCTION

In 1991, the U.S.Geological Survey (USGS) began full-scale implementation of the National Water-Quality Assessment (NAWQA) Program. A major goal of the NAWQA Program is to identify, describe, and explain, to the extent possible, the major natural and human factors that affect observed water-quality conditions and trends in 59 of the Nation's large, representative river basins and aquifer systems (termed study units) (Hirsch and others, 1988; Leahy and others, 1990). The Connecticut, Housatonic, and Thames River Basins were selected to be one of the first 20 NAWQA study units initiated in 1991, and ground-water-quality data collection and analysis began in 1992.

National NAWQA guidelines call for spatial characterization of water-quality conditions of major aquifers through study-unit surveys, flowpath studies, and land-use studies (Gilliom and others, 1995). Study-unit surveys are intended to broadly characterize ground-water quality in major aquifers across the study units, whereas flowpath studies examine specific relations among land-use practices, ground-water flow, contaminant occurrence and transport, and surface- and ground-water interaction on a local scale. Land-use studies are designed to examine natural and human factors that affect the quality of shallow ground water underlying key types of land use at a scale intermediate to the study-unit survey and flowpath studies. Ground-water land-use studies conducted during 1992-95 for the Connecticut, Housatonic, and Thames River Basins NAWQA study focused on surficial, unconsolidated glacial and alluvial aquifers that are broadly distributed throughout the study unit. These aquifers are important sources of municipal, commercial, and industrial water supplies, and they are highly susceptible to contamination.

Purpose and Scope

The primary objective of the land-use studies is to determine the occurrence (frequency of detection and concentration) and distribution of inorganic and organic water-quality constituents in shallow, recently recharged water (generally less than 10 years old) beneath areas of undeveloped (forested), agricultural, and urban land use. The second objective was to relate variations in ground-water quality to natural and human factors.

This report describes the general hydrogeology of surficial aquifers, including information on differences in lithologic or mineralogic composition, how aquifer composition differs across the study area in relation to parent bedrock, and how these differences affect natural ground-water quality. The report also describes the nature and distribution of undeveloped, agricultural, and urban land use in the study area, and how shallow ground-water quality relates to the three land uses. Information is presented on the occurrence and distribution of inorganic and organic constituents in 172 ground-water samples collected from August 12, 1992 through August 4, 1995, from 120 monitoring wells installed in the uppermost part of surficial aquifers in Connecticut, Massachusetts, New Hampshire, New York, and Vermont. The report relates differences in concentration or frequency of detection for 81 water-quality variables detected at least once in water samples. As many as 177 water-quality variables were measured or analyzed for in some water samples from the 120 shallow monitoring wells.

Previous Investigations

Grady and Garabedian (1991) briefly described the location, physiography, climate, geology, and hydrology of the Connecticut, Housatonic, and Thames River Basins NAWQA study unit and identified the major water-quality issues in this setting. Zimmerman and others (1996) reviewed existing water-quality information for the study unit, provided more detailed information on the environmental setting, and summarized water-, fertilizer-, and pesticide-use information.

Grady and Weaver (1988) and Grady (1989; 1994) related statistical differences in concentration or frequency of detection of 27 water-quality variables, including major inorganic constituents, nutrients, volatile organic compounds (VOCs), and pesticides to human sources associated with one or more of seven land-use categories overlying surficial aquifers in Connecticut. Mullaney and others (1991) found that the occurrence of nitrate and pesticides in shallow ground water in Connecticut was significantly related to agricultural land use, depth of well, and soil organic-matter content. Trombley (1992) found elevated concentrations of chloride, nitrate, and ammonia in water from some public-supply wells in Massachusetts, nearly all of which tap surficial aquifers, and attributed these increases to use of deicing chemicals and fertilizers and to effluent from septic systems. Other investigators have reported specific instances of contamination of surficial aquifers at various locations throughout the study area, particularly from nutrients and pesticides associated with agricultural nonpoint sources (Zimmerman and others, 1996).

Interaquifer comparisons of water-quality data for stratified-drift aquifers in Connecticut (Grady, 1994) showed statistically significant differences for nine inorganic water-quality constituents that were attributed to natural geochemical variations among the different aquifers sampled. Trombley (1992) also reported that different water types related to regional differences in geology. The land-use studies conducted for the Connecticut, Housatonic, and Thames River Basins NAWQA study were designed in consideration of the potential for large variability in natural ground-water quality, particularly for inorganic constituents provided from the weathering of minerals in stratified-drift deposits derived from different types of bedrock in the study unit.

Acknowledgments

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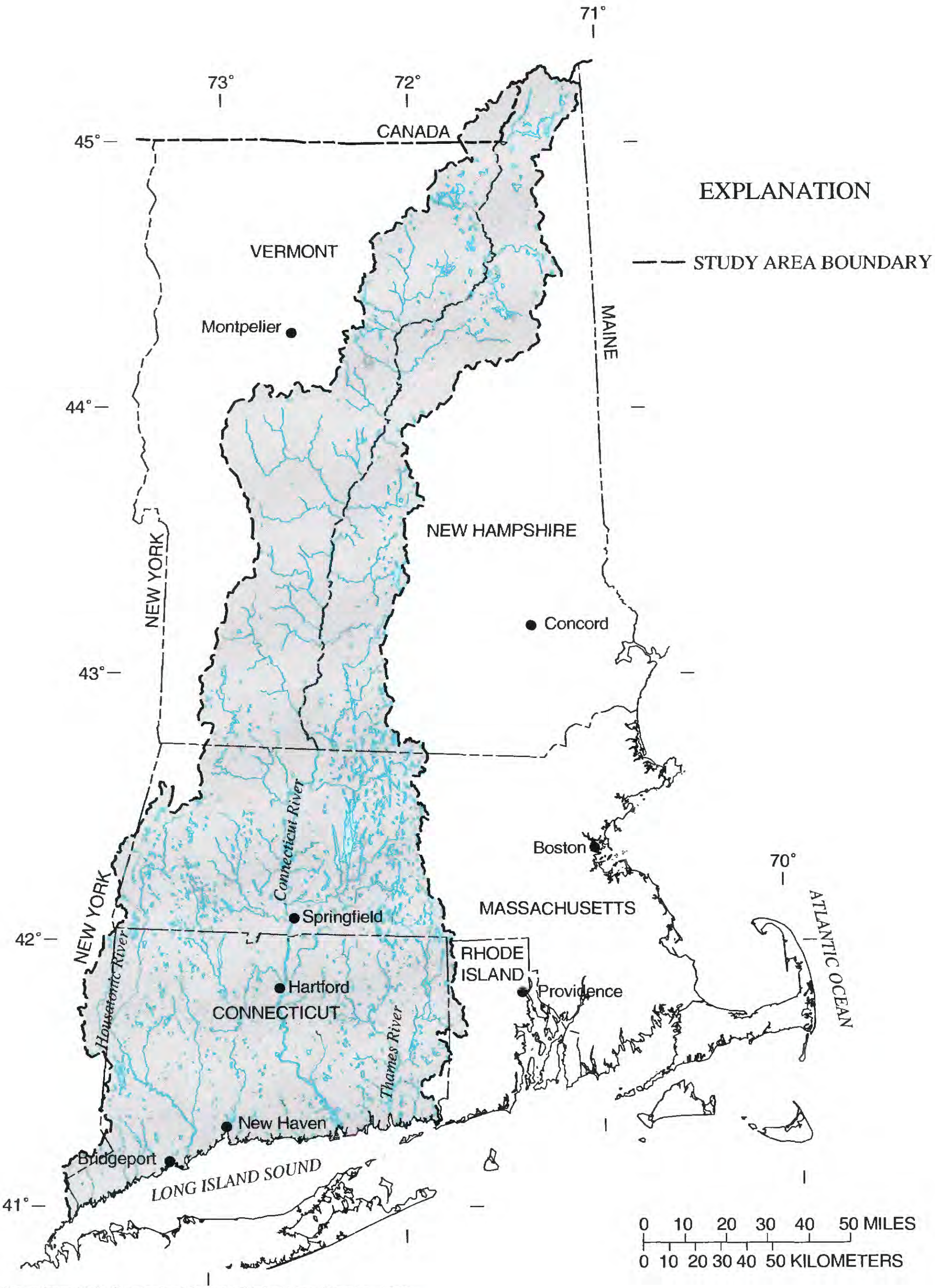
ENVIRONMENTAL SETTING

The study area extends from Canada to coastal Connecticut and includes a 114-mi^2 segment of the Province of Quebec, Canada, 3,928 mi^2 of eastern Vermont, 3,047 mi^2 of western New Hampshire, 3,490 mi^2 in west-central Massachusetts, nearly all (4,853 mi^2) of Connecticut, and small parts of New York (263 mi^2) and Rhode Island (63 mi^2)—an area of 15,758 mi^2. All streams in the study area flow directly to, or are tributary to streams and rivers that discharge into, Long Island Sound (fig. 1).

Two general types of aquifers underlie the study area (fig. 2)—Precambrian to early Mesozoic bedrock aquifers composed of consolidated bedrock of widely different origin and lithology; and Pleistocene to Holocene surficial aquifers composed of unconsolidated glacial and fluvial deposits. Surficial aquifers, in particular coarse-grained glaciofluvial and glaciolacustrine stratified-drift deposits, were targeted for the land-use studies because they best fit the NAWQA design criteria (Gilliom and others, 1995). The NAWQA design specifies that targeted aquifers should (1) be shallow and in the uppermost part of any ground-water-flow system, (2) generally contain water recharged within the previous 10 years, (3) encompass a regionally extensive distribution of targeted land-use categories, and (4) be substantially utilized for water supplies.

Bedrock aquifers primarily store and transmit water through intersecting fractures in consolidated rock. Well yields in fractured crystalline bedrock aquifers depend on the number, size, and degree of interconnection of water-bearing fractures, but commonly range from 2 to 10 gal/min (Olcott, 1995). Bedrock aquifers underlie the entire study area and are an important source of water for self-supplied, rural water users.



Base from U.S. Geological Survey Digital Line Graphs, 1989
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Figure 1. Location of the Connecticut, Housatonic, and Thames River Basins study area.

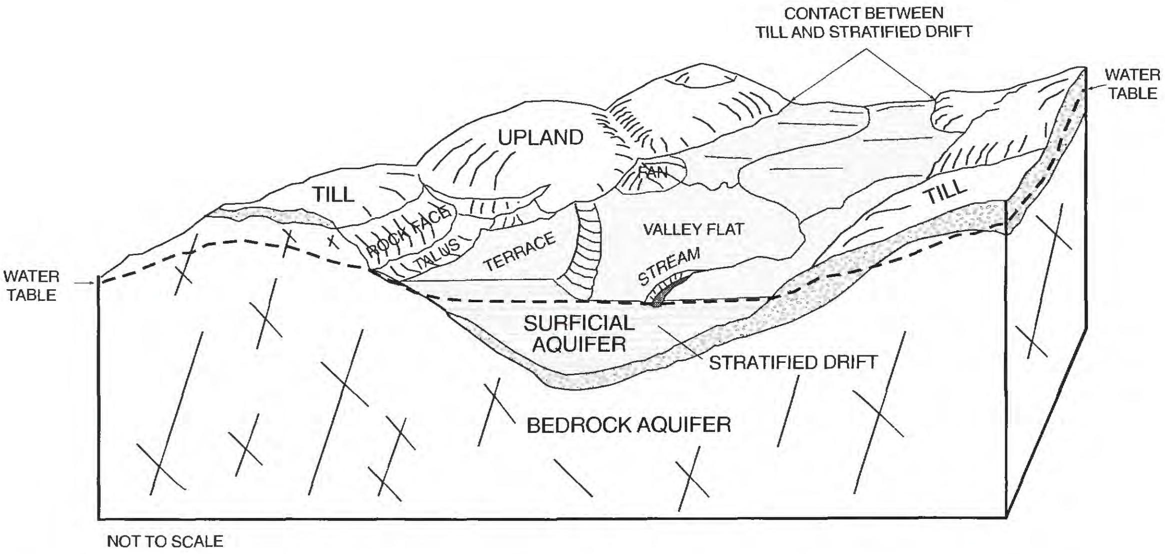


Figure 2. Idealized three-dimensional relations between surficial and bedrock aquifers in the Connecticut, Housatonic, and Thames River Basins (Modified from Frimpter, 1981, fig. 1.)

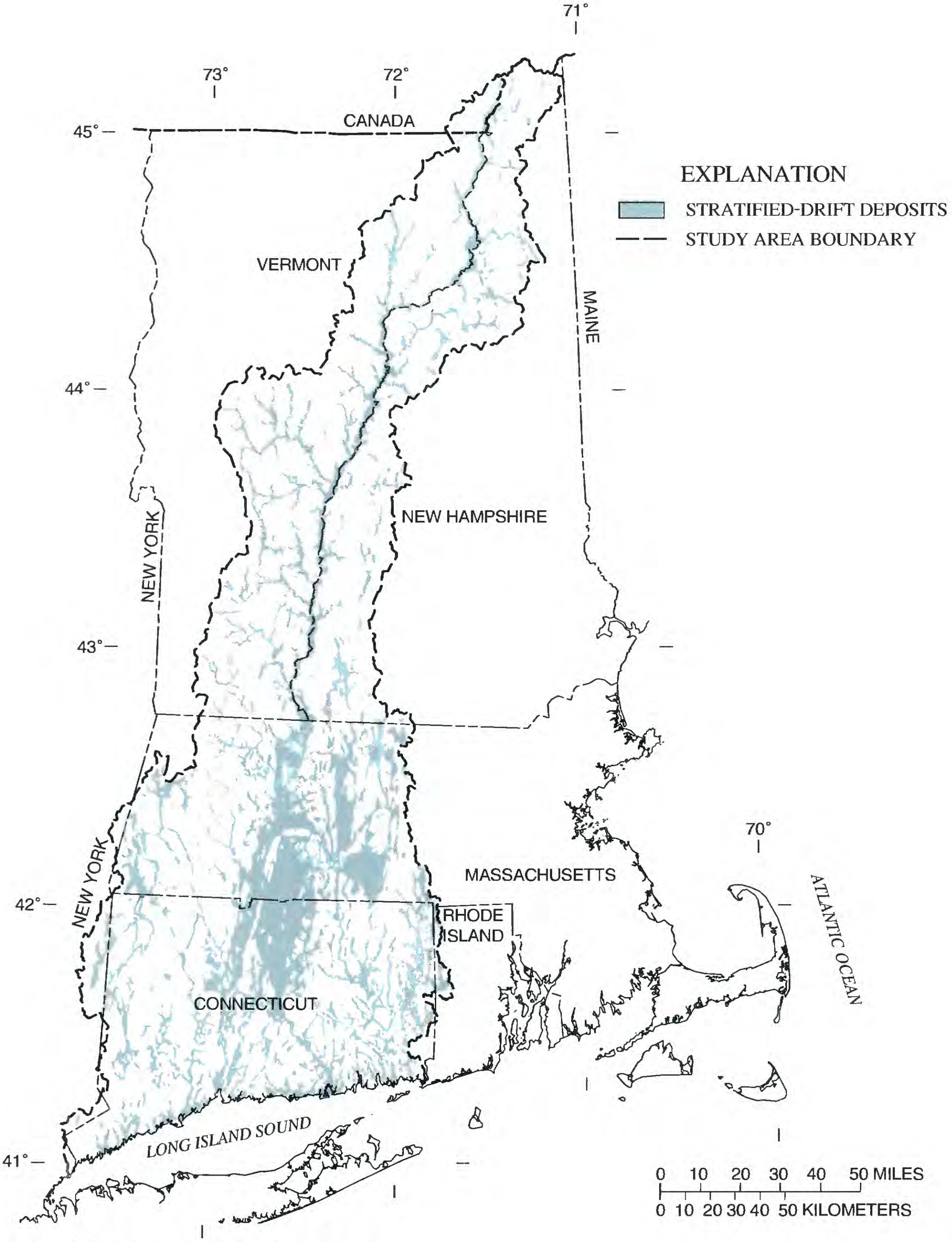
Unconsolidated glacial deposits include till and stratified drift. These sediments were eroded from till and stratified-drift deposits left by earlier glacial advances, from preglacial alluvium or colluvium, and from bedrock. Till is a largely unsorted mixture of boulders, gravel, sand, silt, and clay deposited directly by active ice or through the melting and collapse of stagnant ice, in a generally thin, discontinuous layer that mantles the bedrock. The hydraulic properties of till are not suitable for development of substantial ground-water supplies, and it is not a major aquifer in the study area (Melvin and others, 1992).

Stratified-drift deposits are composed of sediments—boulders, gravel, sand, silt, and clay—that were transported, winnowed, and sorted to some degree by meltwater streams, and largely deposited in proglacial lakes. Where stratified-drift deposits are dominantly coarse grained, their hydraulic properties are generally favorable for development of large ground-water supplies. Stratified-drift aquifers are the most productive sources of ground water in the study area. At some locations in the flood plains of large stream valleys, modern fluvial processes have deposited sediment eroded from bedrock, till, and stratified-drift deposits in thin layers of alluvium. The alluvium often is too thin and discontinuous to form an important aquifer itself, but it is hydraulically connected to and often undifferentiated from the underlying stratified-drift deposits.

Hydrogeology of Surficial Aquifers

Stratified-drift deposits, and the surficial aquifers in these deposits, are widely but unevenly distributed throughout the study area (fig. 3). They are distributed in most of the major and secondary valleys of the study area and are typically elongate, narrow, and thin. Abrupt variations in hydraulic conductivity, thickness, or stratigraphy can disrupt the continuity of surficial aquifers. Individual aquifers, of which there are more than 1,000 in the study area, are small in extent and often less than 100 ft thick. The origin and depositional environment of glacial meltwater deposits strongly affects aquifer geometry and their hydraulic properties. The lithologic composition of stratified-drift sediments can strongly affect water chemistry.

Unconsolidated surficial aquifers store and transmit water through interconnected pores between individual grains of sediment. Differences in the thickness, extent, and permeability of surficial aquifers, along with variations in the proximity and size of surface-water bodies that are sources of recharge, can greatly affect the availability of water to wells. Typical yields of wells in stratified drift are 10 to 400 gal/min, however, yields exceeding 3,000 gal/min have been reported (Olcott, 1995).



Base from U.S. Geological Survey Digital Line Graphs, 1989
Universal Transverse Mercator
1:100,000 scale

Figure 3. Distribution of stratified-drift deposits in the Connecticut, Housatonic, and Thames River Basins. (From Zimmerman and others, 1996, fig. 5.)

Ground water in most surficial aquifers is present under unconfined conditions. Generally, the water table is shallow, a few feet to several tens of feet below land surface. Recharge occurs directly from precipitation that falls on the land surface above the aquifer and infiltrates down to the water table, and from water entering glacial-valley aquifers from upland runoff (Morrissey and others, 1988). The amount of water available annually for recharge (precipitation minus evapotranspiration) ranges from 12 to 30 in. over most of the glaciated Northeast (Lyford and Cohen, 1988). In many locations where large streams cross stratified drift, or where lakes and ponds are present, pumped wells cause induced infiltration from the nearby surface-water bodies. Induced infiltration of surface water is an additional large potential source of recharge to aquifers and can exceed all natural sources combined (Randall and others, 1988).

The extent of surficial ground-water-flow systems in the study area is controlled by the topography. Flow is predominantly localized in shallow flow systems (less than 300 ft deep) between a topographic divide and the closest perennial stream—typically, this is a few hundred to a few thousand feet. Only 5 to 30 percent of large basins in the study area contain major valleys that extend for miles to a few tens of miles between topographic divides (Randall and others, 1988).

Origin and Lithologic Composition of Surficial Aquifers

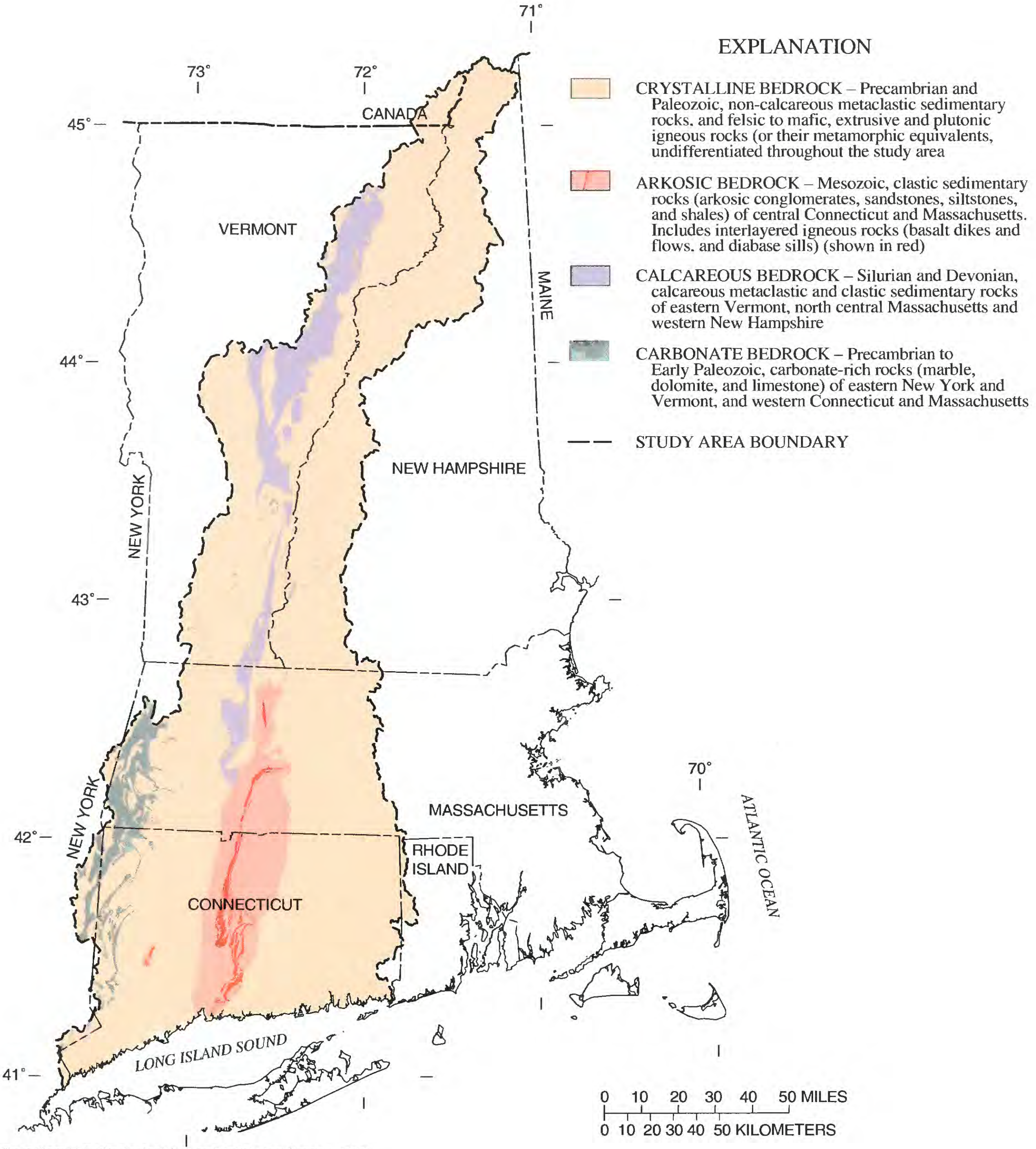
The lithologic composition of surficial aquifers reflect the composition of their source materials—pre-existing glacial stratified-drift and till deposits, preglacial soils, and bedrock. The mineral composition of stratified drift, particularly the coarse-grained (sand and gravel) deposits, has been related to one or more parent bedrock strata in numerous locations in the glaciated Northeast (Krynine, 1937; Randall, 1970; Stone and others, 1979; Stanford, 1989; Force and Stone, 1990). A local origin has been demonstrated for mineral assemblages in till and stratified-drift deposits (Flint, 1961; Newton, 1978; Stone and Force, 1982; Force and Stone, 1990; Melvin and others, 1994) with transport distances of a few miles or less likely for all but the most extensive proglacial meltwater drainage systems.

The lithology and geochemistry of bedrock in the study area is complex and extremely variable. Nearly 600 lithostratigraphic units have been mapped collectively on state bedrock geologic maps (Doll and others, 1961; Fisher and others, 1970; Quinn, 1971; Zen and others, 1983; Rodgers, 1985; Lyons and others, 1986). However, by considering the general geologic character, mineralogic composition and relative reactivity of minerals to weathering, hydrochemical buffering characteristics, the distribution and continuity of units, and structural features (bedding, extent of fracturing, fissility) bedrock units can be classified into 25 categories with broadly generalized chemical and mineralogic characteristics (G.R. Robinson Jr., U.S. Geological Survey, written commun., 1992; J.D. Peper, U.S. Geological Survey, written commun., 1995). These categories were, in turn, further combined and simplified for this study into four general lithologic-composition categories of bedrock (table 1)—crystalline, arkosic, calcareous, and carbonate—largely based on their relative abundance of carbonate minerals.

Delineation of the four bedrock lithologic-composition categories in the Connecticut, Housatonic, and Thames River Basins is shown in figure 4. The crystalline bedrock includes all non-calcareous metaclastic and igneous rocks in the study area. They are largely felsic to mafic metaclastic and metavolcanic rocks (schists, phyllite, slate, granofels, and gneiss) and feldspathic plutonic rocks (granite, quartz monzonite, granodiorite, tonolite, and equivalent gneiss) with little or no carbonate minerals. The arkosic bedrock of the Mesozoic Basin that underlies the Connecticut River Valley lowland in central Connecticut and Massachusetts includes mostly conglomerate, sandstones, siltstones, shales and a few thin limestone

Table 1. Description and lithologic composition of aquifers in the Connecticut, Housatonic, and Thames River Basins

Aquifer type	Description	Lithologic-composition categories
Surficial	Unconsolidated alluvium and stratified drift	Crystalline, arkosic, calcareous, and carbonate
Bedrock	Consolidated, fractured bedrock	Crystalline, arkosic, calcareous, and carbonate



Base from U.S. Geological Survey Digital Line Graphs, 1989
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Figure 4. Distribution of four general lithologic-composition categories of bedrock in the Connecticut, Housatonic, and Thames River Basins.

beds interbedded with basalt flows and diabase dikes; however, diagenesis of these units has produced extensive (13.7 percent of the mineralogical composition) secondary cementation with calcite and ferroan-dolomite (Hubert and others, 1978). The calcareous bedrock of eastern Vermont and north-central Massachusetts generally is grouped with crystalline bedrock because of their similar physical and hydraulic characteristics, but was differentiated for this study because it contains 15 to 45 percent carbonate minerals (J.D. Peper, U.S. Geological Survey, written commun., 1995). The carbonate bedrock (marble, dolomite, and limestone) of the Housatonic River Valley in western Connecticut and Massachusetts has the most carbonate minerals, with bulk compositions of 50 to 100 percent carbonate minerals.

Three bedrock categories—crystalline, arkosic, and calcareous—underlie relatively broad, contiguous tracts of the study area. The fourth category, carbonate bedrock, also is fairly extensive, but its distribution is less contiguous (fig. 4). A simplified lithologic-composition classification for surficial aquifers (table 1) would similarly include crystalline, arkosic, calcareous, and carbonate categories. Wells installed in surficial aquifers from different lithologic-composition categories are expected to yield water with somewhat different chemical compositions. By segregating and statistically comparing water samples from the four categories of surficial aquifers, regional differences in water quality can be related to these natural factors, and the extent of human changes in water quality can be better quantified.

Land Use

Generalized land use in the study area, aggregated to Anderson Level I categories (Anderson and others, 1976), is shown in figure 5. Land-use/land-cover data compiled at a scale of 1:250,000 during 1970-78 was updated using 1990 population data (Hitt, 1994) to indicate new residential (urban) land use. A comparison of Level I land use in the 1970's with data in 1990 indicates that although there has been some expansion of urban areas, particularly in the southern part of the study area, the overall pattern of land use has not changed greatly in the intervening 20 years.

Undeveloped lands (fig. 5), including a large part of the study area that remains forested (74 percent), are the most extensive land use. The largest expanse of forest cover is in the northern part of the study area, including parts of the White and Green Mountain National Forests in New Hampshire and Vermont, but much of the more highly developed southern half of the study area also is covered by forest or woodland. The undeveloped land-use category also includes surface-water bodies, wetlands, rangeland, and other barren lands (about 4 percent of the study area).

Agricultural lands occupy about 12 percent of the study area (fig. 5), including land in tilled cultivation (active, harvested cropland and nonharvested fallow, idle, or cover cropland), pasture or other noncropland used for forage, and areas classified as other agricultural land (feedlots, farmsteads, nonproductive farmland). Major crops produced in the study area are corn, alfalfa, potatoes, tobacco, soy beans, fruit and vegetables, and lesser amounts of small grains, ornamental shrubs, and Christmas trees. Dairy farming, once a principal agricultural enterprise, is decreasing throughout much of the region. In Connecticut alone, the number of dairy farms has decreased from 6,233 in 1940 to 269 in 1997 (G. Moquin, Connecticut Department of Agriculture, written commun., 1997).

Urban lands, including residential, commercial, institutional, and industrial land use; transportation, communication and utility easements and facilities; and mixed or other urban and built-up lands (golf courses, parks, and cemeteries) occupy about 10 percent of the study area (fig. 5). Urban land use is much more extensive in the southern half of the study area, particularly in southwestern Connecticut and the south-central part of the Connecticut River valley. Nearly all (97 percent) of the 68 municipalities with populations of more than 20,000 in 1990, including the principal cities of Bridgeport, New Haven, and Hartford, Connecticut, and Springfield, Massachusetts (fig. 1), are in the southern half of the study area. In 1990, about 4.5 million people lived in the study area (U.S. Bureau of the Census, 1991). Population density averages 285 persons/mi^2 for the study area, but exceeds 1,000 persons/mi^2 on average for 58 municipalities in the study area, and is more than 10,000 persons/mi^2 in parts of some major cities.

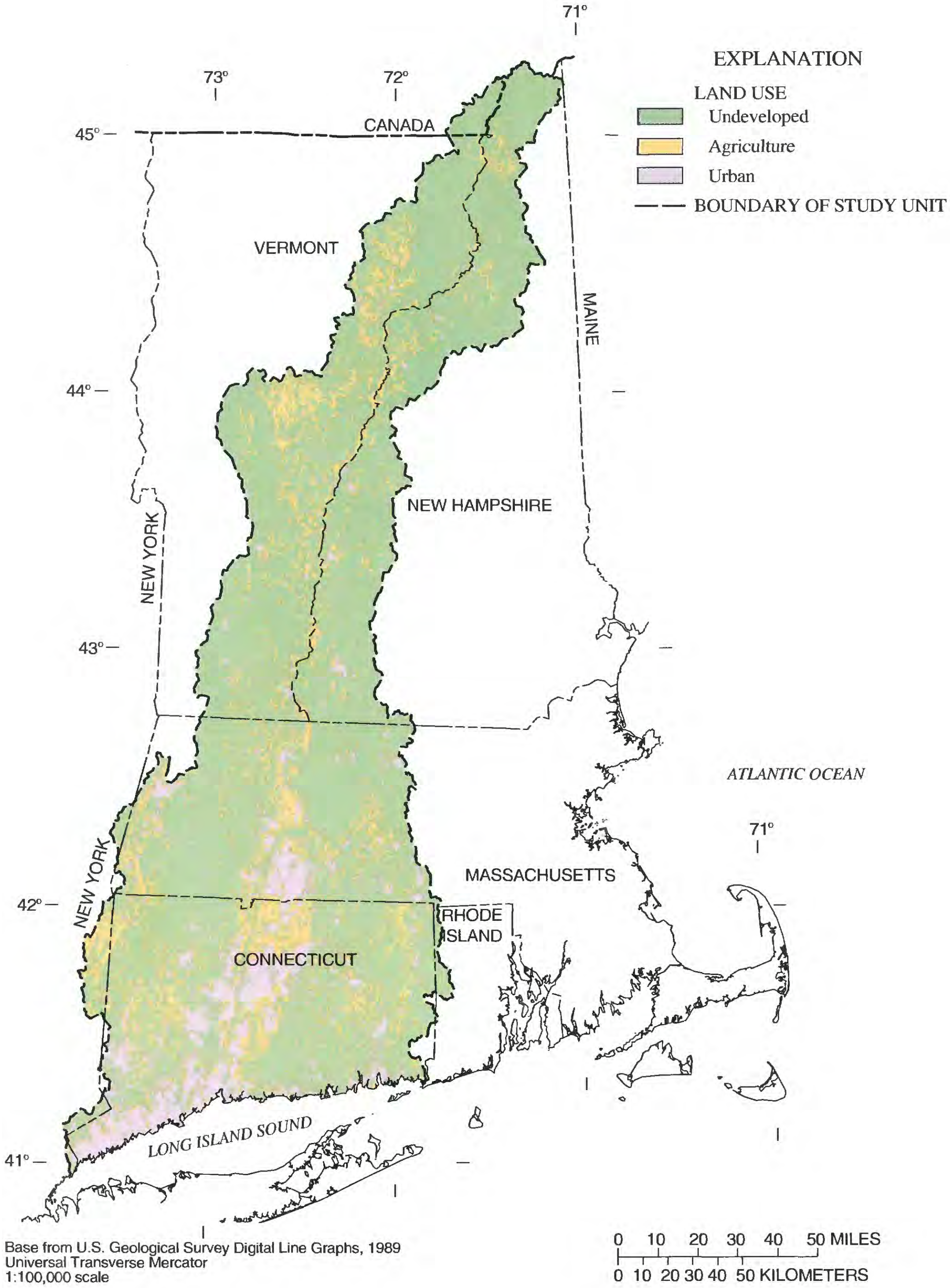


Figure 5. Distribution of undeveloped, agricultural, and urban land use in the Connecticut, Housatonic, and Thames River Basins.

APPROACH

Ground-water, land-use studies were designed and conducted in accordance with national NAWQA guidelines (Gilliom and others, 1995) and data-collection protocols (Koterba and others, 1995; Lapham and others, 1995) to provide nationally consistent data and to produce statistically valid interpretations about the major factors that affect shallow ground-water quality. Although these protocols were intended to foster nationally consistent methods for data collection in all NAWQA study-unit investigations, some modifications or adaptations of the national protocols were used where and when warranted by local conditions. The following sections describe how national protocols were applied or modified in the Connecticut, Housatonic, and Thames River Basins.

Monitoring Well Network

Sampling locations for land-use study wells needed to be randomly distributed throughout the land-use/hydrogeologic setting of interest so that they would provide unbiased information, representative of the overall setting. Other requirements were that (1) wells be located in recharge areas underlying or immediately downgradient from the land use of interest and that (2) the land use has been stable over the past decade. In addition, it was necessary (3) to site new wells or select existing wells that were not affected by any known point source of contamination, and (4) to avoid sites near roads or highways where use of herbicides and road salt may complicate the assessment of water quality in relation to the broader land-use categories. Also, the wells (5) needed to have short screened intervals (less than 10 ft) open to the uppermost part of the ground-water-flow system, (6) be constructed of materials that were compatible with the collection of target analytes, and (7) allow water-quality samples to be collected at a discharge rate of less than 1 gal/min. Small-diameter monitoring wells in the targeted surficial aquifers were used to satisfy these criteria, and most were constructed for this study.

Lack of a comprehensive, consistent, reviewed, and citable geographic information system (GIS) coverage of surficial aquifers in the study area precluded using a GIS-based, stratified-random, site-selection computer program (Scott, 1990) recommended by NAWQA guidelines. Because the pattern of land use in much of the study area is heterogeneous and complex, particularly on a scale comparable with the short, shallow, ground-water-flow systems, random and deterministic processes were used in siting the monitoring wells.

A site-selection method was devised that included delineating and enumerating segments of surficial aquifers for each of the four major lithologic-composition categories—crystalline, arkosic, calcareous, and carbonate. Segments of surficial aquifers of about 2.5 mi^2 were identified and enumerated independently for each aquifer type. A random-number generator was used to sequentially prioritize aquifer segments where from one to three monitoring wells could be sited. At that point in the process, each aquifer segment was evaluated in sequence as determined by the random-number generator, to determine if a monitoring well either already existed or could be installed in or immediately downgradient from a substantial area of undeveloped, agricultural, or urban land use. This process was repeated in each aquifer segment in the order identified by the random-number generator until the network was fully implemented with 120 monitoring wells. Forty monitoring wells were allocated for each of the three land-use categories with 10 wells for each of the four aquifer-lithologic composition categories (table 2).

Table 2. Distribution of monitoring wells by land use and aquifer-lithologic composition in surficial aquifers in the Connecticut, Housatonic, and Thames River Basins

Land use	Aquifer-lithologic composition				
	Crystalline	Arkosic	Calcareous	Carbonate	Total
Undeveloped	10	10	10	10	40
Agricultural	10	10	10	10	40
Urban	10	10	10	10	40
Total	30	30	30	30	120

Only 19 existing monitoring wells in the randomly selected aquifer segments were appropriately constructed for use in the land-use studies. These wells were installed for other USGS studies of ground water and ground-water quality (Mullaney and others, 1991; Grady, 1994; Flanagan, 1996; Olimpio and Mullaney, 1997). The 19 wells were constructed of either stainless steel with 2-foot screens or flush-joint polyvinyl chloride (PVC) with 5-foot screens in accordance with NAWQA protocols outlined by Lapham and others (1995).

A total of 101 new monitoring wells were installed for this study. The new monitoring wells were constructed of flush-joint, 2-inch diameter PVC casing with 5-foot slotted screens, using a hollow-stem auger drill rig. Bentonite pellets were used to seal the annulus around the well from a depth of about 5 ft above the screened interval, and a cement grout and steel protective casing were installed to form a surface seal. Geologist's logs of material present at each site and grain-size analyses of selected soil and aquifer samples collected during well installation are available on file at the East Hartford, Conn., office of the USGS.

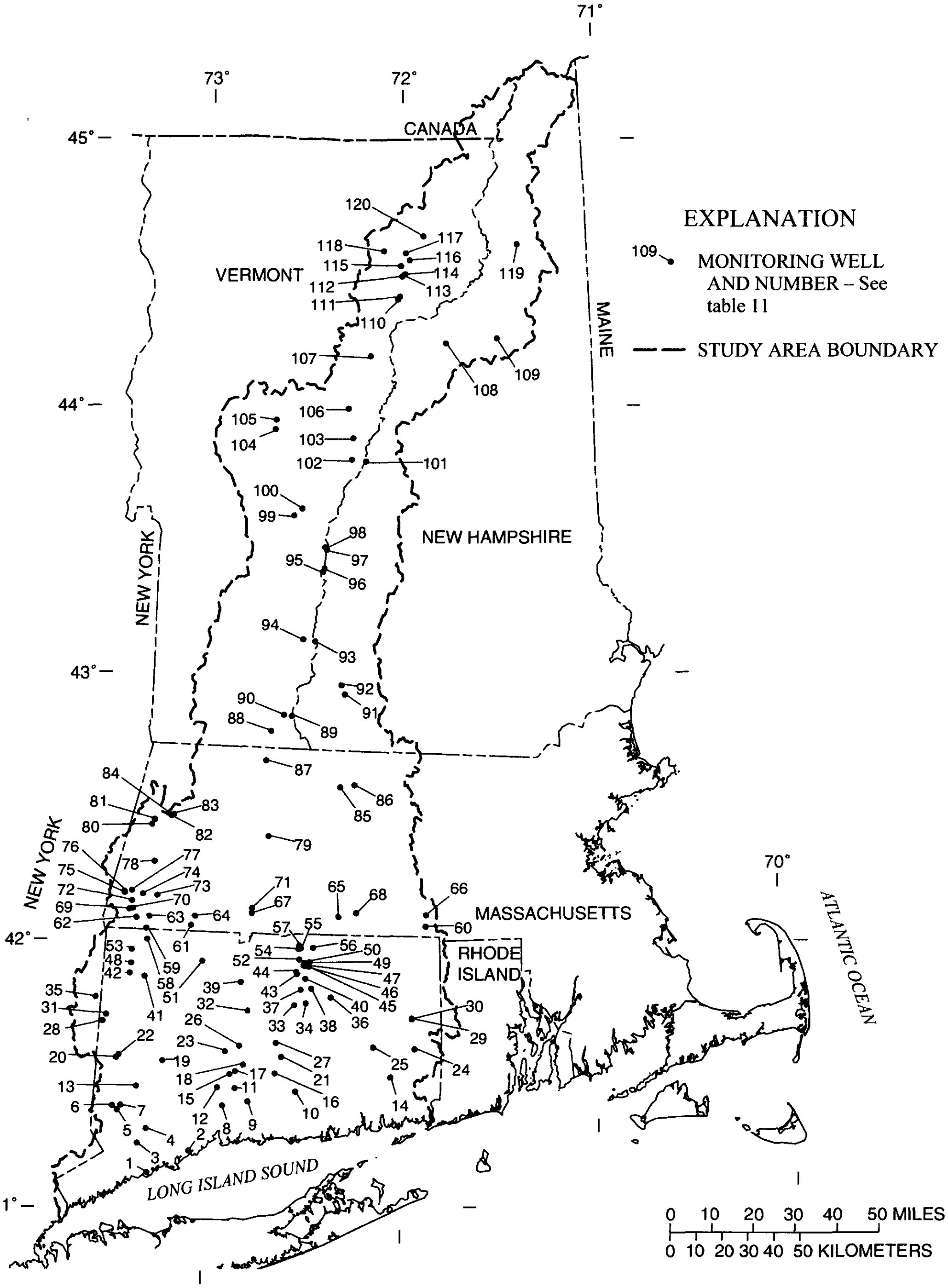
The well network was developed during a 4-year period—17 wells were installed in 1992, 46 wells were installed in 1993, 41 wells were installed in 1994, and the final 16 monitoring wells were installed to complete the network in 1995. Depths of the 120 monitoring wells in the land-use network range from 7 to 54 ft below land surface. Well locations are shown in figure 6, and information on land use, aquifer-lithologic type, dates sampled, and analytical coverage, for each of the 120 wells is tabulated in table 11 (at back of report).

Sample Collection and Analysis

Wells were sampled according to USGS (Claassen, 1982; Busenberg and Plummer, 1987; Wershaw and others, 1987; Fishman and Friedman, 1989) and NAWQA-specific ground-water-sampling protocols (Hardy and others, 1989; Gilliom and others, 1995; Koterba and others, 1995; Lapham and others, 1995). All samples analyzed for organic compounds were collected using sampling equipment constructed entirely of stainless steel and Teflon. Wells were purged of three or more casing volumes, and field measurements of specific conductance, pH, and temperature were monitored until stable, prior to sample collection. Samples for nutrient, pesticide, dissolved organic carbon (DOC), and VOC analyses were chilled and shipped overnight to the USGS National Water Quality Laboratory (NWQL). Laboratory analyses for inorganic, radionuclide, and organic constituents used methods described in Fishman and Friedman (1989); Raese and others (1995); Rose and Schroeder (1995); Zaugg and others (1995); Lindley and others (1996); Werner and others (1996).

A total of 172 ground-water samples were collected from the 120 monitoring wells included in the land-use studies (table 11) from August 17, 1992 through August 4, 1995. Sampling was conducted during a 4-year period similar to and contingent on development of the monitoring-well network—17 samples were collected during 1992, 65 samples were collected during 1993, 74 samples were collected in 1994, and the final 16 samples were collected in 1995. Most wells (75) were sampled once during the study, 38 wells were sampled twice, and 7 wells were sampled on three occasions. Resampling generally was not conducted to evaluate temporal variability but to obtain complete analytical coverage for sites or to replace data on selected VOCs that were affected by systematic or random contamination during 1993.

Not all wells were sampled for all analytes (table 11). Generally, six physical and chemically related properties of ground water (table 3) were measured every time a sample was collected. The 20 inorganic constituents plus DOC (table 3) also were determined for all or nearly all wells. Five radionuclides (table 3), however, only were determined in the 17 wells installed and sampled in 1992 (table 11). Water samples were collected and analyzed for 85 pesticides or their metabolites (table 4) from 103 monitoring wells and for 60 VOCs (table 5) from 86 monitoring wells (table 6). Pesticides and VOCs are associated principally with agricultural and (or) urban land use, but sufficient samples also were collected from undeveloped areas to allow valid statistical comparisons.



Base from U.S. Geological Survey Digital Line Graphs, 1989
Universal Transverse Mercator
1:100,000 scale

Figure 6. Location of 120 monitoring wells installed or selected for the land-use network in surficial aquifers in the Connecticut, Housatonic, and Thames River Basins.

Table 3. Physical and chemically related properties, inorganic constituents, radionuclides, and carbon measured in the field or analyzed at the U.S. Geological Survey National Water Quality Laboratory for water samples collected from monitoring wells in surficial aquifers in the Connecticut, Housatonic, and Thames River Basins, August 17, 1992 through August 4, 1995

[Field sample collection and measurement protocols and laboratory analytical methods are described by Fishman and Friedman (1989); Fishman (1993); Koterba and others (1995); Lapham and others (1995); and Wershaw and others (1987). Units: µS/cm at 25°C, microsiemen per centimeter at 25 degrees Celsius; mg/L, milligram per liter; µg/L, microgram per liter; pCi/L, picocurie per liter]

Property or constituent	Number of wells sampled	Reporting limit(s)
Field Measurements		
Physical and chemically related properties		
Specific conductance (µS/cm at 25°C	120	1.0
pH (standard units)	120	.1
Temperature (°C)	119	.1
Dissolved oxygen (mg/L)	117	.1
Alkalinity as $CaCO_3$ (mg/L)	120	1.0
Bicarbonate (mg/L)	120	1.0
Laboratory Determinations		
Inorganic constituents (mg/L)		
Hardness as $CaCO_3$	120	1.0
Noncarbonate hardness	98	1.0
Calcium	120	.1
Magnesium	120	.1
Sodium	120	.1
Potassium	120	.1
Sulfate	120	.1
Chloride	120	.1
Fluoride	120	.1
Bromide	118	.01
Silica	120	.1
Dissolved solids, residue at 180°C	120	1.0
Nitrite as N	120	.01
Nitrite plus nitrate as N	120	.05
Nitrogen, ammonia as N	120	.01
Nitrogen, ammonia plus organic as N	120	.2
Phosphorus as P	120	.01
Orthophosphate as P	120	.01
Iron (µg/L)	120	3.0
Manganese (µg/L)	120	1.0
Radionuclides (pCi/L)		
Gross alpha radioactivity, dissolved	17	.6
Gross alpha radioactivity, suspended	17	.6
Gross beta radioactivity, dissolved	17	.6
Gross beta radioactivity, suspended	17	.6
Radon-222	17	80
Carbon (mg/L)		
Carbon, dissolved organic as C	119	.1

In addition to environmental samples, 55 quality assurance/quality control (QA/QC) samples also were collected at 32 monitoring wells (table 7). QA/QC samples collected during the study included: 33 field blanks, 5 other (trip or source-water) blanks, 9 field or laboratory spikes (fortified samples), and 8 environmental replicates. All spikes and most of the blanks were analyzed for organic constituents (VOCs, pesticides, and (or) DOC). Environmental replicates were mostly for inorganic constituents, but some radionuclide, DOC, and pesticide replicates also were obtained.

Field blanks indicated that most ground-water samples were not contaminated from any systematic source (for example, by cross contamination among wells or from routine cleaning or handling of sampling equipment, supplies, or samples) for most constituents. Analyses of tetrachloroethene, trichloroethene, toluene, and xylene for 30 samples collected in 1993 suggested cross-contamination had occurred, and all 30 wells were subsequently resampled for VOCs. The suspect samples were flagged in the database and are not used in this report. QA/QC samples also documented that three other VOC compounds, 1,2-dichloroethane, chloroethane, and chloromethane (methyl chloride) were affected by systematic contamination associated with the preservation of NAWQA VOC samples with hydrochloric acid. All data for these three compounds have been flagged in the database and are not used in this report.

QA/QC samples for DOC showed that concentrations in field blanks were not significantly different from DOC concentrations in environmental samples. Use of detergents and methanol to clean the sampling equipment between wells may account for some or all DOC measured in field blanks and environmental samples. Even a small residue of stock methanol remaining on the equipment after cleaning could produce the concentrations measured in field blanks and complicate interpretation of the environmental data. DOC concentrations in ground-water samples varied greatly from site to site, but were relatively consistent for sites where DOC resampling was conducted.

Table 4. Pesticide compounds analyzed for in water samples collected from 103 monitoring wells in surficial aqufiers in the Connecticut, Housatonic, and Thames River Basins, July 29, 1993 through July 31, 1995

[All pesticide analyses were performed by the U.S. Geological Survey National Water Quality Laboratory by solid-phase extraction and capillary-column gas chromatography/mass spectrometry (Zaugg and others, 1995; Lindley and others, 1996), or by high-performance liquid chromatography (Werner and others, 1996). Method detection limits (MDL) and minimum reporting limits (MRL) are compound specific and expressed in micrograms per liter (µg/L). Use: F, fungicide, H, herbicide, I, insecticide; M, metabolite]

Pesticide compound (common chemical name)	MDL (MRL if different)	Use
Acetochlor	0.002	H
Acifluorfen (Blazer)	.035	H
Alachlor (Lasso)	.002	H
Aldicarb (Temik)	.016	I
Aldicarb sulfone	.016	M
Aldicarb sulfoxide	.021 *(.007)	M
Atrazine	*.001	H
Atrazine, desethyl	**.002 *(.001)	M
Azimphos, methyl (Guthion)	**.001	I
Benfluralin (Benefin)	.002	H
Bentazon (Basagran)	.014	H
Bromacil (Bromax)	.035	H
Bromoxynil (Torch)	.035	H
Butylate (Genate plus)	.002	H
Carbaryl (Sevin)	**.003	I
Carbofuran (Furandan)	.003	I
3-OH-Carbofuran	.014	M
Chloramben (Amiben)	.011	H
Chlorothalonil (Bravo)	**.035	F
Chlorpyrifos (Lorsban)	.004	I
Clopyralid (Stinger)	.050	H
Cyanazine	.004	H
Dacthal (DCPA)	.002 *(.001)	H
Dacthal, mono-acid	.017	M
Diazinon	.002	I
Dicamba (Banval)	.035	H
Dichlobenil	**.020	H
Dichlorodiphenyldichloroethylene (*p,p*'-DDE)	.006 *(.001)	M
2,4-Dichlorophenoxyacetic acid (2,4-D)	.035	H
4-(2,4-Dichlorophenoxy) butyric acid (2,4-DB)	.035	H
Dichlorprop (2,4-DP)	.032	H
Dieldrin	.001	I
2,6-Diethylanaline	.003	M
4,6-Dinitro-o-creosol (DNOC)	.035	H,I
Dinoseb (DNPB)	**.035	H,I
Disulfoton	.017	I
Diuron (DCMU)	.020	H
EPTC	.002	H
Ethalfluralin (Sonalan)	.004	H
Ethoprop (Mocap)	.003	I
Esfenvalerate (Asana)	**.019	I
Fenuron (Beet-Klean)	.013	H
Fluometuron	0.035	H
Fonofos (Dyfonate)	.003	I
HCH, *alpha*-	.002	I
HCH, *gamma*- (Lindane)	.004	I
Linuron	.002	H
Malathion	.005	I
MCPA (Metaxon)	.050	H
MCPB (Tropotox)	.035	H
Methiocarb (Mesurol)	.026	I
Methomyl (Lannate)	.017	I
Metolachlor (Dual)	*.002	H
Metribuzin (Sencor)	.004 *(.002)	H
Molinate (Ordram)	.004	H
Napropamide (Devrinol)	.003	H
1-Napthol (Alpha Napthol)	**.007	M
Neburon (Neberex)	.015	H
Norflurazon (Telok)	.024	H
Oryzalin (Surflan)	.019	H
Oxamyl (Vydate)	.018	I
Parathion, ethyl	.004	I
Parathion, methyl	.006	I
Pebulate (Tillam)	.004	H
Pendimethalin (Prowl)	.004	H
Permethrin, *cis*	.005 *(.004)	I
Phorate (Thimet)	.002	I
Picloram (Amdon)	.050	H
Prometon	.018 *(.003)	H
Pronamide (Kerb)	.003	H
Propachlor (Ramrod)	.007	H
Propanil (Stampede)	.004	H
Propargite (Omite)	.013 *(.009)	I
Propham (IPC)	.035	H
Propoxur (Baygon)	.035	I
Silvex (2,4,5-TP)	.021	H
Simazine (Princep)	.005 *(.002)	H
Tebuthiuron (Spike)	.010	H
Terbacil (Sinbar)	**.007	H
Terbufos (Counter)	.013	I
Thiobencarb (Bolero)	.002	H
Triallate (Far-Go)	.001	H
2,4,5-Trichlorophenoxy-acetic acid (2,4,5-T)	.035	H
Triclopyr (Crossbow)	.050	H
Trifluralin (Treflan)	.002	H

*Some reported values are estimated for concentrations equal to or less than the MDL or greater than the calibration range.

**All reported values are estimates because of problems with gas chromatography or extraction.

Table 5. Volatile organic compounds analyzed for in water samples collected from 86 monitoring wells in surficial aquifers in the Connecticut, Housatonic, and Thames River Basins, July 29, 1993 through July 31, 1995

[All volatile organic compound analyses were performed by the U.S. Geological Survey National Water Quality Laboratory using purge and trap capillary gas chromatography/mass spectrometry methods (Rose and Schroeder, 1995; Raese and others, 1995). The reporting limit for all volatile organic compounds is 0.2 µg/L (micrograms per liter) except for dibromochloropropane, which has a reporting limit of 1.0 µg/L]

Volatile organic compound
Benzene
Bromobenzene
Bromochloromethane
Bromodichloromethane
Bromoform
Bromomethane
n-Butylbenzene
sec-Butylbenzene
tert-Butylbenzene
Carbon tetrachloride
Chlorobenzene
Chloroethane
Chloroform
Chloromethane
2-Chlorotoluene
4-Chlorotoluene
Dibromochloromethane
Dibromochloropropane (DBCP)
1,2-Dibromoethane (EDB)
Dibromomethane
1,2-Dichlorobenzene
1,3-Dichlorobenzene
1,4-Dichlorobenzene
Dichlorodifluoromethane
1,1-Dichloroethane
1,2-Dichloroethane
1,1-Dichloroethene
cis-1,2-Dichloroethene
trans-1,2-Dichloroethene
1,2-Dichloropropane
1,3-Dichloropropane
2,2-Dichloropropane
1,1-Dichloropropene
cis-1,3-Dichloropropene
trans-1,3-Dichloropropene
Ethylbenzene
Hexachlorobutadiene
Isopropylbenzene
p-Isopropyltoluene
Methylene chloride
Methyl *tert*-butyl ether (MTBE)
Naphthalene
n-Propylbenzene
Styrene
1,1,1,2-Tetrachloroethane
1,1,2,2-Tetrachloroethane
Tetrachloroethene
Toluene
1,2,3-Trichlorobenzene
1,2,4-Trichlorobenzene
1,1,1-Trichloroethane
1,1,2-Trichloroethane
Trichloroethene
Trichlorofluoromethane
1,2,3-Trichloropropane
Trichlorofluoromethane
1,2,4-Trimethylbenzene
1,3,5-Trimethylbenzene
Vinyl chloride
Xylenes (*meta*-, *para*-, *ortho*-)

The process of collecting a ground-water sample, whereas using exactly the same cleaning procedures as used before collecting field blanks, does normally involve flushing the sample pump with much larger volumes of native water than the amount of rinse water used prior to taking a field blank. DOC concentrations in the field blanks possibly were an artifact of this unavoidable difference in processing blanks and environmental samples. If so, the DOC concentrations in environmental samples would represent actual conditions in the aquifer, or a combination of native DOC plus some variable input of DOC from pre-sample cleaning. Which ground-water samples that may or may not have been affected was impossible to determine; therefore, all DOC data were flagged as suspect but are presented in this report as possible indicators of maximum DOC concentrations.

Low concentrations of 12 inorganic constituents also were measured in field blanks. Most of these constituents were detected only once or twice and at concentrations less than the range of concentrations measured in environmental samples. Three constituents (nitrogen-ammonia as N, phosphorus as P, and silica), however, were detected in one-half or more of the field blanks. Silica concentrations in field blanks (0.01 to 0.04 mg/L) were substantially less than the range measured in environmental samples (3.4 to 35 mg/L) and are inconsequential to interpretations of silica data presented in this report. Concentrations of nitrogen-ammonia as N and phosphorus as P in field blanks (0.01 to 0.03 mg/L) were equal to or slightly greater than the reporting limits for these constituents, and concentrations of many of the environmental samples were similar. Some low-level detections of ammonia and phosphorus concentrations and a few other inorganic constituents detected in field blanks possibly were from concentrations present in the inorganic blank water itself.

Table 6. Distribution of monitoring wells sampled for pesticides and volatile organic compounds by land use and aquifer-lithologic composition in surficial aquifers in the Connecticut, Housatonic, and Thames River Basins

Land use	Aquifer-lithologic composition				
	Crystalline	Arkosic	Calcareous	Carbonate	Total
PESTICIDES					
Undeveloped	7	6	5	5	23
Agricultural	10	10	10	10	40
Urban	10	10	10	10	40
Total	27	26	25	25	103
VOLATILE ORGANIC COMPOUNDS					
Undeveloped	7	5	5	5	22
Agricultural	6	7	6	5	24
Urban	10	10	10	10	40
Total	23	22	21	20	86

Table 7. Land-use category, quality-control sample type, date sampled, and analytical coverage for 55 quality assurance/quality control samples at 32 monitoring wells in surficial aquifers in the Connecticut, Housatonic, and Thames River Basins

[Site identification number is latitude and longitude plus a two-digit sequence number. Local well number is a sequential number assigned to wells inventoried by the U.S.Geological Survey. Analytical coverage: C, dissolved organic carbon; I, physical and chemically related properties, and inorganic chemical constituents; P, pesticides; R, radionuclides; V, volatile organic compounds. Chemical analyses of quality-control samples collected' for the wells are maintained in the U.S. Geological Survey's computer Water Data Storage and Retrieval System (WATSTORE), and are on file in the U.S. Geological Survey's East Hartford, Conn. office]

Map reference No. (fig. 6)	Site identification No.	Local well No.	Land use	Quality-control sample type	Date sampled	Time sampled	Analytical coverage
2	411314073033501	MI 315	Urban	Field blank	02-07-94	1310	V
9	412422072460401	NBR 118	Undeveloped	Replicate	08-27-93	1140	I
				Field blank	08-27-93	1300	I
11	412722072495701	WLD 279	Urban	Field spike	08-05-94	1101	P,V
				Field blank	08-05-94	1230	V
14	413001072025701	PS 137	Agricultural	Replicate	08-10-93	1420	C,P
				Field spike	08-10-93	1425	P
				Field blank	08-10-93	1430	C,P,V
16	413044072375701	MT 394	Agricultural	Field blank	06-24-94	1320	V
				Source-water blank	06-24-94	1330	V
17	413114072495401	ME 219	Urban	Field blank	07-28-94	1400	V
20	413354073253901	NMI 32	Agricultural	Field blank	06-29-94	1500	V
22	413434073245301	NMI 38	Urban	Field blank	04-05-94	1200	V
				Field blank	04-08-94	1130	V
29	414258071562701	PL 471	Undeveloped	Field blank	03-29-94	1130	V
31	414327073285201	KT 45	Urban	Field blank	07-21-95	1030	V
33	414557072320301	M 190	Urban	Field blank	06-14-94	0900	V
				Field blank	06-14-94	1130	C,V
37	414926072300801	V 96	Urban	Field blank	07-26-94	1330	V
38	414942072265601	V 97	Agricultural	Field blank	07-17-95	1106	C,V
42	415249073215901	SR 21	Undeveloped	Field blank	07-18-95	1400	I
44	415329072313501	EW 140	Agricultural	Replicate	08-20-92	1221	I,P,R
				Source-water blank	08-20-92	1222	I
				Field blank	08-20-92	1230	I
				Replicate	08-31-93	1110	P
				Lab spike	08-31-93	1120	V
				Field spike	08-31-93	1130	P,V
				Trip blank	08-31-93	1140	V
48	415504073213601	CRN 26	Undeveloped	Replicate	08-25-93	1015	I
				Field blank	08-25-93	1030	I
50	415542072273601	EL 142	Agricultural	Field blank	07-27-94	1500	C,P
54	415837072305501	EF 125	Agricultural	Field blank	05-05-94	1400	V
59	420302073171501	NKW 54	Agricultural	Field spike	08-24-93	1110	P,V
				Lab spike	08-24-93	1115	V
				Replicate	08-24-93	1120	C
				Field blank	08-24-93	1145	P,V
				Trip blank	08-24-93	1155	V
				Source-water blank	08-24-93	1205	V
60	420347071521801	WLW 72	Urban	Field blank	08-02-94	1200	I
67	420637072451401	WVW 172	Urban	Field spike	08-11-93	1146	V
				Field spike	08-11-93	1147	V
				Replicate	08-11-93	1148	I,C,P
				Field spike	08-11-93	1149	P
				Field blank	08-11-93	1230	C,P,V

Table 7. Land-use category, quality-control sample type, date sampled, and analytical coverage for 55 quality assurance/ quality control samples at 32 monitoring wells in surficial aquifers in the Connecticut, Housatonic, and Thames River Basins—*Continued*

Map reference No. (fig. 6)	Site identification No.	Local well No.	Land use	Quality-control sample type	Date sampled	Time sampled	Analytical coverage
78	421813073150101	LOW 78	Urban	Field blank	08-25-94	1115	I
81	422737073150901	PTW 54	Urban	Field blank	08-26-94	0900	P,V
83	422850073091501	DAW 36	Urban	Field blank	07-13-94	1400	V
85	423511072183801	ORW 70	Urban	Field blank	08-22-94	1330	V
91	425558072171701	KEW 118	Urban	Field blank	07-31-95	1400	I
93	430746072263701	RKW 120	Urban	Replicate	08-12-94	1020	I
94	430813072301901	RKW 121	Urban	Field blank	07-27-95	1130	V
96	432413072235001	CRW 41	Agricultural	Field blank	08-09-94	1045	I
101	434819072110901	TFW 13	Agricultural	Field blank	08-10-94	1100	C,P,V
107	441202072095701	RYW 12	Agricultural	Field blank	08-15-94	1545	C,V
110	442439072012001	SDW 12	Urban	Field blank	08-16-94	1400	I

Analytical results for QA/QC samples from some lots of water used during this study had reported detections of nitrogen-ammonia as N, phosphorus as P, calcium, potassium, sodium, chloride, and silica at concentrations approaching those measured in some field blanks.

Sequential replicate environmental samples were collected to evaluate if field and laboratory procedures were consistent. The variability of most (95 percent) of the replicate analyses was less than 10 percent, but ranged to 69 percent for some replicate nitrogen-ammonia as N, orthophosphate as P, iron, and metolachlor analyses when low concentrations were measured. Most pesticide analytes were not detected in either of the two pesticide replicates. Replicate VOC samples were not collected.

Spiked ground-water samples were collected to provide information on the accuracy and precision of organic analyses, the stability of target analytes during typical sample holding times, and if other natural or manmade compounds that may be in the samples interfere with the analysis for target analytes. Samples from four monitoring wells were spiked in the field with VOCs (two spikes were collected at one site) and samples from two wells were shipped to the NWQL where they were spiked with VOCs (table 7). Samples from five monitoring wells were spiked in the field with pesticide compounds (table 7).

Recovery of VOCs from field-spike samples ranged from 34 to 92 percent and averaged 51 to 79 percent for individual compounds. Recovery values were less than 70 percent for about one-third of the analyses of field-spiked compounds. Recoveries for VOC analytes fortified at the NWQL ranged from 68 to 100 percent and averaged 70 to 98 percent for individual compounds. Recovery values were less than 70 percent for only 4 percent of analyses for laboratory-spiked compound. Degradation of some VOCs prior to analysis or matrix effects associated with some ground-water samples from the study area may have produced an overall negative bias in the VOC data. The QA/QC data, however, were not sufficient to quantify the magnitude of the bias, and none of the data have been adjusted to compensate or correct for the perceived negative effect on VOC concentrations.

Pesticides were analyzed using two different methods—the first (NWQL schedule 2001/2010) uses solid-phase extraction of pesticide compounds from water onto C-18 columns and analysis by capillary-column gas chromatography/mass spectrometry (GC/MS) (Zaugg and others, 1995); the second (NWQL schedule 2050/2051) uses Carbopak-B solid-phase extraction with quantification by high-performance liquid chromatography (HPLC) (Werner and others, 1996). Recoveries reported by Zaugg and others (1995) and Werner and others (1996) for the two methods are 37 to 126 percent and 37 to 88 percent, respectively, but mean recovery for the 2001/2010 method was better (78 percent) than for the 2050/2051 method (61 percent). Recoveries of pesticide compounds in field spikes ranged from 6 to 253 percent and averaged 15 to 193 percent for individual compounds. Mean recovery for the method 2001/2010 field spikes collected at 4 wells was similarly higher (89 percent) than mean recovery for the 2050/2051 method samples (57 percent) collected at three monitoring wells (table 7). Data for nine pesticide compounds (table 4) are reported as "estimated values" by the NWQL because they demonstrate variable performance and recovery.

Statistical Analysis

The land-use studies were designed to provide sufficient numbers of unbiased data on ground-water quality to allow valid statistical inference concerning relations between water-quality variables and natural (aquifer-lithologic composition) and human (land use) factors. Water-quality data typically are not normally distributed because data populations are either bounded at zero or censored at some detection or reporting limit, and commonly are highly skewed with infrequent extreme values or "outliers." Nonparametric statistical procedures are more robust (the power of the test to detect differences between groups of data is high) than traditional methods that assume normal population distributions (Helsel, 1987). Nonparametric statistical procedures (Conover, 1980; Iman and Conover, 1983; Helsel and Hirsch, 1992) have been used to analyze the data collected for the land-use studies.

Four statistical procedures have been used to describe distributions of data grouped by aquifer-lithologic-composition or land-use category, or to test for differences in the concentration or frequency of detection of water-quality variables for each respective grouping. Descriptive statistics that identify the range (maximum and minimum), central tendency (the median), and variation of the data (the interquartile range) have been tabulated (table 12, at back of report) for all water-quality variables detected in ground-water samples. When 25 percent or more of the data are censored, descriptive statistics were estimated where possible using the method of Helsel and Cohn (1988). Boxplots (Velleman and Hoaglin, 1981; Helsel and Hirsch, 1992) were constructed to show differences between groups of data that are uncensored or slightly censored (75 percent or more of the data greater than detection or reporting limits). Boxplots of selected data presented in this report illustrate the 10th, 25th (1st quartile), 50th (median), 75th (3rd quartile), and 90th percentiles of the data distributions, plus values outside of the 10th and 90th percentiles (outliers).

Hypothesis tests were used to test for significant differences in water-quality variables among population groupings. A two-factor analysis of variance (ANOVA) of rank-transformed data for 2 hydrogeologic and 22 uncensored or slightly censored water-quality variables was used to test the null hypothesis that the mean rank (an estimate of the median) of the data from different land-use and aquifer-lithologic groups was equal (Sokal and Rohlf, 1969; Conover and Iman, 1981; Helsel and Hirsch, 1992). Rejection of the null hypothesis at the $\alpha = 0.05$ level of significance was considered evidence supporting the alternative hypothesis, that is, the existence of a relation between the variable and the factor(s) tested. Because the number of wells with data was not the same for all aquifer-lithologic-composition and land-use categories, an unbalanced ANOVA design was required (Helsel and Hirsch, 1992). The general linear models (GLM) procedure was used because it provides a "type III" sums of squares statistic that is valid for unbalanced data (SAS Institute, Inc., 1990).

Tukey's honest significant-difference test (Sokal and Rohlf, 1969; Stoline, 1981; Helsel and Hirsch, 1992), a multiple-comparison procedure, was used to discriminate which group or groups of data by land use or aquifer type differed when the ANOVA procedure rejected the null hypothesis at $\alpha = 0.05$. For all possible pairwise comparisons, the Tukey test uses the within-group variance to calculate the minimum difference in mean rank that is necessary to consider groups significantly different. The overall probability of making a type I error (declaring at least one false difference) is limited to $\alpha = 0.05$ (Helsel and Hirsch, 1992) by the Tukey test.

If censoring is severe (fewer than 25 percent of the data are greater than detection or reporting limits), only categorical methods can be used to statistically evaluate groups of data. Contingency-table tests (Conover, 1980; Helsel and Hirsch, 1992) were used to compare the frequency of detection of 54 moderately to severely censored water-quality variables. Data were tabulated by row and column according to land-use or aquifer-lithologic groupings and whether or not the constituent was detected. The null hypothesis tested was that detection or nondetection of any water-quality variable is independent of the land-use or aquifer-type group. Rejection of the null hypothesis at $\alpha = 0.05$ was evidence of a significant relation between the frequency of detection of the water-quality variable and the factor(s) tested.

Multiway (4 by 2 and 3 by 2) contingency tables were computed for comparisons of detection frequencies by aquifer-lithologic composition and by land-use category. Exact probability determinations for a multinomial distribution were calculated (Sokal and Rohlf, 1969; Conover, 1980; Helsel and Hirsch, 1992) using a computer program (R.B. Alexander, U.S. Geological Survey, written commun., 1989). If a significant difference in the frequency of detection of any water-quality variable was noted from the 4 by 2 or 3 by 2 exact-probability contingency tables, separate 2 by 2 tables for all possible pairwise comparisons were computed to determine which groups of data differed.

If more than one observation of any uncensored variable was made at any well, the median value was used for all descriptive statistics and ANOVAs. If for any well, more than one observation of a censored variable was made, any detection of the variable caused the well to be included in the "number of detections" statistic in table 12 and contingency-table tests. If a censored variable was detected more than once at any well, the highest concentration for samples from that well was used to calculate or estimate descriptive statistics in table 12 and was included in data used to prepare boxplots of censored water-quality variables.

NATURAL AND HUMAN FACTORS AFFECTING SHALLOW WATER QUALITY IN SURFICIAL AQUIFERS

Natural processes and human activities can affect the quality of water at each phase of the hydrologic cycle. Chemical, physical, and biological processes act individually and collectively to produce numerous changes in the quality of water as it moves from the atmosphere, to the land surface, into the subsurface, back out to swamps, streams, lakes, and oceans, and ultimately back into the atmosphere. The natural processes are controlled by climatic, physiographic, geologic, and biological phenomena and produce natural waters with chemical compositions that differ regionally and locally. The effects of human activities are superimposed on waters of different natural composition, and vary considerably, often on a local scale, depending on the nature and intensity of human land and water uses.

Human effects on water quality are often negative and degrade the overall water quality, except where human intervention has been specifically designed to correct the quality of water that has already been substantially impaired by natural or human factors. Human activities, such as those commonly associated with deforestation, agriculture, industrialization, and urbanization, can and frequently have impaired natural water quality (Novotny and Olem, 1994). Common causes of ground-water contamination in the northeastern United States include point sources (municipal and industrial wastewater-effluent discharge to the land; leachate from solid-waste disposal sites; infiltration from concentrated animal feedlots; and leaks and spills from above- and below-ground fuel and chemical storage or transportation facilities) and nonpoint sources (infiltration of wastes and contaminants from logging and chemical or manual deforestation; aerial spraying of insecticides and herbicides in forested, agricultural, and urban areas; infiltration and return flow from irrigated cropland and pasture; infiltration of urban runoff; leaching of septic-tank effluents and exfiltration from sanitary sewers; infiltration of wet and dry atmospheric deposition contaminants and atmospheric diffusion of gaseous contaminants to shallow water tables). By design, any known point-source contamination was intentionally avoided during implementation of the monitoring-well network for this study.

Results of two-factor ANOVA by land use and aquifer-lithologic composition on the rank-transformed data for 2 hydrogeologic and 22 uncensored or slightly censored water-quality variables are shown in table 8. Attained significance levels (p-values) indicate that one of the hydrogeologic variables (depth of well) and 18 water-quality variables were significantly different at $\alpha = 0.05$ for one or more land-use category, and 16 water-quality variables were significantly different for one or more aquifer-lithologic-composition category (table 8). Land use and aquifer-lithologic composition were significant factors for 15 water-quality variables

Table 8. Attained significance levels (p-values) for two-factor analysis of variance on rank-transformed hydrogeologic and water-quality variables compared by land use and aquifer-lithologic composition in the Connecticut, Housatonic, and Thames River Basins

[p-values, the probability that observed differences are due to chance rather than the factor tested, are for SAS General Linear Models type III sum of squares (SAS Institute, Inc., 1990); p-values significant at $\alpha = \mathbf{0.05}$ are shown in **bold**]

Hydrogeologic or water-quality variable	Factor		
	Land use	Aquifer-lithologic composition	Interaction
HYDROGEOLOGIC VARIABLES			
Depth to water	0.3077	0.7341	0.5423
Depth of well	**.0372**	.1002	.9590
WATER-QUALITY VARIABLES			
Specific conductance	**0.0001**	**0.0001**	0.1935
pH	.3607	**.0001**	.8259
Temperature	**.0098**	**.0023**	.6660
Dissolved oxygen	**.0003**	**.0008**	.8817
Hardness as $CaCO_3$	**.0001**	**.0001**	.2384
Noncarbonate hardness	**.0001**	.3163	.4357
Calcium	**.0001**	**.0001**	.3115
Magnesium	**.0001**	**.0001**	.1372
Sodium	**.0001**	**.0090**	.1809
Potassium	**.0022**	**.0006**	**.0443**
Bicarbonate	**.0001**	**.0001**	.7063
Alkalinity as $CaCO_3$	**.0001**	**.0001**	.7047
Sulfate	**.0001**	**.0391**	.1642
Chloride	**.0001**	.2326	.1202
Bromide	**.0001**	**.0358**	.1106
Silica	**.0017**	**.0001**	.1917
Dissolved solids	**.0001**	**.0001**	.3939
Nitrite plus nitrate as N	**.0001**	**.0036**	.8332
Nitrogen, ammonia as N	.4872	.2340	.9812
Iron	.6535	.4122	.8387
Manganese	**.0052**	.3644	.4590
Carbon, dissolved, organic	.6873	.2854	.3566

and only potassium demonstrated significant interaction effects between land use and aquifer lithologic composition. For those variables that are significantly related to one or both of the two factors tested, the lack of a significant interaction means that the effect of land use is identical for all aquifer-lithologic-composition categories; conversely, the effect of aquifer-lithologic composition is identical for all land-use groups. Interaction, which can result from a synergistic (positive) or antagonistic (negative) effect, means that the effects of land use are not consistent for all aquifer-lithologic-composition categories or, conversely, the effects of aquifer-lithologic composition are not the same for all land uses. Further discussion on the implications of significantly different populations for some of the 24 variables compared by ANOVA, and boxplots that display similarities and differences in the sampled populations by land use and aquifer-lithologic composition for selected variables, are presented in the following sections.

Results of contingency-table tests of the frequency of detection by land use and aquifer-lithologic composition for 54 moderately to severely censored water-quality variables are shown in table 9. Attained significance levels (p-values) for eight water-quality variables show a significantly different frequency of detection for one or more land-use category at $\alpha = 0.05$, and six of the variables had significantly different detection frequencies for one or more of the aquifer-lithologic categories. Discussion of the possible sources and significance of these compounds, and histograms showing the differences between detection frequencies for land-use and aquifer-lithologic-composition categories, are presented in the following sections.

Effects of Aquifer-Lithologic Composition on Water Quality

The monitoring-well network for the ground-water land-use studies was designed to distribute the 120 land-use study wells equally among four categories of surficial aquifers on the basis of their lithologic composition, particularly with respect to the carbonate minerals in the aquifer matrix (table 2). The designation of surficial aquifers into one of four lithologic-composition categories—crystalline, arkosic, calcareous, and carbonate—was based on the areal distribution of the parent bedrock of similar lithologic compositions (from published bedrock geologic maps) and general knowledge of the origin of the stratified-drift materials (determined from information on the direction and extent of glacial and meltwater transport). The four general aquifer-lithologic-composition categories were used as a surrogate for detailed quantification of the prevailing geochemical reactions that affect natural water composition.

Table 9. Attained significance levels (*p*-values) for contingency-table tests of the frequency of detection for water-quality variables compared by land use and aquifer-lithologic composition in the Connecticut, Housatonic, and Thames River Basins

[*p*-values, the probability that observed differences are due to chance rather than the factor tested, are for exact probability 3 by 2 (land use) and 4 by 2 (aquifer-lithologic composition) contingency tests; *p*-values significant at α = **0.05** are shown in **bold**. <, actual value is less than value shown]

Water-quality variable	Factor	
	Land use	Aquifer-lithologic composition
INORGANIC CONSTITUENTS		
Fluoride	0.2685	**0.0304**
Nitrite as N	.8756	.7065
Nitrogen, ammonia plus organic as N	1.0000	.7065
Phosphorus as P	.5070	.1712
Orthophosphate as P	.1056	**.0411**
VOLATILE ORGANIC COMPOUNDS		
Benzene	1.0000	0.4771
Bromobenzene	.5349	.7326
Bromodichloromethane	.2558	.7326
n-Butylbenzene	1.0000	.2326
sec-Butylbenzene	1.0000	.2326
Carbon tetrachloride	1.0000	.2326
Chloroform	**.0110**	.1693
1,2-Dibromoethane (EDB)	.5349	.7326
Dichlorodifluoromethane	1.0000	.4767
1,1-Dichloroethane	.1870	.4533
cis-1,2-Dichloroethene	.1870	1.0000
Ethylbenzene	1.0000	.2326
Isopropylbenzene	1.0000	.2326
p-Isopropyltoluene	.4966	.6030
Methylene chloride	.2011	.6126
Methyl *tert*-butyl ether (MTBE)	**.0001**	.0794
Naphthalene	.4752	.1246
n-Propylbenzene	1.0000	.2326
Tetrachloroethene	**.0013**	.6359
Toluene	.4430	.1363
1,1,1-Trichloroethene	.3352	**.0398**
Trichloroethene	**.0339**	.1797
1,2,4-Trimethylbenzene	.1440	.7399
1,3,5-Trimethylbenzene	1.0000	.2326
Xylenes, *meta-*, *para-*, *ortho-*	1.0000	.2326

Water-quality variable	Factor	
	Land use	Aquifer-lithologic composition
PESTICIDES		
Aldicarb sulfoxide	0.6954	0.1747
Atrazine	**<.0001**	.9923
Atrazine, desethyl	**<.0001**	.9259
Benfluralin	1.0000	.4855
Bromacil	1.0000	.4855
Carbaryl	.05507	**.0012**
Carbofuran	.3451	.2427
Dacthal	1.0000	.4855
Dichlobenil	1.0000	.4855
Dichlorodiphenyldichloroethylene (*p,p*'-DDE)	.6325	**.0254**
Dichlorprop	1.0000	.4855
Ethalfluralin	1.0000	.4855
Metolachlor	**.0027**	**.0033**
Metribuzin	.3451	.6094
Napropamide	1.0000	.7379
cis-Permethrin	.3451	.1142
Prometon	**<.0001**	.1891
Propanil	1.0000	.4855
Propargite	1.0000	.4855
Simazine	.1639	.2411
Tebuthiuron	.3451	.1142
Terbacil	.3451	.6094
Triallate	1.0000	.4855
Trifluralin	.3451	.1142

Statistical comparisons of 21 field measurements and inorganic water-quality variables plus DOC by ANOVA (table 8), and 5 inorganic water-quality variables by contingency-table tests (table 9), indicate that the concentrations or the frequency of detection for 18 of the tested variables differ significantly for one or more of the aquifer-lithologic categories. The significant variables include the physical and chemically related properties of specific conductance, pH, temperature, dissolved oxygen (DO), alkalinity, hardness (carbonate but not noncarbonate), and dissolved solids; the major cations—calcium, magnesium, sodium, and potassium; the major anions—bicarbonate, sulfate, and nitrite plus nitrate-nitrogen; silica and bromide. The *p*-values for the ANOVA tests range from 0.0391 to 0.0001, indicating that the aquifer-lithologic composition is a highly significant factor (96.1 to 99.9-percent certainty that the null hypothesis is untrue) in the occurrence and distribution of most major inorganic chemical species and field measurements that define the composition and chemical type of ground water in surficial aquifers in the study area. Differences in the frequency of detection of fluoride and orthophosphate among the four aquifer-lithologic-composition categories also were significant at the 95.9 to 96.9-percent levels.

The relative abundance of major ions in natural ground water from each of the four aquifer-lithologic-composition categories is shown in figure 7. Only data for wells from the undeveloped land-use study were used in the trilinear diagram (Piper, 1944) to avoid confounding natural water types with human effects. Most natural waters from surficial aquifers in the study area are alkaline, calcium bicarbonate types. Even in the absence of a dominant carbonate source, natural waters of low ionic strength are affected by the presence of atmospheric and biologically produced carbon dioxide in soils and incongruent dissolution reactions that yield dissolved bicarbonate as the

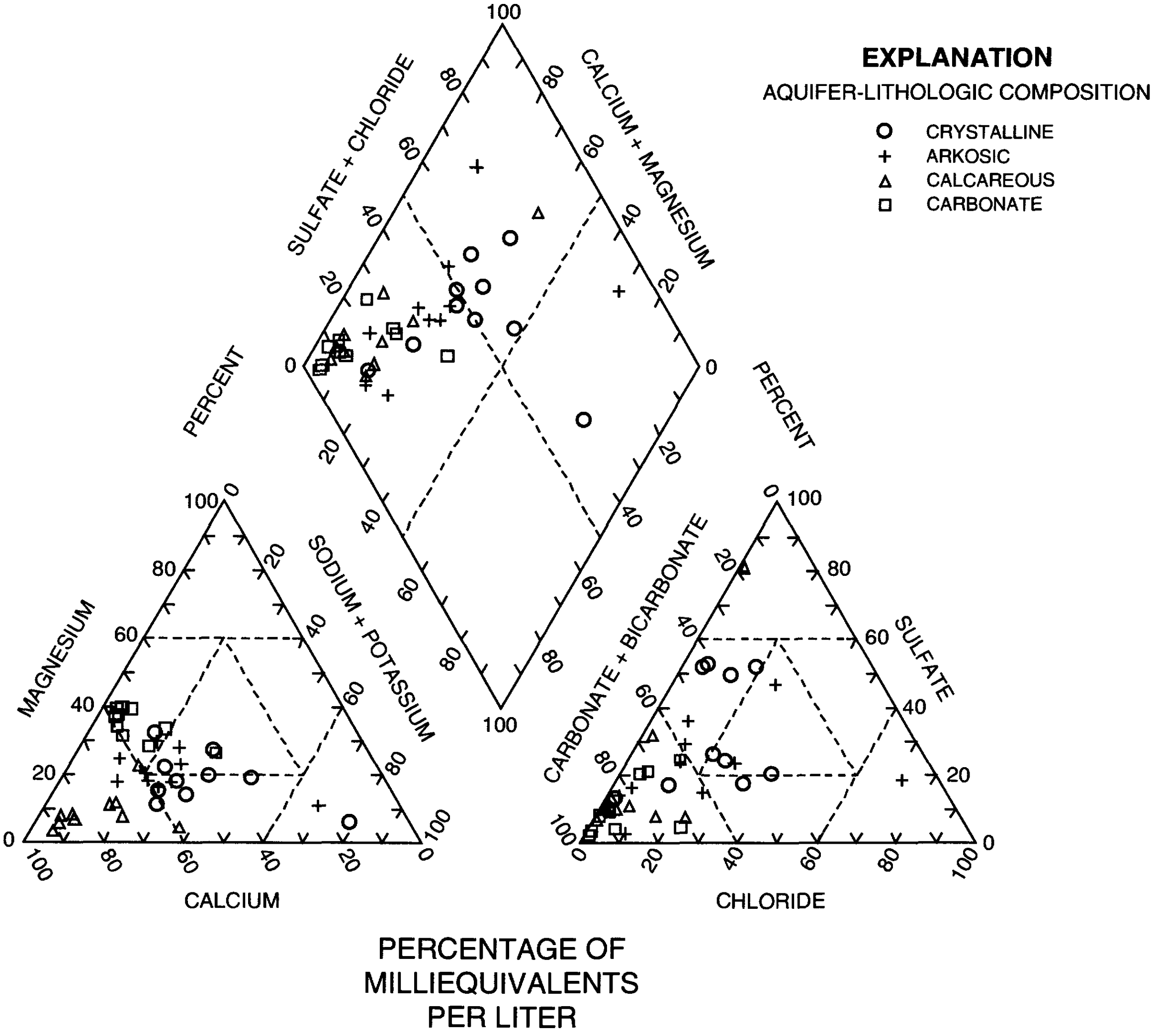
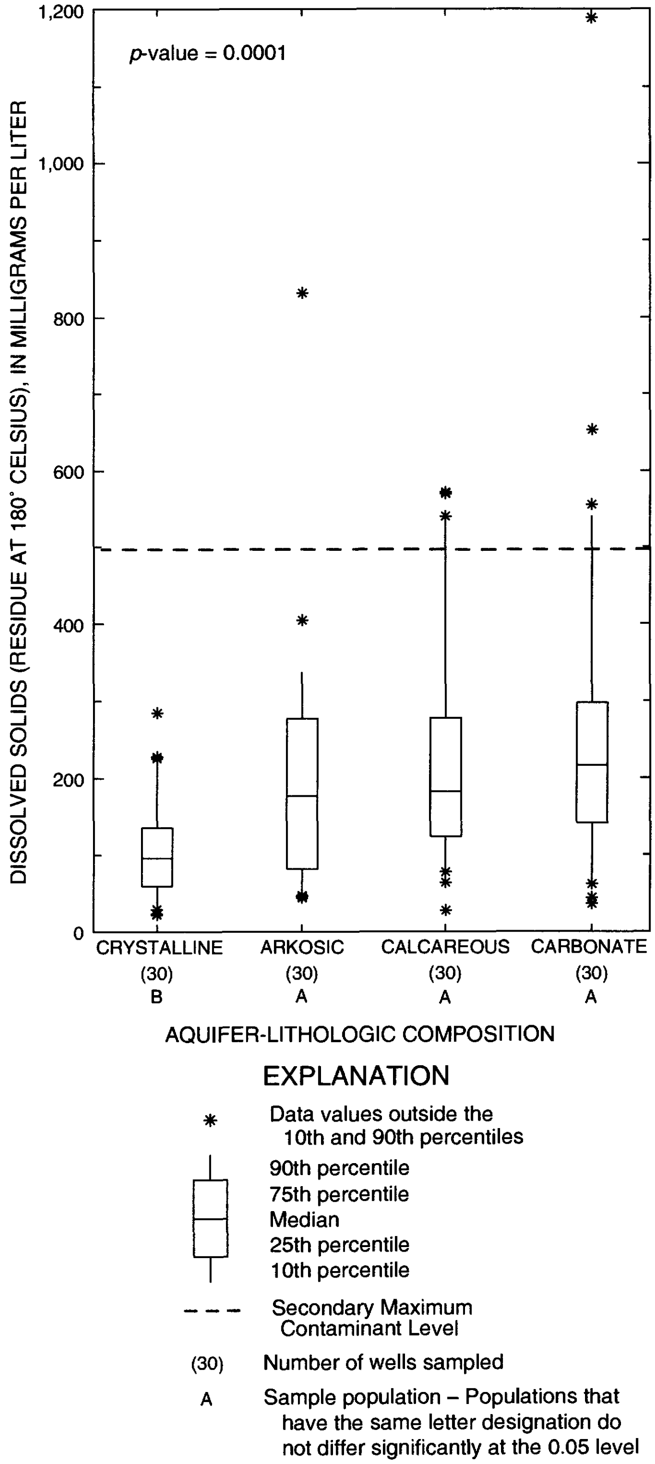


Figure 7. Dominant cations and anions in water samples from natural, undeveloped areas of surficial aquifers relative to aquifer-lithologic composition in the Connecticut, Housatonic, and Thames River Basins.

dominant anion in most fresh waters (Stumm and Morgan, 1981). The plotting position of water samples on the diagram (fig. 7) suggests that there are some important differences among the four aquifer-lithologic categories. Calcium and bicarbonate were the dominant cation and anion species in all samples from the carbonate surficial aquifers, and were prevalent in 90 percent of the calcareous-aquifer samples. Magnesium becomes an important secondary cation in some samples, particularly from the carbonate aquifer, where the carbonate mineralogy includes substantial dolomite ($CaMg(CO_3)_2$). Calcium and bicarbonate were still the dominant ions in 80 percent of the samples from arkosic surficial aquifers and in 60 percent of the crystalline surficial aquifers. However, in a few samples mostly from the crystalline aquifers, sulfate replaced bicarbonate in importance, and two samples were sodium sulfate or sodium chloride types.

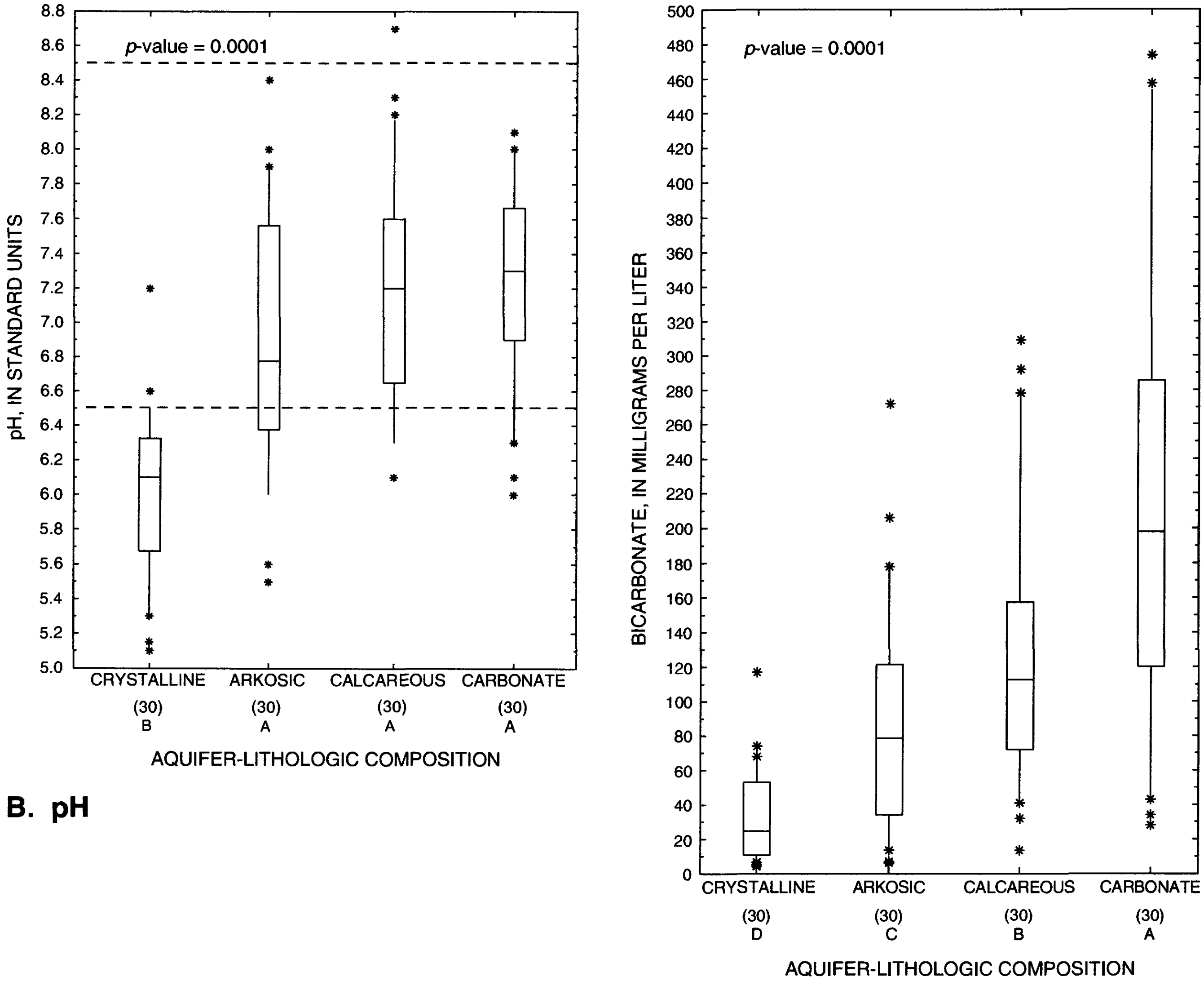
Boxplots comparing measurements or concentrations of several physical or chemically related properties and inorganic constituents of ground-water samples from surficial aquifers, among the four lithologic-composition categories (figs. 8*A*-*E*), also demonstrate how aquifer-lithologic composition affects water quality. Data shown in boxplots include analyses of samples from all land-use wells in each aquifer-composition category. This aggregation was done to provide a statistically valid population size for each aquifer, but does result in the mixing of natural and human factors in the data presented. However, because wells were distributed equally by land-use category for each aquifer, and the results of the two-factor ANOVA for all uncensored or slightly censored water-quality variables except potassium indicate that there was no significant aquifer-composition—land-use interaction, the comparisons are unbiased and valid.

Although figure 7 showed that most of the water in surficial aquifers was a calcium bicarbonate type, substantial and significant differences can be seen (figs. 8*A*-*E*) in the total concentration of dissolved constituents. The median dissolved-solids concentration (and correspondingly, the specific conductance of water samples) was significantly less for samples from crystalline aquifers than the three other surficial aquifers. The reason dissolved-solids concentrations were less in water from the crystalline aquifers is that the overall chemistry of these waters are controlled by the lower solubility of the predominant aluminosilicate mineralogy relative to carbonate



A. Dissolved solids

Figure 8. Measurements or concentrations of physical and chemical related properties and inorganic constituents in water samples from surficial aquifers relative to aquifer-lithologic composition in the Connecticut, Housatonic, and Thames River Basins. *A*. Dissolved-solids concentrations. *B*. pH. *C*. Bicarbonate. *D*. Calcium. *E*. Magnesium.

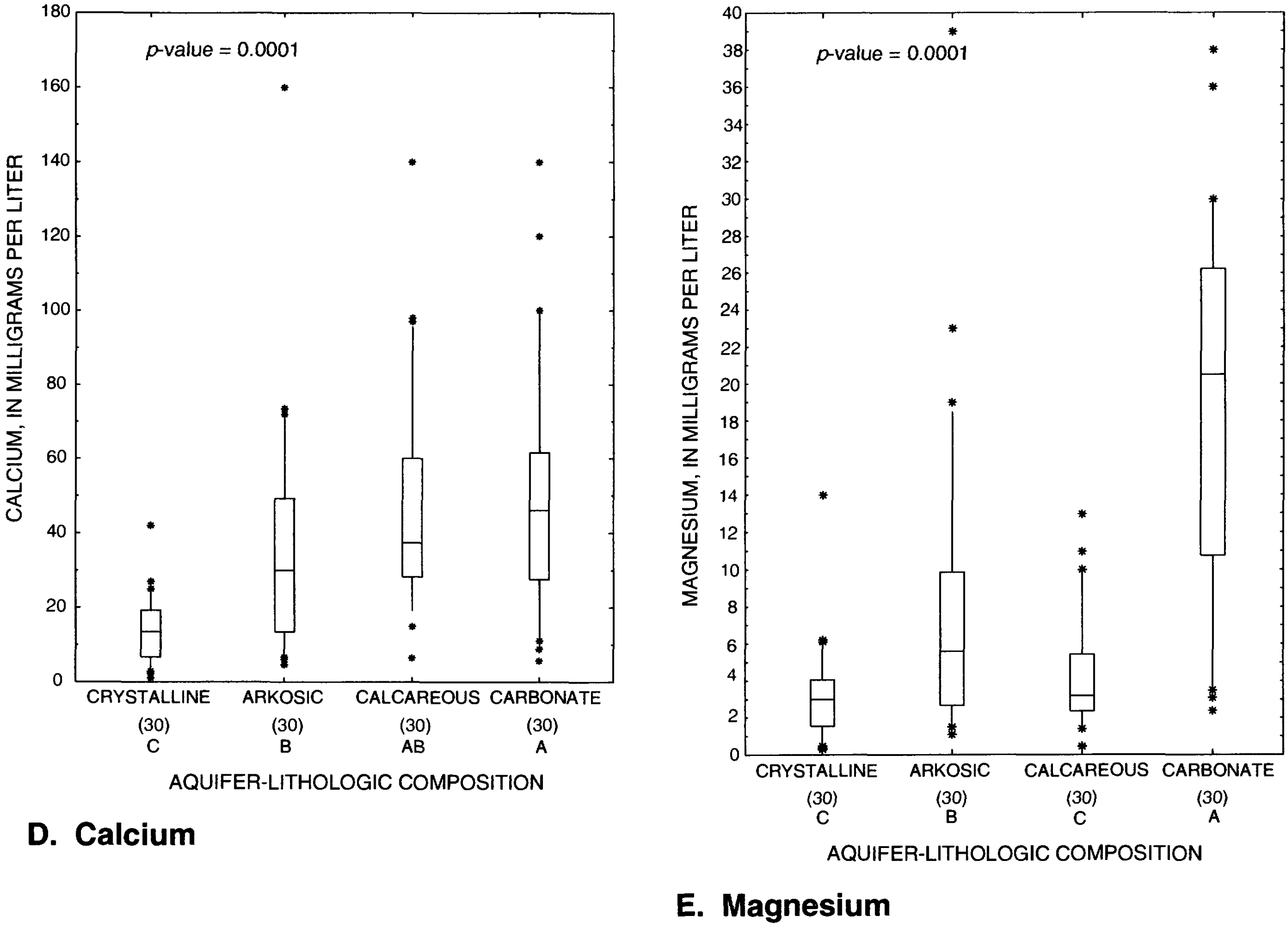


B. pH

C. Bicarbonate

Figure 8. Measurements or concentrations of physical and chemical related properties and inorganic constituents in water samples from surficial aquifers relative to aquifer-lithologic composition in the Connecticut, Housatonic, and Thames River Basins—*Continued.*

minerals. The median dissolved-solids concentration for water from the crystalline surficial aquifers was 96 mg/L, and the interquartile range, a measure of the variation or spread in the data, and the maximum value were just 76 and 286 mg/L, respectively (table 12). Median dissolved-solids concentrations increased progressively from 177 mg/L for water from the arkosic aquifers to 216 mg/L for water from the carbonate aquifers and the concentrations for the arkosic, calcareous, and carbonate surficial aquifers were not significantly different from each other. Maximum dissolved-solids concentrations in water from the arkosic, calcareous, and carbonate aquifers ranged from 572 to 1,190 mg/L, and about 9 percent of the samples from these three aquifers exceeded the U.S. Environmental Protection Agency's (USEPA) Secondary Maximum Contaminant Level (SMCL) of 500 mg/L for total dissolved solids.



D. Calcium

E. Magnesium

Figure 8. Measurements or concentrations of physical and chemical related properties and inorganic constituents in water samples from surficial aquifers relative to aquifer-lithologic composition in the Connecticut, Housatonic, and Thames River Basins—*Continued.*

pH values were neutral to alkaline in most waters from surficial aquifers. pH of waters in surficial aquifers also reflects the enhanced presence of carbonate minerals in the carbonate, calcareous, and arkosic aquifers relative to the siliceous mineralogy of the crystalline aquifers (fig. 8*B* and table 12). Carbonate-mineral dissolution leads to concentrations of carbonate and bicarbonate ions that provide a natural acid-buffering capacity to natural waters and produces pH values in the neutral (at or near 7.0 units) to somewhat alkaline range (greater than 7.0 to about 8.5 units). Median pH of water for the arkosic, calcareous, and carbonate surficial aquifers were 6.8, 7.2, and 7.3, respectively, and were not significantly different from each other. The median pH of 6.1 units for water samples from the crystalline aquifers was, however, significantly less than medians from all three other surficial aquifers. This pH was mildly acidic and less than the SMCL of 6.5 to 8.5 for potable water supplies, intended to minimize the potential for leaching metals from plumbing by chemically aggressive, low pH waters.

A comparison of bicarbonate concentrations among the four surficial aquifers shows that four separate and significantly different sample populations are evident for each aquifer-lithologic-composition category (fig. 8*C* and table 12). Median bicarbonate concentrations for samples from arkosic, calcareous, and carbonate surficial aquifers were 3.2, 4.7, and 8.2 times higher than the median bicarbonate concentration

(24 mg/L) for the crystalline waters. The resolution of bicarbonate and alkalinity data (table 12) into four significantly different populations represents the large differences in the relative abundance of carbonate minerals in each surficial aquifer.

Further evidence of the effect on water quality by carbonate minerals can be seen by comparing the concentrations of calcium among the four aquifer lithologic-composition categories (fig. 8*D* and table 12). Calcium concentrations were similar to those for bicarbonate concentrations (fig. 8*C*) in that median concentrations increased progressively from the crystalline (14 mg/L) to the carbonate (46 mg/L) aquifer categories, and the median concentrations were significantly higher in the arkosic, calcareous, and carbonate surficial aquifers than the crystalline aquifers. Calcium concentrations differ from bicarbonate concentrations in that the calcareous aquifer was not significantly different from either arkosic or carbonate aquifers. The interpretation of this distribution is that there is more calcium available for dissolution into ground waters for the arkosic, calcareous, and carbonate aquifers than for the siliceous crystalline aquifer.

Although the carbonate surficial aquifers have the most carbonate minerals (and the highest median calcium concentration in water samples), the replacement of calcium ions by magnesium ions in the carbonate-mineral structure, which occurs during dolomitization of limestones, reduces the relative amount of calcium available to weathering. Magnesium concentrations were highest in ground water from the carbonate surficial aquifers (fig. 8*E*), which are derived in large part from dolomitic rocks in the Housatonic River valley (fig. 4). Water from the calcareous aquifers has much lower magnesium concentrations. The median magnesium concentration for the calcareous aquifer was significantly different from the carbonate aquifer but not significantly different from the crystalline aquifer. Magnesium concentrations were significantly higher in waters from the arkosic surficial aquifers than the calcareous and crystalline aquifers because they also are affected by the dolomite and ferroan-dolomite ($CaMgFe(CO_3)_2$) cementation that fills the interstitial openings in the arkosic sedimentary rocks (Hubert and others, 1978).

The weight ratio of calcium to magnesium in nearly pure calcium carbonate rocks is about 50:1 but decreases to about 1.7:1 in pure dolomites (Garrels and Mackenzie, 1971, p. 237). The calcium-to-magnesium ratio in waters from aquifers containing calcite and dolomite can vary greatly depending on the distribution of these minerals along ground-water-flow paths, and can be affected by sequential or incongruent dissolution, the partial pressure of carbon dioxide, temperature, and cation exchange reactions (Freeze and Cherry, 1979). The ratio of calcium to magnesium in ground water relative to aquifer-lithologic composition is shown in figure 9. The ratio in the calcareous aquifer was significantly higher than in all other surficial aquifers. The median

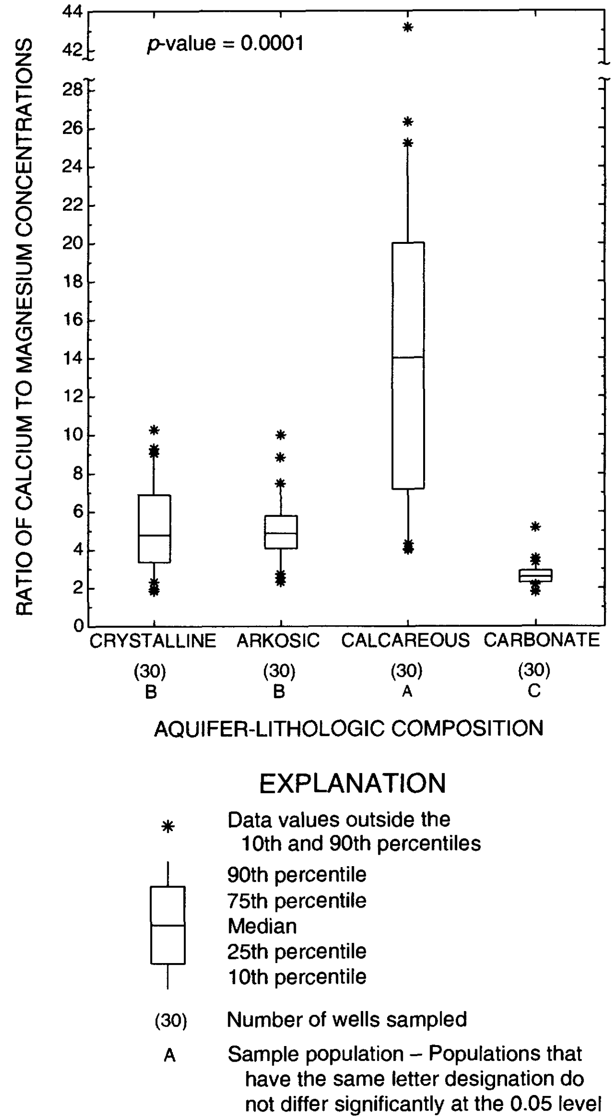


Figure 9. Ratio of calcium to magnesium concentrations in water samples from surficial aquifers relative to aquifer-lithologic composition in the Connecticut, Housatonic, and Thames River Basins.

calcium-to-magnesium ratio of 14 and ratios that range as high as 43.2 in waters from the calcareous aquifers are most similar to those characteristic of the mineral calcite. Ground water from the carbonate surficial aquifers had the lowest calcium-to-magnesium ratios, ranging from 1.8 to 5.2 and were significantly lower than arkosic and crystalline aquifers. The low ratios for the carbonate aquifer are, therefore, representative of a predominantly dolomite source.

Concentrations of other inorganic constituents also differ significantly in relation to surficial aquifer lithology. Median silica, sodium, and sulfate concentrations were significantly higher in the water samples from the arkosic aquifer than one or more of the other three surficial aquifers (although the Tukey multiple comparison test could not differentiate among sulfate populations, the samples from the arkosic aquifers had the greatest median and minimum sulfate concentrations). The median silica (as SiO_2) concentration was 15 mg/L and concentrations ranged to 35 mg/L in water samples from the arkosic surficial aquifers; they were significantly higher than silica concentrations in the calcareous, carbonate, and crystalline aquifers (table 12). Elevated silica concentrations in water samples from the arkosic surficial aquifers may be explained in part because the parent arkosic bedrock is composed predominantly (about 40 percent) of feldspar and clay minerals (Hubert and others, 1978). The arkosic mineralogy is, therefore, somewhat more likely to weather than the highly indurated quartz and secondary feldspar mineralogy of the igneous and metamorphic crystalline-bedrock fragments in the crystalline surficial aquifers. The calcareous and carbonate aquifers yield the lowest median dissolved silica concentrations.

Median sodium concentrations were significantly higher for the arkosic aquifer than the crystalline and carbonate aquifers, but sulfate concentrations were only slightly higher in ground waters from the arkosic surficial aquifers than the other aquifers. Anhydrite ($CaSO_4$) and gypsum ($CaSO_4 \bullet 2H_2O$) and molds of halite (NaCl) and glauberite ($Na_2Ca(SO_4)_2$) have been reported in some lakebeds among the Mesozoic arkosic strata (Krynine, 1950; Hubert and others, 1978); however, these minerals would not have likely persisted through glacial erosion, transport, and weathering to still be present in the arkosic surficial aquifers. Oxidation of detrital pyrite (FeS_2) and barite ($BaSO_4$) are the most probable sources of sulfate in both arkosic surficial and bedrock aquifers (Rogers, 1987). However, sodium and sulfate concentrations were elevated in some ground water in the arkosic bedrock aquifers (Ryder and others, 1981; Rogers, 1987), and circulation in the bedrock aquifers possibly may infiltrate and mix with waters in the surficial arkosic aquifers in some locations.

Conversely, the median potassium concentration was slightly but significantly lower in waters from the arkosic aquifers than for the other three surficial aquifers. The median potassium concentration was 1.4 mg/L for water samples from the arkosic surficial aquifers compared to median concentrations of 2.0 to 3.0 mg/L for the other aquifer-lithologic-composition categories (table 12). Arkosic surficial aquifers might be expected to yield waters with high potassium concentrations because of the relative abundance of potassium feldspar minerals in the arkosic aquifers; however, the formation of potassium-rich clay minerals in the arkosic surficial aquifers may be removing the potassium from the arkosic sediments.

Although the concentrations of bromide from surficial aquifers in the study area were all low, and generally within the range reported for concentrations in precipitation (5 to 150 µg/L) (Hem, 1985), the two-factor ANOVA rejected the null hypothesis that the bromide concentrations are the same for all four surficial aquifers. Bromide populations were not differentiated with application of the Tukey test, however, bromide was detected most frequently (87 percent) in samples from the arkosic aquifer and least frequently (60 percent) in samples from the calcareous aquifer (table 12).

The detection frequencies of orthophosphate as P and fluoride differ significantly when compared by aquifer. Two-by-two contingency-table tests indicate that the detection of orthophosphate in 66 percent of the water samples from the arkosic surficial aquifers (table 12) was significantly higher than orthophosphate detections in 16 percent of the calcareous and 30 percent of the water samples from the crystalline aquifers. Two-by-two contingency-table tests could not resolve differences in the frequency of fluoride detections for any combination of interaquifer comparisons, however, fluoride was most frequently detected (33 percent) in water samples from arkosic aquifers and least frequently detected (10 percent) in samples from the crystalline aquifers (table 12). The elevated frequencies of fluoride and orthophosphate in water samples from the arkosic aquifer may relate to a possible increased abundance of some minor accessory mineral(s), such as fluorite (CaF_2) and fluorapatite ($Ca_5(PO_4)_3F$).

Three other water-quality variables, nitrite plus nitrate as N, DO, and water temperature, also differed significantly by aquifer-lithologic composition. Median nitrite plus nitrate as N, DO concentrations, and the median water temperature were all highest for water samples from the arkosic surficial aquifers (table 12). Nitrite plus nitrate and DO concentrations were lowest in the carbonate aquifers and were significantly lower than in the arkosic aquifers. Although nitrogen and DO can be strongly affected by human activities, those activities are not likely to be the cause for the differences in concentrations among the surficial aquifers. The interaction factor for the ANOVA comparisons for these variables was not significant. Water temperatures in the arkosic aquifer were significantly higher than in the calcareous aquifer and are likely an artifact of geographic and physiographic differences in the study area. The arkosic aquifers are all in or adjacent to the relatively mild temperate zone in the Connecticut Valley Lowland in Connecticut and south-central Massachusetts, whereas the calcareous aquifers underlie river valleys in the cooler northern mountainous regions of eastern Vermont and western New Hampshire.

The lack of any significant differences in some water-quality variables compared by aquifer-lithologic composition also is noteworthy. Although the median chloride concentration was slightly higher for water samples from the arkosic aquifers than the other surficial aquifers (table 12), it was not significantly different. The slightly elevated chloride concentrations in water samples from the arkosic aquifers may reflect a maritime effect as a result of the aquifers proximity to Long Island Sound. The lack of significance by aquifer-lithochemical composition was expected because chloride in shallow ground water commonly is an indicator of human sources.

Elevated concentrations of iron and manganese, two widespread natural ground-water-quality problems in the Northeast, are endemic to all four aquifer-lithologic-composition categories (table 12). Iron concentrations exceeding 300 µg/L and manganese concentrations exceeding 50 µg/L, the USEPA's SMCL's for each constituent (U.S. Environmental Protection Agency, 1996), were measured in 12 and 48 percent of all wells, respectively. Iron concentrations exceeded the SMCL in 7 percent of water samples from the arkosic aquifers and 20 percent of water samples from the carbonate aquifers, whereas manganese concentrations exceeded the SMCL in 33 percent of samples from arkosic aquifers and 57 percent of samples from the calcareous and carbonate surficial aquifers. The highest iron (22,000 µg/L) and manganese (5,800 µg/L) concentrations measured during this study were from samples from wells in crystalline aquifers near swampy areas.

High concentrations of naturally occurring radionuclides (radon and uranium) are a human health concern. The USEPA has proposed radon and uranium drinking water MCLs of 300 pCi/L and 20 µg/L, respectively (U.S. Environmental Protection Agency, 1996). In some parts of the study unit, crystalline bedrock includes rocks that are relatively enriched with uranium (Olszewski and Boudette, 1986), and high concentrations of radon (median radon-222 activity of 6,470 pCi/L) have been reported (Dupuy and others, 1991) in ground water from metamorphosed sedimentary and igneous rocks underlying southeastern Connecticut that contain more than 20 parts per million of uranium.

Few data are available on the occurrence of radionuclides in ground water from surficial aquifers in the study unit, but five radionuclides (table 3) were measured in water samples from 17 monitoring wells installed for this study in 1992 in Connecticut, Massachusetts, and Vermont (table 11). Too few data were collected to statistically compare the occurrence and distribution of the radionuclides by surficial aquifer-lithologic composition and land-use categories in the same manner as data on other water-quality variables presented in this report. The 17 wells sampled for radionuclides in this study include only three aquifer-lithologic-composition categories and two land uses (table 12). However, 30 domestic or institutional water-supply wells in fractured crystalline-bedrock aquifers also were sampled during 1995 for radon for the study-unit survey component of the Connecticut, Housatonic, and Thames River Basins NAWQA study.

Data on the activity of radon-222 in the 17 water samples from surficial aquifers are compared to the 30 water samples from crystalline bedrock aquifers (fig. 10) to show the relative magnitude of this natural water-quality problem for each aquifer type.

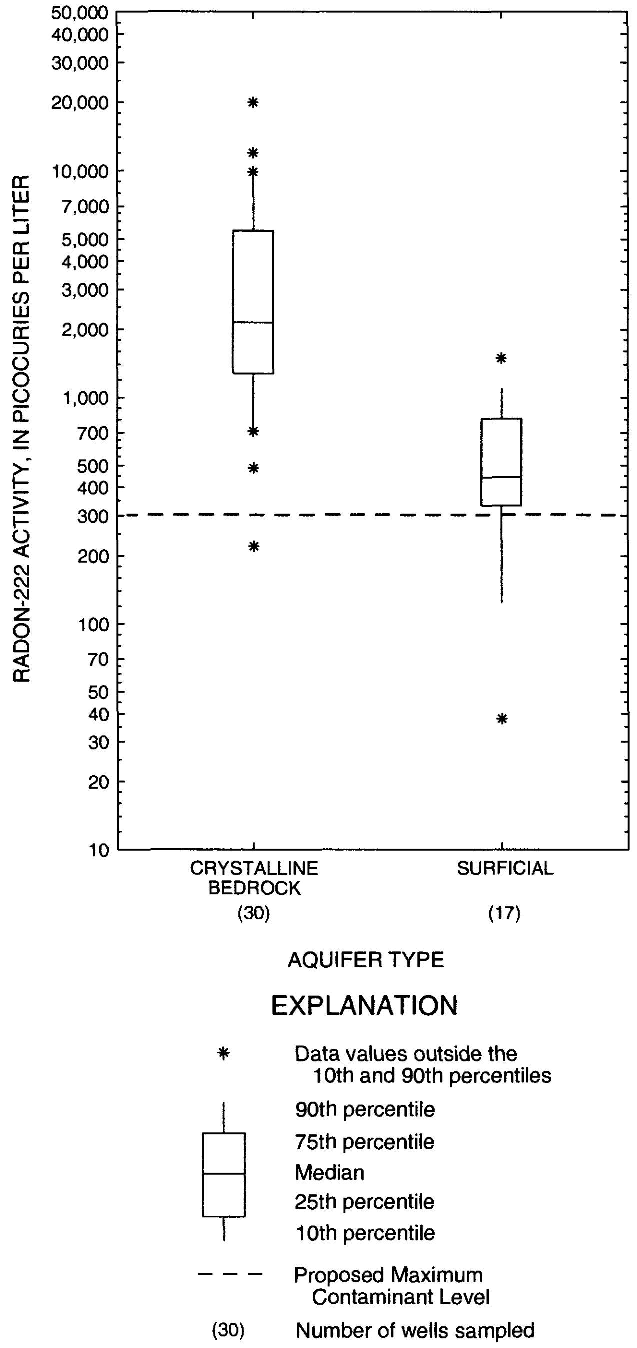


Figure 10. Radon-222 activities in water samples from crystalline bedrock and surficial aquifers in the Connecticut, Housatonic, and Thames River Basins.

Median radon-222 activity was 440 pCi/L for water samples from the 17 shallow monitoring wells in surficial aquifers, and 82 percent of the water samples from these wells exceeded the proposed MCL of 300 pCi/L. Median radon-222 activity was 2,150 pCi/L for water samples from the 30 water-supply wells in crystalline bedrock aquifers, and 97 percent of the water samples from these wells exceeded the proposed MCL. Median radon-222 activity exceeded 1,000 pCi/L in only 18 percent of the water samples from wells in surficial aquifers, but 88 percent of the water samples from wells in crystalline bedrock exceeded 1,000 pCi/L and two samples (7 percent) exceeded 10,000 pCi/L. Overall, radon-222 activity exceeded the proposed MCL in 94 percent of water samples from 47 wells in bedrock and surficial aquifers sampled in the study unit. The radon-222 activities were similar to those reported by Dupuy and others (1991) for a large sample of wells in crystalline bedrock (2,530 pCi/L) and a few wells in the surficial aquifers (about 480 pCi/L) in Connecticut. Uranium was not included in the analyses for the surficial-aquifer samples, but it was detected in 60 percent of the bedrock wells, with one detection exceeding the proposed MCL of 20 µg/L.

Effects of Land Use on Water Quality

The principal objective of the land-use studies was to describe and evaluate differences in shallow ground-water quality in relation to land use. By knowing the extent of the variations in water quality that can be ascribed to natural differences in the lithologic composition of the aquifers, evidence of the extent of human effects on water quality can be more accurately evaluated.

Statistical tests of the relation between water quality and three broadly defined land-use categories—undeveloped, agricultural, and urban—are presented in the absence of quantified data on the type and volume of contaminants that may be introduced by human activities associated with an area of relatively uniform demographic features. Land use integrates a host of human factors that affect water quality, including population density, housing density, number of septic systems per unit area, percentage of impervious area, traffic patterns, street and highway maintenance practices, construction practices and condition of sanitary sewers, vegetative cover, tillage practices, farm animal density and feeding practices, and nutrient and pesticide application rates. Because many of these factors cannot be quantified readily, and may differ substantially from one area to the next, land-use categories were used as a surrogate for identifying and quantifying specific contaminant sources.

The null hypothesis tested is that there was no significant difference in the concentration or frequency of detection of each variable compared by land use. The value of testing this hypothesis is greatly enhanced by the presence of water-quality data beneath largely natural, undeveloped areas. Rejection of the null hypothesis typically was caused by higher concentrations or more frequent detections of water-quality constituents in ground-water samples associated with either or both the agricultural and urban land uses than in samples from undeveloped areas. Where this effect occurs, it is considered direct evidence of manmade contamination of ground water. Because certain types of contaminants are associated with specific human practices in agricultural or urban areas, the following sections discuss separately the effects of land use on the occurrence of inorganic constituents, pesticides, and VOCs in ground water.

Statistically significant differences in concentration or the frequency of detection associated with one or more of the three land-use categories for 18 of the 22 water-quality variables were compared by ANOVA (table 8), and 8 of the 54 variables were compared by contingency-table tests (table 9). One hydrogeologic variable—depth of well—differed significantly (table 8) when compared by land use. Because differences in water-quality variables can relate to the depth of wells sampled, it was necessary to first address this observation.

The median depth of wells in undeveloped areas is 5 ft less than those in urban areas (fig. 11; table 12). Depth is somewhat more variable in wells in undeveloped areas, as a group, than in agricultural and urban wells. In particular, three of the undeveloped wells were installed at depths less than 10 ft below land surface. This variability probably reflects the somewhat larger topographic and hydrogeologic variability in undeveloped settings than is typical of the more developed agricultural and urban areas. Undeveloped sites include some locations near the aquifer boundaries and, occasionally, swampy lowland

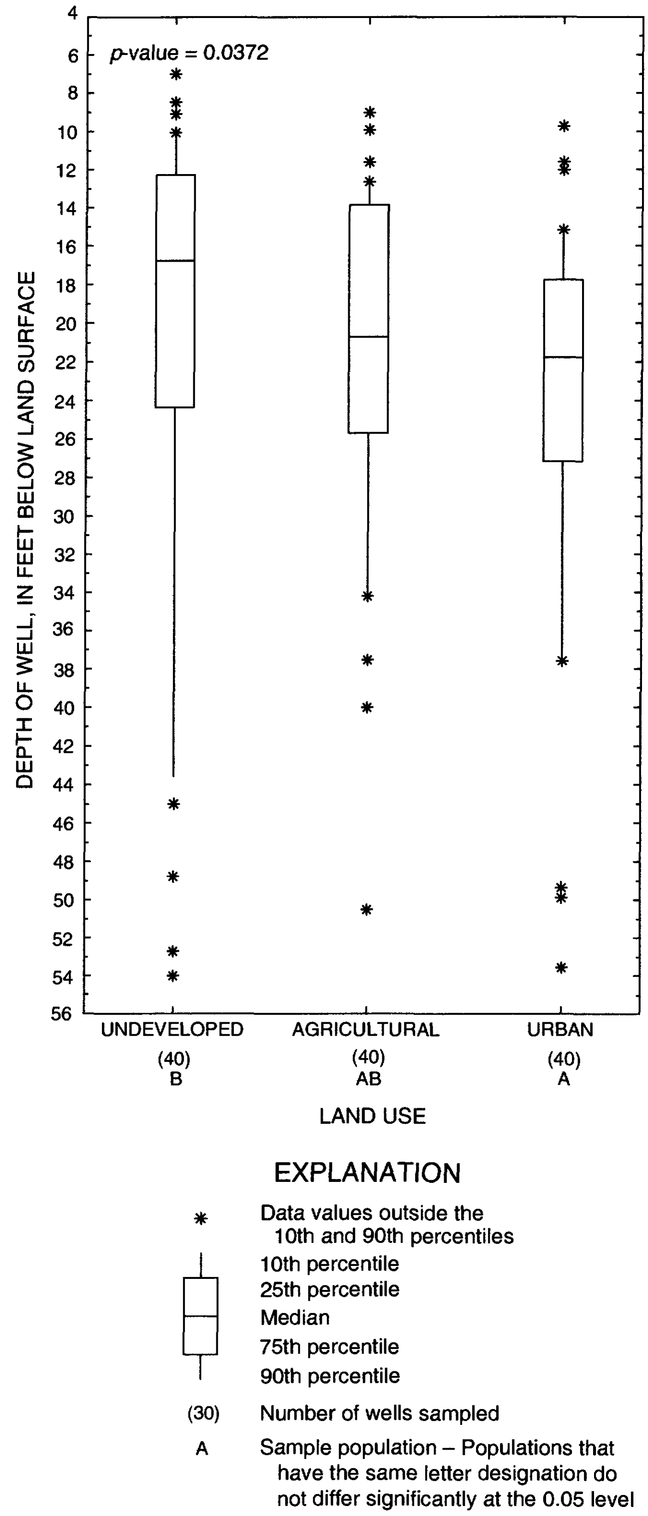


Figure 11. Depth of monitoring wells in surficial aquifers relative to land use in the Connecticut, Housatonic, and Thames River Basins.

areas. Agricultural land use is frequently in relatively flat floodplain and valley terrace settings. Urban areas were largely developed away from lowland areas prone to flooding and typically are concentrated on the high terraces and other appropriate building locations. The relatively small difference in depths among the land-use wells is not considered to be an important factor in the interpretation of the water-quality data. Moreover, depth to water does not differ significantly among the three land-use categories (table 4; table 12).

Inorganic Constituents

Eighteen inorganic constituents and physical and chemical properties of water were significantly different by land-use category (table 8). For most of these constituents and properties (15), median concentrations or measurements are lowest for the ground-water samples from the undeveloped areas and the highest for samples from the urban areas (table 12). Median DO concentrations reflect a reverse pattern with the highest for undeveloped areas and lowest for urban areas. Median concentrations of nitrite plus nitrate also were lowest in the undeveloped areas, but the highest median concentrations were in agricultural areas rather than urban areas.

The variability of most water-quality constituents by land-use categories similarly is consistent with the pattern for median concentrations. Most constituents showed the least variability (as measured by the interquartile range) for ground-water samples from undeveloped areas and the most variability in the samples from urban areas (table 12). The small interquartile ranges for most constituents of the ground-water samples from undeveloped areas can be interpreted to mean that human contaminants were rarely present in these samples. Natural water-quality variations are small and largely are artifacts of differences in lithologic composition and ground-water residence times. The variability of the data for agricultural and urban areas includes natural variations in water quality but also is affected by differences in the extent and magnitude of human sources, which may or may not be present at all sites. Consequently, the conclusion can be made that ground-water quality in surficial aquifers beneath undeveloped, mostly forested areas of the study area is largely unaffected by human activities, whereas the quality of ground water beneath agricultural, and especially urban areas, is significantly affected. Ground-water-quality data in undeveloped areas represent natural, background conditions, which can be compared to ground-water-quality data in agricultural and urban areas to quantify the magnitude of human effects.

Dissolved solids (as well as the related physical property of specific conductance) is a widely used indicator for evaluating the overall chemical quality of water and a convenient means of comparing water from different sources. The concentration of dissolved solids includes all major solutes in a water sample that were not volatilized during the analytical process of heating and evaporation. The median concentration of dissolved solids for the urban areas (217 mg/L) was more than twice that of the undeveloped areas (98 mg/L) (fig. 12). Fifteen percent of the samples from urban monitoring wells exceeded the 500 mg/L SMCL (U.S. Environmental Protection Agency, 1996). Three distinct sample populations are evident in figure 12; dissolved-solids concentrations in agricultural areas were significantly higher than the undeveloped areas but significantly lower than urban areas. Elevated dissolved-solids concentrations in ground-water samples from urban areas represent the cumulative effect of human activities and practices, such as the application of highway deicing chemicals, lawn and garden soil treatments, and the use of septic systems and sanitary sewers that may release or leak inorganic constituents such as sodium, chloride, calcium, magnesium, potassium, and nitrate to infiltrate to the water table. Elevated dissolved-solids concentrations in ground-water samples from agricultural areas likely result from soil treatments and agricultural chemicals, as well as manure and sewage sludge applied to some agricultural lands in the study area.

Specific conductance also differs significantly by land use (table 8) at higher than the 99.9-confidence level ($p = 0.0001$) and demonstrates the same pattern as the dissolved-solids concentrations. The median specific conductance of ground water increased from 170 µS/cm in undeveloped areas to 276 µS/cm for agricultural areas and more than doubled (361 µS/cm) in the urban areas (table 12). Similarly, three sample populations are evident—the conductivity of ground water beneath undeveloped areas was significantly less than ground water beneath agricultural and urban areas, and conductivity was significantly higher in samples from urban areas than in agricultural areas.

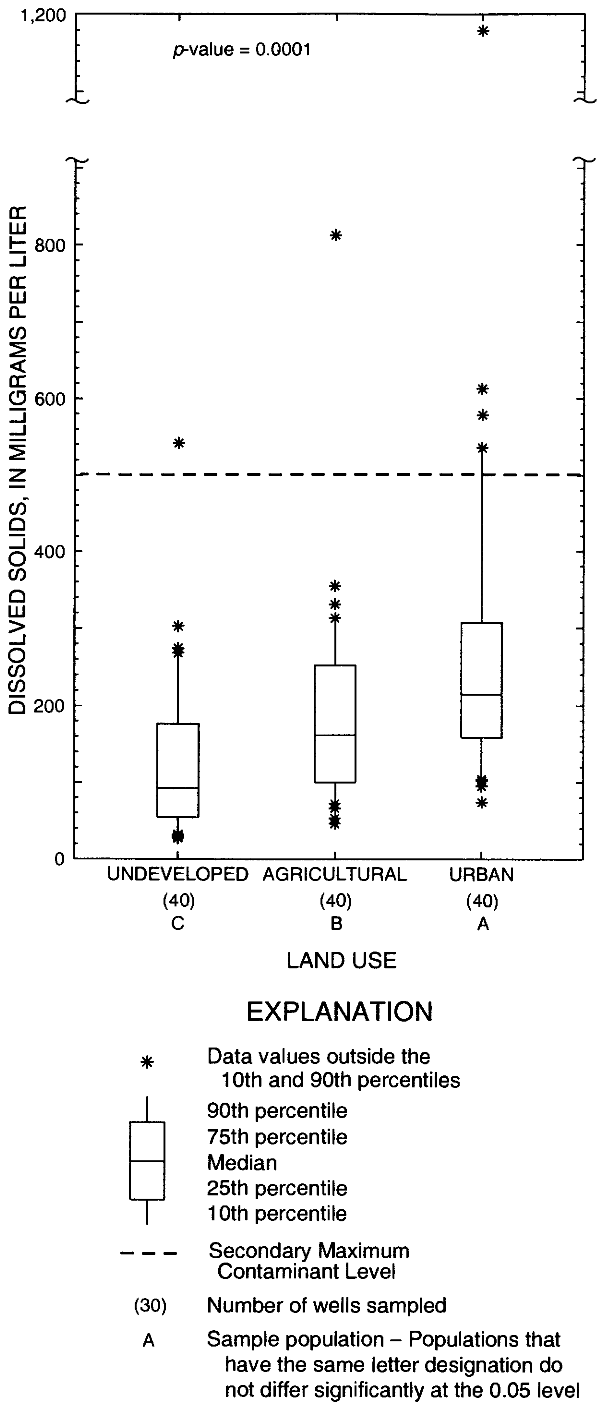


Figure 12. Dissolved-solids concentrations in water samples from surficial aquifers relative to land use in the Connecticut, Housatonic, and Thames River Basins.

Chloride is a particularly good indicator of the effect of human activities on ground-water quality because there are no substantial, natural sources of chloride in the study area, with the exception of precipitation containing evaporated seawater on a relatively narrow coastal area. Conversely, chloride is a well known and widely detected contaminant from human sources, such as highway deicing chemicals and effluent from septage. Chloride was one of only a few water-quality variables that did not significantly relate to aquifer-lithologic composition in the ANOVA results (table 8).

As with dissolved solids, chloride concentrations demonstrate three significantly different populations (fig. 13; table 12). The median chloride concentration

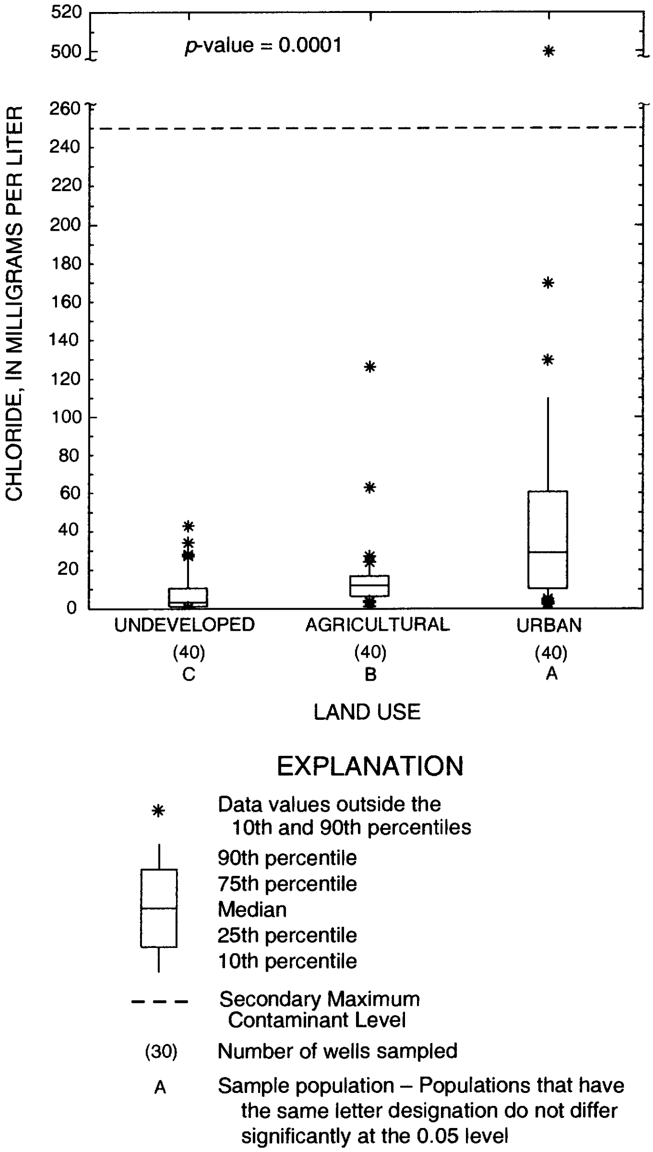


Figure 13. Chloride concentrations in water samples from surficial aquifers relative to land use in the Connecticut, Housatonic, and Thames River Basins.

was lowest (3.1 mg/L) in the undeveloped areas, which was significantly less than medians for the ground-water samples from the agricultural and urban areas. The median chloride concentration of 12 mg/L for samples from the agricultural area was four times higher than the samples from undeveloped areas. This may be related to the application of animal manure, which contains 0.03 to 0.08 percent chloride (Meister Publishing Company, 1991), sewage sludge, or muriate of potash (KCl) fertilizer to agricultural lands. Other chloride sources in agricultural areas may include salt blocks left in pastures for grazing farm animals, on-site septic systems of farmsteads, and application of deicing chemicals to highways and roads traversing agricultural areas. The median chloride concentration of ground water beneath urban areas, 29 mg/L, was nearly ten times higher than the median for the undeveloped areas and was more than twice that of the agricultural areas. The median chloride concentration was significantly higher in ground-water samples from urban areas than in undeveloped and agricultural areas; more than 25 percent of the samples from the urban areas exceeded 50 mg/L, and one sample exceeded the SMCL of 250 mg/L (fig. 13). Sources of elevated chloride concentrations in urban ground water are likely the relatively high use of deicing chemicals on highways, residential streets, parking lots, sidewalks and driveways; leaching effluents from septic systems; exfiltration from sanitary sewers; and wastes from domestic animals.

In addition to chloride, the other inorganic constituent most frequently associated with human sources is nitrogen. Nitrogen generally is present as nitrate (NO_3) in aerobic ground waters; however, for this study, the combined concentrations of nitrite (NO_2) and nitrate expressed as nitrogen (N) is reported. Nitrite was determined separately for all nutrient samples, but it was rarely detected (11 percent of all wells), and the highest nitrite concentration was 0.28 mg/L (table 12). Three significantly different sample populations for nitrite plus nitrate as N are shown in figure 14. The median nitrogen concentration of ground-water samples associated with undeveloped land use was 0.14 mg/L (table 12). Only two samples from undeveloped areas (5 percent) contained more than 1.0 mg/L as N, and these samples were from sites

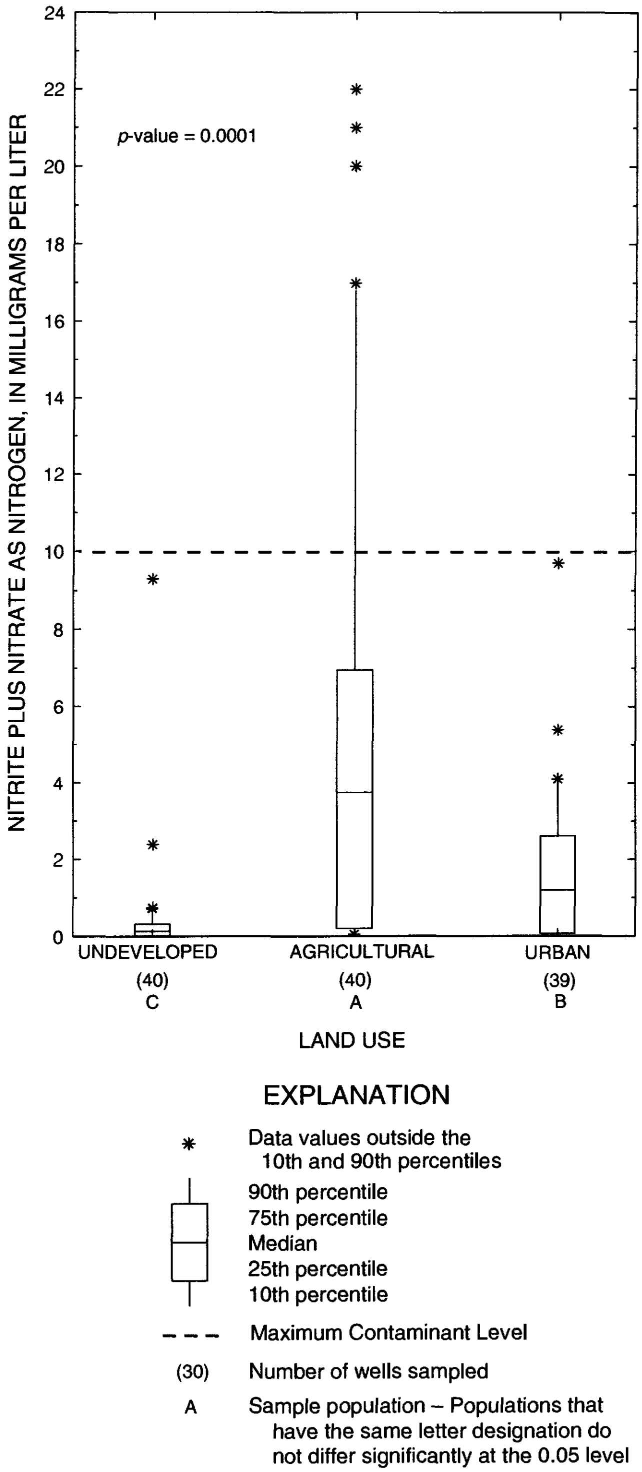


Figure 14. Nitrite plus nitrate concentrations in water samples from surficial aquifers relative to land use in the Connecticut, Housatonic, and Thames River Basins.

where airborne, surface runoff or ground-water transport of nitrogen from nearby agricultural fields to the undeveloped lands was possible. Forest soil processes, such as plant uptake, denitrification, and off-gassing of nitrogen gas (N_2) and nitrous oxide (N_2O), remove sufficient nitrogen from the subsurface to limit concentrations in ground water.

Nitrogen concentrations were highest in ground-water samples from agricultural areas. Sources of nitrogen in agricultural areas include extensive use of inorganic and organic fertilizers and, in some parts of the study area, sewage sludge on cropland, as well as the accumulation of animal wastes in pasture and feedlots, and atmospheric deposition. The median nitrite plus nitrate concentration of ground water beneath agricultural areas was 3.8 mg/L. Nearly 13 percent of the agricultural samples exceeded the 10-mg/L MCL for nitrogen (U.S. Environmental Protection Agency, 1996), and some concentrations were as high as 22 mg/L (table 12). Zimmerman and others (1996, p. 18) reported that total nitrogen fertilizer applications in the study area increased from 17 million kg in 1970 to 20 million kg in 1985, and they estimated that inorganic nitrogen fertilizer use for 1985 ranged from 20 to 50 kg/acre. Much of the agricultural land use in the study area produces silage corn and alfalfa to support dairy operations; consequently, the use of cow manure is prevalent. Information on the amount of nitrogen from inorganic fertilizer and from manure applied during 1987 to agricultural lands in the study area (R.B. Alexander, U.S. Geological Survey, written commun., 1992; Puckett, 1994) indicates that use of manure could be adding 200 to nearly 3,000 times more nitrogen than fertilizer to the soil.

Nitrogen concentrations in ground-water samples from urban areas were significantly higher than in samples from undeveloped areas but were significantly lower than in samples from agricultural areas. The median nitrite plus nitrate concentration for ground-water samples in urban areas was 1.1 mg/L, and concentrations ranged as high as 9.7 mg/L (fig. 14; table 12). Nitrogen sources in urban areas are primarily from septic or sanitary-sewer effluents, lawn and garden fertilizers, domestic animal wastes, infiltration of runoff from urban streets and parking lots, and atmospheric deposition. Atmospheric deposition of nitrogen in the study area varies with the percentage of urban area; average loads of 2,200 to 2,400 $(kg/yr)/mi^2$ have been estimated for most of the Connecticut, Housatonic, and Thames River Basins (Zimmerman and others, 1996, p. 111). The magnitude of nitrogen sources in urban areas is substantially less than nitrogen sources in agricultural areas (Novotny and Chesters, 1981) because the sources are less extensive (more widely dispersed and intermittent) and generally less intensive than agricultural fertilizer and manure sources.

Dissolved oxygen concentrations in surficial aquifers are significantly related to land use (table 8) and demonstrate a pattern of progressively lower concentrations in samples from undeveloped to urban areas (fig. 15). The median DO concentration measured in ground water beneath undeveloped areas was 7.8 mg/L. The range of equilibrium concentrations for oxygen in water in contact with air at the prevailing water temperatures and atmospheric pressure conditions during sampling was 9.3 to 12.4 mg/L (American Public Health Association and others, 1981, p. 392). DO concentrations were in the above range in about 37 percent of the water samples from wells in the undeveloped areas and only 8 percent of the DO concentrations in undeveloped areas were less than 1.0 mg/L.

The principal controls on DO in ground water are the permeability and moisture content of soils and the presence or absence of oxidizable organic and inorganic materials in the unsaturated zone and the aquifer. In undeveloped areas, decreased DO concentrations were mostly in areas enriched with natural organic matter (typically wetland areas) or where low-permeability soils and subsurface materials retard the infiltration and migration of oxygenated ground water. In agricultural areas, the same natural processes can decrease DO, but they may be augmented by microbial respiration and biologically mediated nitrification of ground water with elevated ammonia-nitrogen concentrations. DO concentrations were significantly less in agricultural areas than in undeveloped areas. The median DO concentration of ground water in agricultural areas was 6.0 mg/L, but DO concentrations were less than 1.0 mg/L in 15 percent of the samples. DO was not measurable at three agricultural wells. DO concentrations were lowest in samples from wells in urban areas, and the median DO (3.0 mg/L) was significantly lower than the median DO

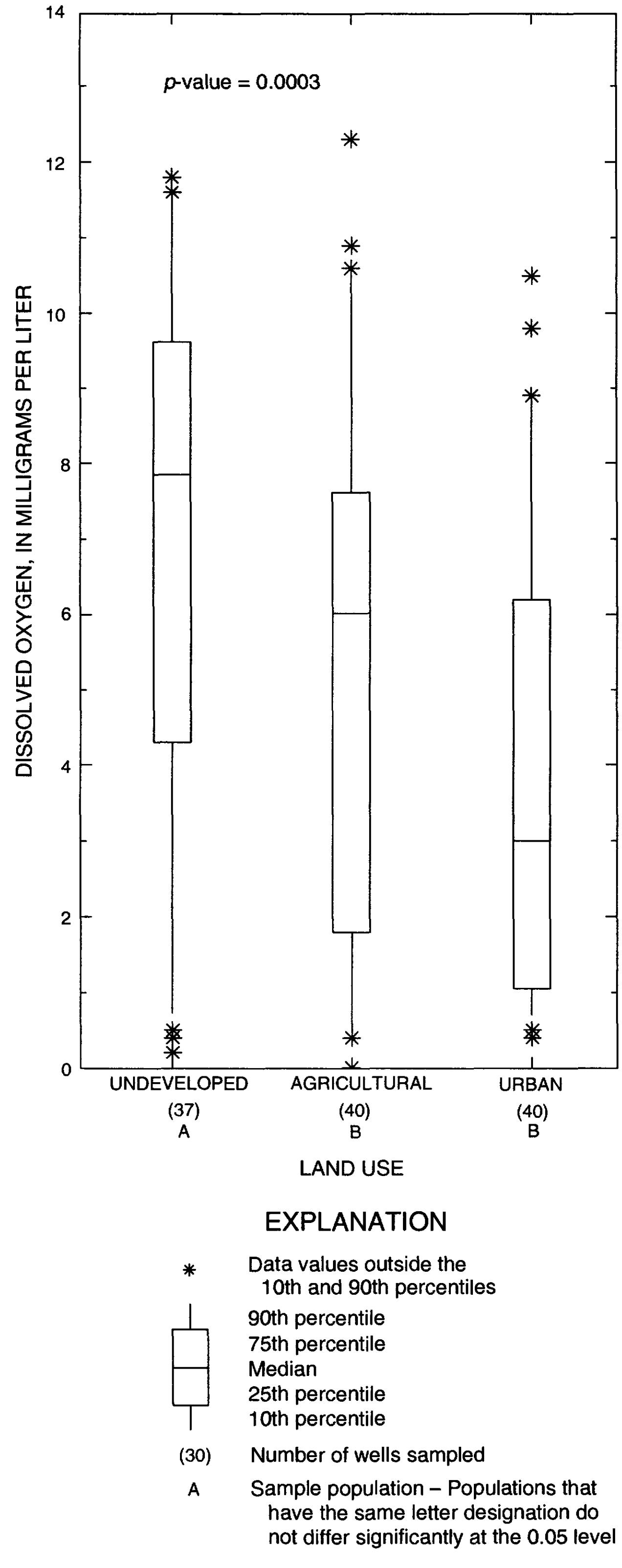


Figure 15. Dissolved oxygen concentrations in water samples from surficial aquifers relative to land use in the Connecticut, Housatonic, and Thames River Basins.

in samples from wells in undeveloped areas (fig. 15; table 12). Nearly one-quarter of DO concentrations in samples from urban areas were less than 1.0 mg/L. Low DO in ground water beneath urban areas may result from microbial degradation of septic-tank effluents or sewage from leaky sanitary sewers. Reducing conditions are commonly present in the subsurface adjacent to residential septic systems, filtration beds, or leach fields. Slightly but significantly higher ground-water temperatures (table 12) were measured in urban than in undeveloped areas, possibly related to the greater presence of impervious areas, and the lower DO concentrations may result, in part, from lower oxygen solubility in warmer waters. Generally, however, surficial aquifers afford ideal conditions for replenishing shallow ground water through rapid infiltration of oxygen-enriched recharge.

Significant differences in other major inorganic constituents of ground water also were indicated when compared by land use (table 8), even in the presence of the previously defined natural variations in many of these constituents. Concentrations of water-quality constituents such as calcium and magnesium, hardness as $CaCO_3$, sodium, bicarbonate, alkalinity, sulfate, and silica, all of which have been shown to be related to aquifer-lithologic composition, also were strongly affected by human factors related to land-use patterns. For all inorganic constituents except potassium that were compared using ANOVA, these human factors affect water quality in a consistent manner as evidenced by the lack of a significant interaction factor between land use and aquifer type (table 8). Concentrations of some minor inorganic constituents (bromide and manganese) also varied significantly by land use (table 12).

Pesticides

Pesticides are used to control a variety of pest organisms including insects, mites, nematodes, birds, and rodents, as well as fungi, molds, weeds, and microorganisms. Pesticides generally are grouped by the type of pest that they are intended to control; pesticides specifically applied to control plants are called herbicides, and similarly, other kinds of pesticides are insecticides, acaricides, nematocides, rodenticides, fungicides, algicides, and bactericides (or disinfectants). Pesticides also are classified by their chemical structure into major classes such as benzonitriles, carbamates, chloroacetamides, chlorophenoxy acids, dinitroanilines, organochlorines, organophosphates, thiocarbamates, triazines, phenyl ureas, pyrethroids, and uracils. Since the 1940's, thousands of chemicals have been synthesized and introduced into the environment to control nuisance organisms, but for this report, the scope of pesticide analyses includes only those 85 compounds listed in table 4.

Twenty-four pesticide compounds or metabolites (transformation products) were detected (tables 9 and 12) in one or more of the 103 monitoring wells sampled for pesticides. Ninety percent of the total 162 pesticide detections were herbicides (fig. 16) with triazine herbicides alone accounting for 72 percent of all detections. Detected triazine herbicides include the compounds atrazine (and its metabolite, desethylatrazine), and simazine that are used primarily in agriculture, particularly on silage and sweet corn fields (the principal crops grown in the study area), and prometon, used in urban settings along highways and utility rights-of-way. Detections of atrazine and desethylatrazine constitute 53 percent of all pesticide detections, whereas simazine and prometon each accounted for 9 percent of the overall pesticide detections. The chloroacetamide herbicide metolachlor, which is widely used in corn production as well as applied in urban areas, was the only other herbicide detected more than twice. Detections of metolachlor in 14 wells also accounted for 9 percent of the total. Carbamates dominated (53 percent) the limited number (17) of insecticide detections (fig. 16), and carbaryl, detected in samples from five wells, was the most frequently detected carbamate. The only other insecticide detected in more than two wells was the organochlorine dichlorodiphenyldichloroethylene (*p,p*-DDE), a transformation product of the long-banned insecticide DDT.

Comparisons of the frequency of pesticide detections can be easily misinterpreted because of the number of factors that affect the occurrence and behavior of chemical compounds in the environment (Barbash and Resek, 1996), as well as differences in the ability of analytical methods to identify and quantify pesticides in ground water (Kolpin and others, 1995). Whether or not a specific pesticide will actually occur in ground water depends on a host of factors including: the amount, method, and timing of pesticide applications; the timing and intensity of precipitation or irrigation; hydrogeologic characteristics such as soil and aquifer type, and the type and depth of well sampled; and chemical and biological processes that degrade, transform, or consume the chemical compound. An additional factor is whether or not the analytical method can detect the compound if it is present; this varies depending on the actual concentration of the compound (lower concentrations generally are less likely to be detected) as well as the characteristics inherent to the analytical method used for each specific analyte. Some of these include sample filtering and preservation procedures, holding times, compound extraction and preparation methods, instrument technology and performance, and the analyst's experience and precision. All these analytical factors are reflected in the method detection limits and minimum reporting limits provided for each compound detected in this study in table 4. Because of the above factors, two compounds may be detected or reported at entirely different frequencies, although their occurrence in ground water is the same.

The occurrence of pesticides in shallow ground water from surficial aquifers in the Connecticut, Housatonic, and Thames River Basins is related to the overlying land use. The frequency of pesticide detections was significantly different among the three land-use categories ($p = 0.0215$). Detections of one or more pesticides in 80 percent of water samples from wells in agricultural areas were significantly higher than in samples from wells in undeveloped areas (48 percent of samples from wells) (fig. 17). Pesticide detections in 60 percent of the samples from wells in urban areas were not significantly different from either the undeveloped or agricultural areas. The high frequency of pesticide detections in ground-water samples from agricultural areas was not unexpected considering the number and amount of pesticide used in these areas (Zimmerman and other, 1996). Also, documentation of widespread pesticide occurrence in shallow ground water beneath agricultural fields, as well as golf courses, parks, highways, and other urban lands has recently been presented for the region (Mullaney and others, 1991; Grady, 1994; Zimmerman and others, 1996) and the Nation (Barbash and Resek, 1996).

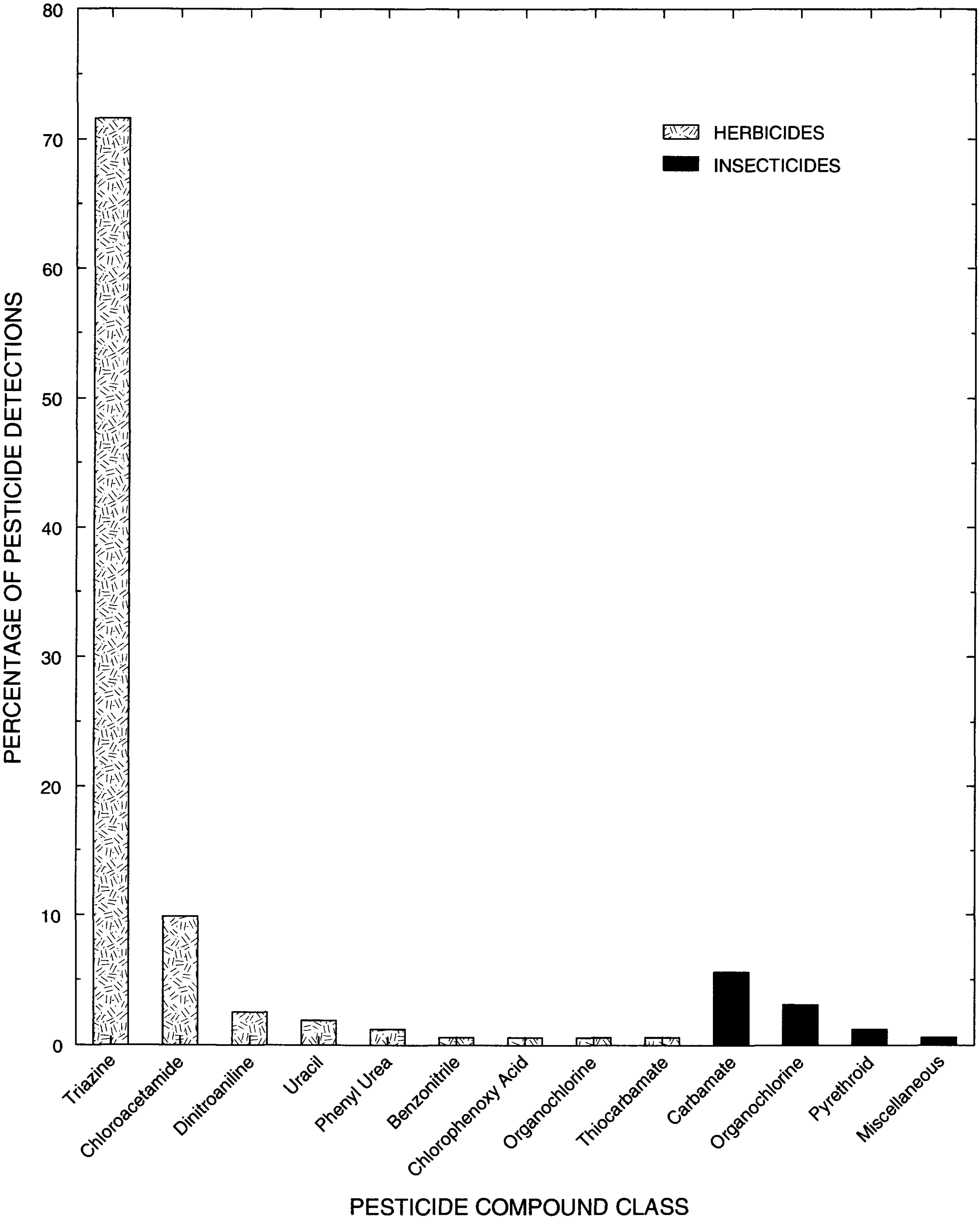


Figure 16. Frequency of detection of pesticides in water samples from surficial aquifers by compound class in the Connecticut, Housatonic, and Thames River Basins.

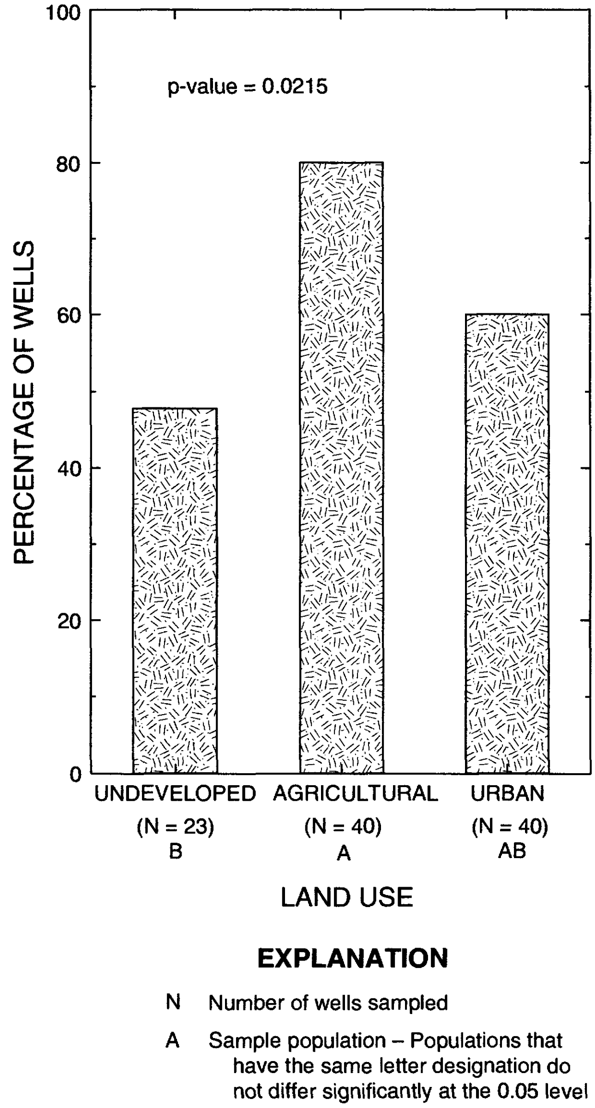


Figure 17. Frequency of detection of pesticides in water samples from surficial aquifers relative to land use in the Connecticut, Housatonic, and Thames River Basins.

But the presence of pesticides in nearly one-half of the wells in undeveloped, forested areas was substantially higher than previously reported. Pesticide detections in forested areas may reflect pesticide usage related to commercial silviculture, but relatively little of the forested regions overlying surficial aquifers are involved in silviculture. The elevated frequency of detections in this study was likely related to the effort made to identify and quantify more pesticide analytes than previous studies and to report new and previously detected pesticides at lower concentrations. Forty-one percent of all pesticide detections reported in this study were at trace-level concentrations less than 0.01 µg/L.

The number of pesticide compounds detected per well (fig. 18*A*) and the range in pesticide concentrations (fig. 18*B*) varied by land use. Pesticide detections in ground-water samples from undeveloped areas were fewer overall than in ground-water samples in either agricultural or urban areas. Where pesticides were detected in undeveloped areas, typically only one compound was detected per well (fig. 18*A*). More than one pesticide was detected in only three of the wells (13 percent) in the undeveloped areas. Nearly one-half (47 percent) of all pesticide detections in ground-water samples from undeveloped areas were at concentrations less than 0.01 µg/L, and only one detection exceeded 0.1 µg/L (fig. 18*B*). Conversely, relatively few of the samples from agricultural areas (28 percent) had one or no pesticides. More than one-half of the agricultural samples (58 percent) contained two or three pesticides, and 15 percent had four or more pesticides detected (fig. 18*A*). This distribution reflects the more diverse and intense use of pesticides on agricultural lands. Relatively few of the detections in agricultural samples (35 percent) were at concentrations less than 0.01 µg/L, whereas more than one-third were at or higher than 0.1 µg/L, and 6 percent were equal to or greater than 1.0 µg/L (fig. 18*B*). Only one pesticide detection in this study exceeded a USEPA MCL or MCLG; this was atrazine at 3.6 µg/L in a sample from an agricultural well (well No. 39 in fig. 6) in Simsbury, Connecticut.

The pattern of pesticide detections and concentrations in ground-water samples from urban areas was intermediate to that measured in samples from undeveloped and agricultural areas. Use of pesticides in urban areas is widespread, but the total amount of pesticides applied is likely less than in agricultural areas. One or no pesticides were detected in 68 percent of the samples from urban areas; 2 or 3 pesticides were detected in 18 percent of the samples, and 4 or more compounds were detected in 15 percent of the samples (fig. 18*A*). One-half of the pesticide detections in urban ground water were at concentrations less than 0.01 µg/L, whereas only 16 percent were equal to or greater than 0.1 µg/L (fig. 18*B*).

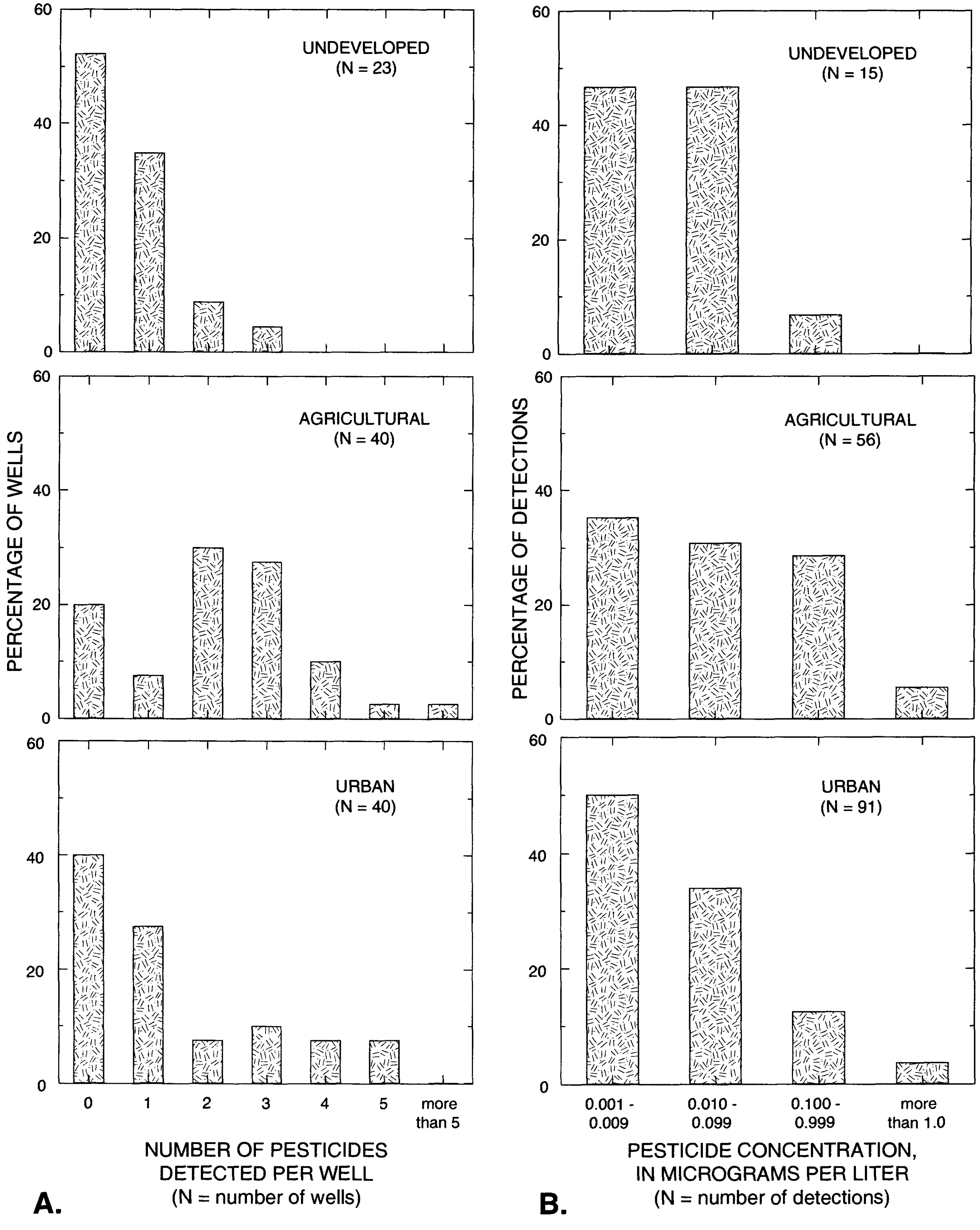


Figure 18. Frequency of detection of pesticides relative to land use in the Connecticut, Housatonic, and Thames River Basins. *A.* Number of detections per well. *B.* Concentration in water samples from surficial aquifers.

The frequency of detection for 24 pesticide compounds or metabolites detected in water samples from the 103 monitoring wells is compared by land use in figure 19. Nineteen of the 24 compounds detected were in samples from the agricultural areas, including 12 compounds that were detected exclusively in the agricultural samples. Most (14) of the 19 compounds detected in agricultural samples were herbicides. Three herbicides detected in samples from agricultural areas—atrazine and its metabolite desethylatrazine, and metolachlor—were detected significantly more often than in samples from the undeveloped and urban areas (table 9). More than 70 percent of the samples from agricultural areas contained atrazine and (or) desethylatrazine, and 28 percent contained metolachlor. Frequent detections of these three herbicide compounds in agricultural areas reflects their widespread use for pre-emergent control of broadleaf weeds in corn fields. Atrazine was the most heavily used pesticide in the study area with applications of more than 300,000 lb/yr of active ingredient during 1982-85 (Zimmerman and others, 1996). Metolachlor was the third most heavily used pesticide with applications of more than 89,000 lb/yr of active ingredient.

Atrazine and desethylatrazine concentrations generally were higher in samples from agricultural areas than in samples from either the undeveloped or urban areas (fig. 20; table 12). Median atrazine and desethylatrazine concentrations for ground-water samples from the agricultural areas were 0.013 and 0.014 μg/L, respectively. Atrazine concentrations greater than 1.0 μg/L were measured in one sample each from agricultural and urban areas. A single sample from an agricultural well in a corn field in Connecticut (3.6 μg/L) exceeded the atrazine MCL of 3.0 μg/L (U.S. Environmental Protection Agency, 1996). The desethylatrazine concentration in that sample was 1.4 μg/L, but presently (1997) there are no Federal drinking water-quality standards or guidelines for that compound.

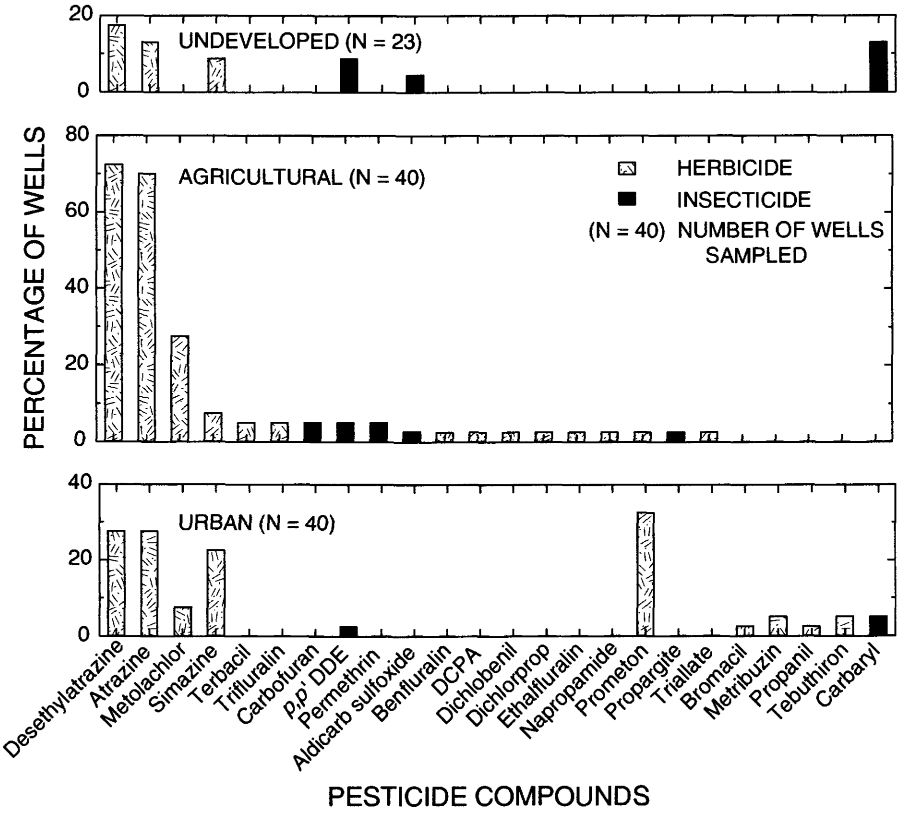


Figure 19. Frequency of detection of 18 herbicide and 6 insecticide compounds or metabolites in water samples from surficial aquifers relative to land use in the Connecticut, Housatonic, and Thames River Basins.

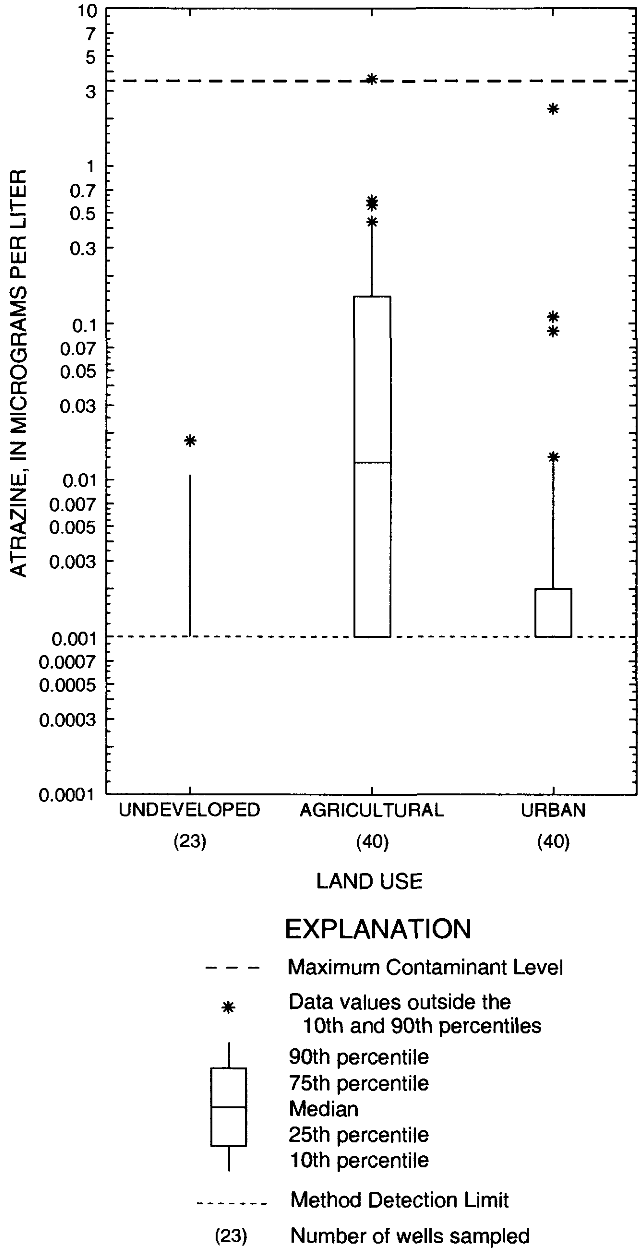


Figure 20. Atrazine concentrations in water samples from surficial aquifers relative to land use in the Connecticut, Housatonic, and Thames River Basins.

Desethylatrazine, which forms largely in the soil where applications of the parent compound (atrazine) undergoes biotic degradation with de-ethylation (Adams and Thurman, 1991), was actually detected slightly more frequently than atrazine in ground-water samples (fig. 19). A soil dissipation half-life of 60 days has been widely reported for atrazine (Barbash and Resek, 1996). The product-to-parent concentration ratio of desethylatrazine to atrazine (the DAR) in a water sample may provide evidence as to the source and the spatial and temporal distribution of atrazine applications (Thurman and others, 1991). The longer atrazine resides in the soil, the more likely it is to degrade to desethylatrazine (or other metabolites not analyzed for in this study) and the higher the DAR. The concentration of desethylatrazine, and hence the DAR, has been reported to increase over time in soil and pore water, even though desethylatrazine is more mobile than atrazine (Mills and Thurman, 1994). DARs that show concentrations of the parent compound reduced with respect to the metabolite (that is, ratios greater than 1.0) may indicate that movement of atrazine through the soil zone is prolonged with ample time for biological degradation (Adams and Thurman, 1991) or that ground-water flow had transported the pesticide some distance from its source area (Denver and Sandstrom, 1991). DAR values higher than 1.0 indicate that the source of the atrazine may be distant in space or time, whereas values less than 1.0 may be the result of fresh parent atrazine entering the aquifer from recent, local applications in areas where the atrazine passes through the soil zone rapidly. Median DAR values were slightly less than 1.0 for samples from agricultural areas but were equal to or greater than 1.0 for the samples from undeveloped and urban areas (fig. 21). However, the widespread occurrence of DAR values less than 1.0 suggests that the sandy, permeable soils and unsaturated zones commonly present above surficial aquifers in the study area allow for rapid infiltration and transport of parent atrazine in the surficial ground-water-flow systems of the study area.

The frequency of detection of prometon also differed significantly by land use (table 8), but the pattern of detections was not the same as other triazines. Prometon was not detected in ground-water samples from undeveloped areas and was only detected once in samples from agricultural areas (fig. 19, table 12), but it was detected in 13 of the samples (32 percent) from urban areas. As a nonselective herbicide effectively used for either pre- or postemergent, perennial broadleaf weed and grass control (Meister Publishing Company, 1991), prometon is one of the most commonly used herbicides on railroad, powerline, pipeline, and roadway rights-of-way. Many of the detections of prometon in ground waters beneath different areas of the United States can be attributed to

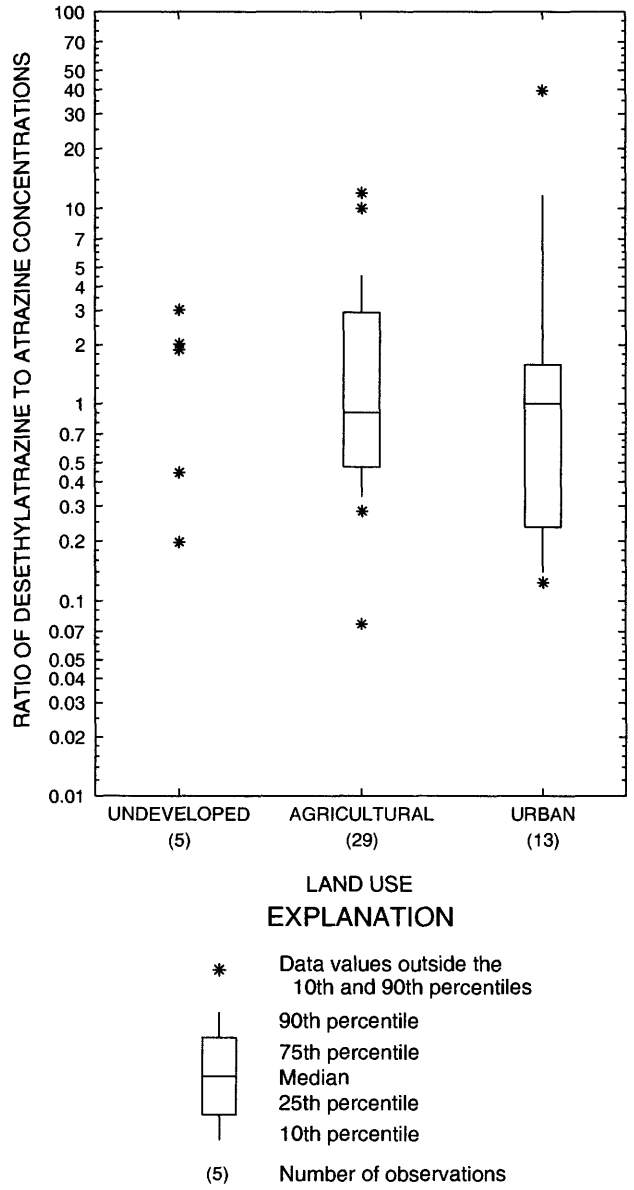


Figure 21. Ratio of desethylatrazine to atrazine concentrations in water samples from surficial aquifers relative to land use in the Connecticut, Housatonic, and Thames River Basins.

non-agricultural use (Barbash and Resek, 1996). In addition, four other herbicides were detected exclusively in ground-water samples from urban areas. Bromacil and tebuthiuron have well documented usage on rights-of-way (Barbash and Resek, 1996), but metribuzin and propanil primarily are agricultural chemicals. Rare detections of the last two compounds may relate to unreported use on residential lawn and gardens or may reflect their usage on former or adjacent agricultural areas.

Three other pesticide compounds, carbaryl, dichlorodiphenyldichloroethylene (*p,p'*-DDE), and metolachlor, also demonstrated statistically significant differences in their detection frequencies when compared by aquifer (table 9). Because there is no natural source for these chemicals, their relation to aquifer-lithologic-composition category likely reflects regional differences in their use that correlate with the regional distribution of surficial aquifers by their lithologic-composition categories. The best example of this phenomenon may be carbaryl, which was detected in three undeveloped wells and two urban wells, all of which were in carbonate aquifers (table 12). The presence of carbaryl in shallow wells in the carbonate surficial aquifers in the greater Housatonic River Valley in western Connecticut and Massachusetts may stem from its use to control infestations by gypsy moths that affected this region in recent years. Similarly, the *p,p'*-DDE detections were largely in the calcareous aquifers and may reflect a former use of DDT in northern parts of the study area. Metolachlor, an herbicide, was significantly related to agricultural use and was largely detected in arkosic aquifers with a few detections in the carbonate and crystalline aquifers. All metolachlor detections, however, were in the southern part of the study area with 93 percent of the detections in Connecticut alone.

Volatile Organic Compounds

VOCs are natural and manmade chemicals that typically are characterized by high vapor pressures, high solubilities, and low octanol-water partition coefficients. They include hydrocarbons, halocarbons, aldehydes, ketones, alcohols, acids, and methyl-sulfur compounds. VOCs are used in and produced by the manufacture of paints, adhesives, petroleum products, pharmaceuticals, and refrigerants. They include, or are components of gasoline, solvents, hydraulic fluids, paint thinners, and dry cleaning agents and are most commonly used in urban settings. Some VOCs also are active and inert components of fertilizers and pesticides (particularly fumigants) used in agricultural settings (Verschueren, 1983). VOC contamination of drinking-water supplies is a human health concern nationally because many of the compounds are toxic and are known or suspected human carcinogens (U.S. Environmental Protection Agency, 1996).

Twenty-five of the 60 VOC analytes (table 5) were detected in ground water from 1 or more of the 86 wells in the Connecticut, Housatonic, and Thames River Basins study area sampled for VOCs (table 9).

Overall, 1 or more VOCs were detected in 36 (42 percent) of the wells for a total of 97 VOC detections. A disproportionate number (86 percent) of the wells with VOC detections were located in Connecticut or Massachusetts where the largest extent of urban lands (fig. 5) and the highest population density are found.

Collectively, halogenated (chlorinated or fluorinated) alkanes, including chloroform, 1,1-dichloroethane, dichlorodifluoromethane, plus five additional compounds, were most frequently detected, encompassing 31 percent of all VOC detections (fig. 22). Detections of 12 alkyl benzenes accounted for

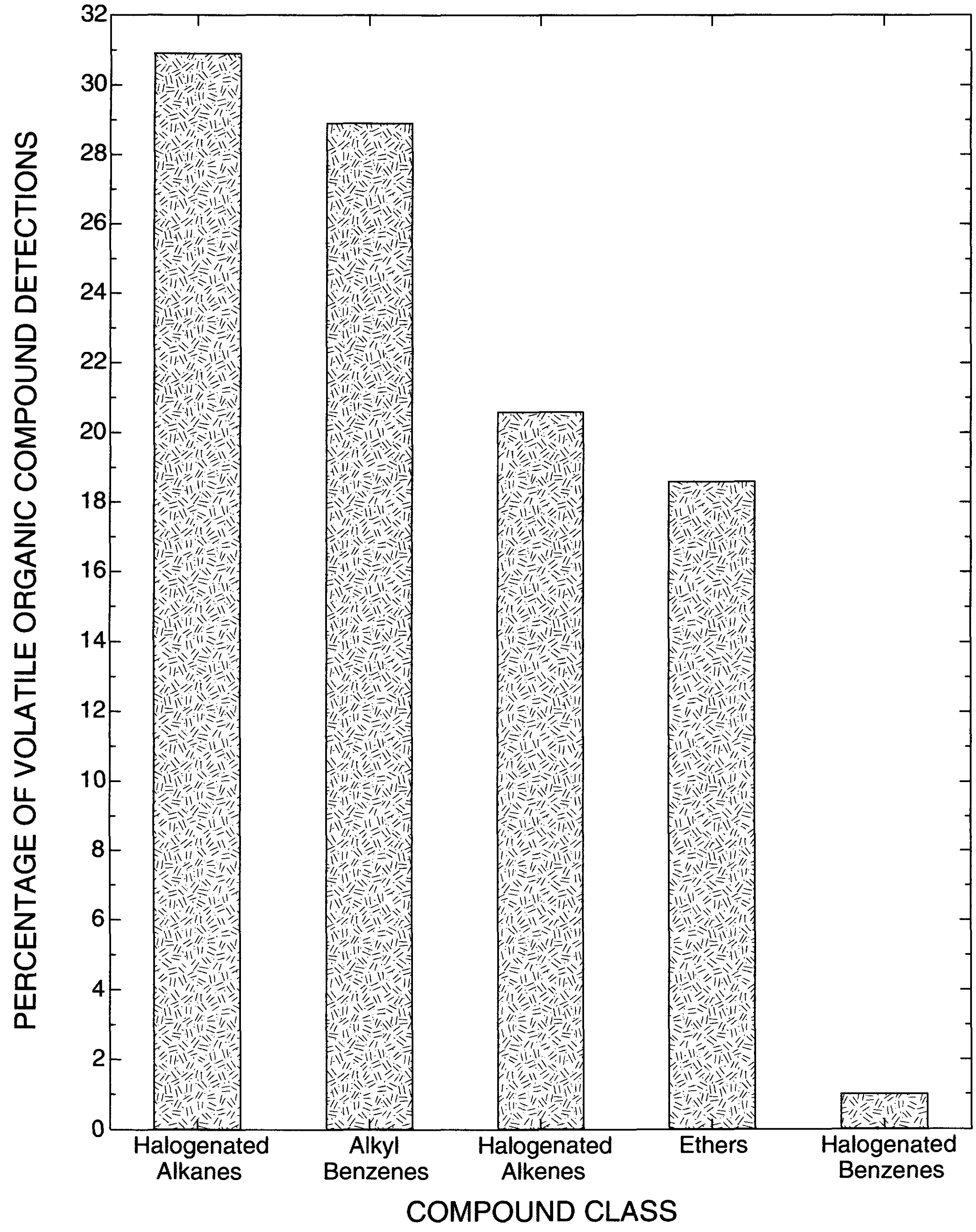


Figure 22. Frequency of detection of volatile organic compounds in water samples from surficial aquifers by compound class in the Connecticut, Housatonic, and Thames River Basins.

29 percent of all VOC detections, but 7 of these were exclusively detected in 1 well with gross hydrocarbon contamination. Twenty-one percent of VOC detections were halogenated alkenes, including the solvents (or their degradation by-products) tetrachlorethane, trichloroethene, and *cis*-1,2-dichloroethene. Methyl *tert*-butyl ether (MTBE), the only ether detected, accounted for 19 percent of all VOC detections, and only one halogenated benzene (bromobenzene) was detected.

Concentrations of VOCs detected in the study area ranged from less than 0.2 to 300 µg/L (table 12). The U.S. Environmental Protection Agency (1996) has issued, drafted, or proposed drinking-water regulations and (or) health advisories for 23 of the 25 VOCs detected in ground water and has identified 8 of the 25 compounds detected as known, probable, or possible human carcinogens. Five of the 25 compounds detected in monitoring wells—benzene, 1,2-dibromoethane, naphthalene, tetrachloroethene, and trichloroethene—were measured at concentrations exceeding USEPA's MCLs or HAs. Most of the samples that exceeded MCLs or HAs were from wells in urban areas where public drinking water is supplied by surface-water sources or deep wells. Although none of the monitoring wells in this study are used for drinking-water supplies, municipal, commercial, and industrial water supplies are developed from some of the same surficial aquifers sampled by the monitoring wells. Reporting limits (tables 5 and 12) for all VOC analytes except 1,2-dibromoethane (EDB) and dibromochloropropane (DBCP) were substantially less than their MCLs or HAs (U.S. Environmental Protection Agency, 1996).

The detection of VOCs in shallow ground water from surficial aquifers in the Connecticut, Housatonic, and Thames River Basins is related to the overlying land use. The overall frequency of detection of all VOCs combined differed significantly among the three land-use categories ($p = 0.0002$). VOC detections in samples from 62 percent of the wells in urban areas and 38 percent of the wells in agricultural areas were significantly higher than detections in 9 percent of wells in undeveloped areas (fig. 23*A*). Widespread detections in urban areas were not unexpected as previous studies have shown that VOCs were prevalent in ground water beneath urban areas of the region (Grady, 1994) and the Nation (Westrick, 1990; Mackay and Smith, 1993). The elevated frequency of VOC detections in agricultural areas was comparable to detections in 46 percent of agricultural samples reported by Grady (1994), but the VOC detections in undeveloped areas during this study were less frequent than noted by Grady for undeveloped areas (36 percent).

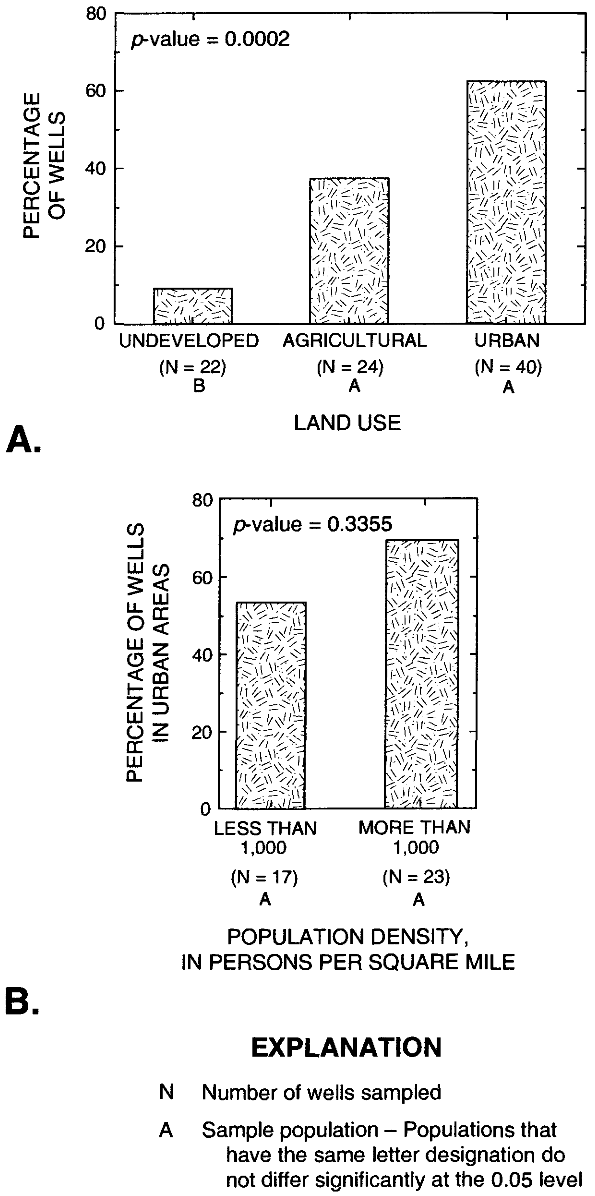


Figure 23. Frequency of detection of volatile organic compounds in water samples from surficial aquifers relative to (*A*) land use and (*B*) population density for wells in urban areas in the Connecticut, Housatonic, and Thames River Basins.

Grady (1997) also observed that the frequency of VOC detections in ground water increased significantly with increasing population density. Presenting data for surficial and bedrock aquifers (133 wells), including data for the 86 monitoring wells in this study, Grady compared VOC detections for five population-density classes ranging from less than 20 to more than 2,000 persons/mi^2. Examining data only for the 86 monitoring wells, a similar significant relation ($p = 0.0009$) between VOC detections and population density can be demonstrated for three population-density classes (less than 100, 100 to 1,000, and more than 1,000 persons/mi^2). However, a strong correlation between the land-use categories and the range of population density associated with each is evident in the data.

Using only data for the urban land-use category, the frequency of VOC detections for two population-density categories are compared in figure 23*B*—less than and more than 1,000 persons/mi^2. With VOC detections in 53 percent of the wells in areas of less than 1,000 persons/mi^2 and in 70 percent of those in areas with more than 1,000 persons/mi^2, there was no significant difference in the frequency ($p = 0.3355$) between the two broad population-density categories. The close association of VOCs in ground water with urban land use appears to be nearly as consequential in less populated, somewhat less developed, suburban settings as in the higher density, often older, more commercialized urban areas. This finding is important because a population density of 1,000 persons/mi^2 has been recognized by Hitt (1994) as the break between “urban” and “non-urban” land use, and this criteria may be used to design future urban ground-water studies. The limited data from this study suggest, however, that important and widespread human effects on ground-water quality also occur at lower population densities.

The number of VOCs detected per well (fig. 24*A*) and the range in VOC concentrations (fig. 24*B*) are related to land use. VOCs were not detected in samples from about 91 percent of the 22 wells in undeveloped areas. VOCs were detected in only two wells in undeveloped areas of Connecticut; a single VOC was detected in the water from one well, and two VOCs were detected in the second well. All VOC concentrations in samples from undeveloped areas were less than 10 µg/L, and two of the three detections were less than 1.0 µg/L. Conversely, more than 1 VOC was detected in nearly one-half (48 percent) of the 40 wells in urban areas and more than 4 compounds were detected in 5 of the wells; 10 VOCs were detected in 1 well. Most concentrations of VOCs in water samples from urban areas were less than 1.0 µg/L, but VOC concentrations in 16 percent of the samples were higher than 10 µg/L and were as high as 300 µg/L. Many of the highest VOC concentrations were measured in the well containing 10 VOCs. This well located in Pittsfield, Massachusetts (well No. 80 in fig. 6) appeared to be affected by gasoline contamination from a nearby point source. VOC detections were less numerous in the 24 wells in agricultural areas than in urban areas, but more than one VOC was detected in 21 percent of the wells. All VOC concentrations in the agricultural areas were less than 10 µg/L and most (76 percent) were less than 1.0 µg/L.

The frequency of detection for each of the 25 VOCs detected in water samples from the 86 monitoring wells is compared by land use in figure 25. Twenty-two of the 25 compounds were present in water samples from wells in urban areas, and 15 of these compounds were detected exclusively in samples from urban areas. Those VOCs detected only in urban areas include the seven alkyl benzenes (*n*-butylbenzene, *sec*-butylbenzene, ethylbenzene, isopropylbenzene, *n*-propylbenzene, 1,3,5-trimethylbenzene, and total xylenes) detected in the one well with gasoline contamination. Other compounds (carbon tetrachloride, dichlorodifluoromethane, 1,1-dichloroethane, *cis*-1,2-dichloroethene, *p*-isopropyltoluene, tetrachloroethene, trichloroethene, and 1,1,1-trichloroethane) used as solvents, heat-transfer fluids, flame retardants, refrigerants, propellants, and fumigants and commonly found in municipal and industrial wastewater effluents (Smith and others, 1988) also were among the VOCs exclusively detected in ground-water samples from urban areas.

Ten VOC’s were detected in ground-water samples from agricultural and undeveloped areas. These detections generally were infrequent, but a few compounds were exclusively detected in these land uses. Bromobenzene and 1,2-dibromoethane (EDB) were each detected in one agricultural well. The occurrence of these and other VOCs (naphthalene, in

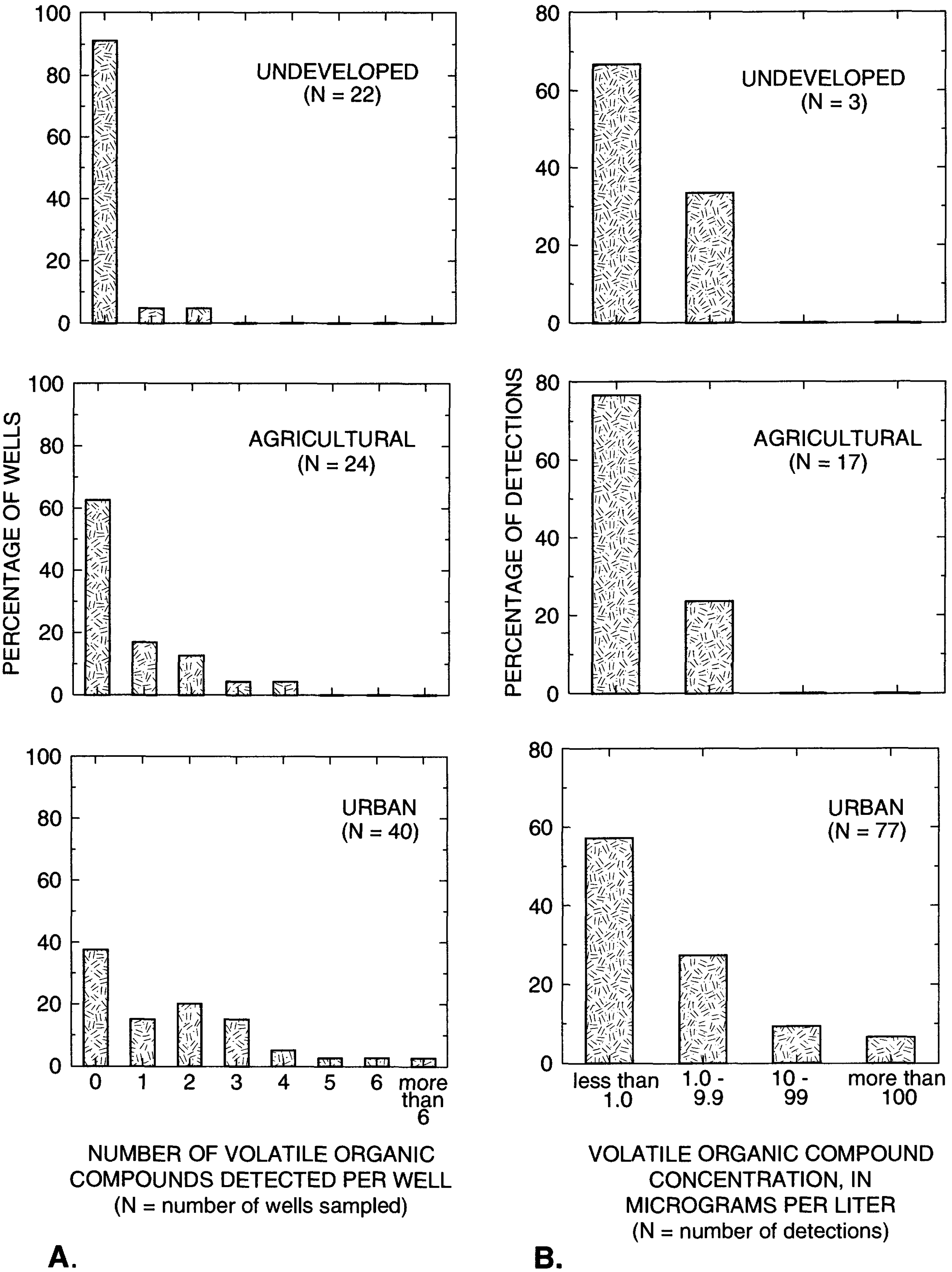


Figure 24. Frequency of detection of volatile organic compounds by (*A*) number of detections per well and (*B*) concentration in water samples from surficial aquifers relative to land use in the Connecticut, Housatonic, and Thames River Basins.

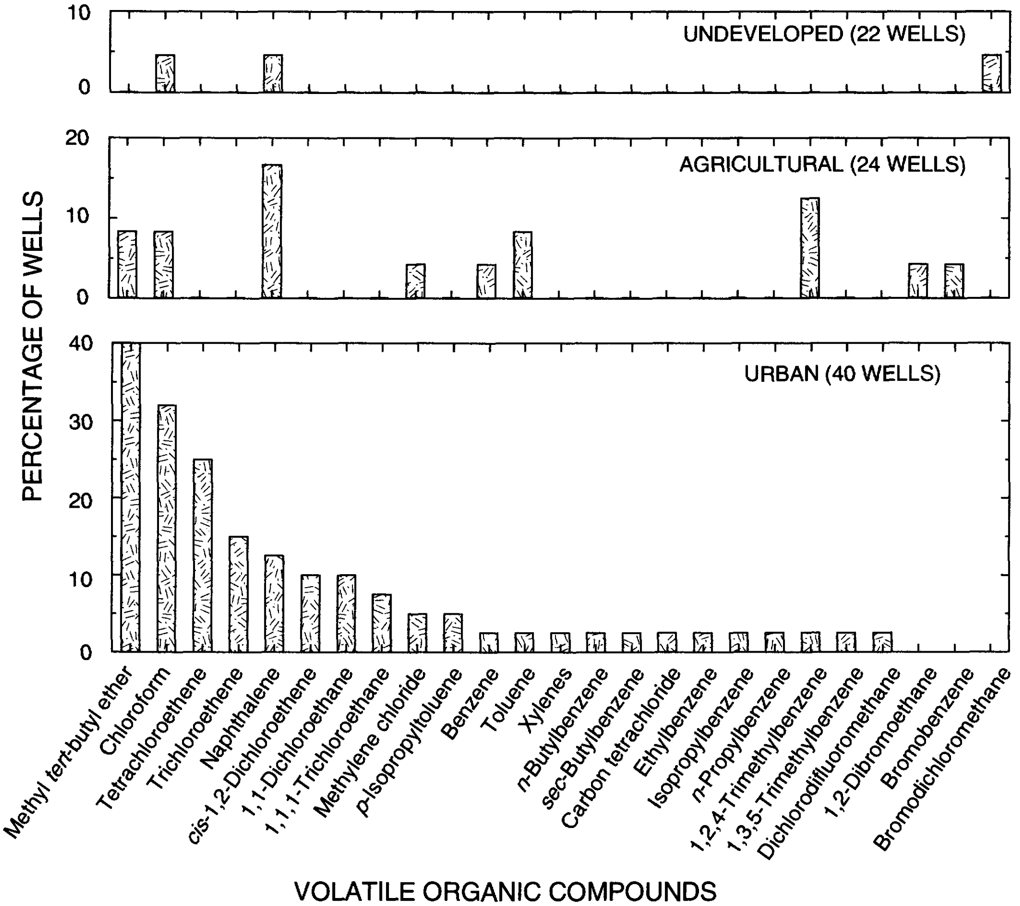


Figure 25. Frequency of detection of 25 volatile organic compounds in water samples from surficial aquifers relative to land use in the Connecticut, Housatonic, and Thames River Basins.

particular) in ground water beneath agricultural areas may relate to their use as fumigants or as inert ingredients in some pesticide formulations. Widespread EDB contamination of ground water in Connecticut and Massachusetts was attributed to its use as a soil fumigant on tobacco-growing areas of the Connecticut River Valley (Zimmerman and others, 1996). Detection of other VOCs in ground water beneath undeveloped and agricultural areas may be attributed to atmospheric sources or minor incongruent land-use or human sources within or adjacent to the targeted land-use areas.

Detection frequencies for the four most commonly detected VOCs—MTBE, chloroform, tetrachloroethene, and trichloroethene—differed significantly by land use (table 9) and all four VOCs were detected much more frequently in urban areas. MTBE, a gasoline oxygenate widely used in the Northeast, was the most commonly detected VOC, and was present in nearly 21 percent of the wells. MTBE detections in 40 percent of the wells in urban areas were significantly higher than the lack of detections in undeveloped wells (p = 0.0005) and the two detections in agricultural wells (p = 0.0064). Although widely detected in ground water in this study, MTBE concentrations were low (from 0.2 to 2.4 µg/L) and substantially less than the 20-µg/L lower limit of the draft lifetime HA for drinking water (U.S. Environmental Protection Agency, 1996). Chloroform, a trihalomethane by-product of the process of disinfecting drinking-water supplies (chlorination), was the second most frequently detected VOC. Low concentrations (0.3 to 3.1 µg/L) of chloroform were detected in 19 percent of all wells sampled, but most widely detected in the urban areas (32 percent of urban wells). *P*-values for the contingency-table comparisons of chloroform detections in samples from urban and undeveloped areas ($p = 0.0122$) and urban and agricultural areas ($p = 0.0343$) were highly significant.

Tetrachloroethene and trichloroethene, two solvents commonly used in a variety of industrial and commercial activities associated with urban land use, were detected only in ground water beneath urban areas. Concentrations as high as 130 to 250 µg/L of tetrachloroethene and 63 µg/L of trichloroethene, substantially greater than the 5.0-µg/L MCLs for these compounds, were measured in water samples from two monitoring wells (well Nos. 2 and 20 in fig. 6) in urban areas of Milford and New Milford, Connecticut. Detections of these two compounds in urban areas were significantly higher ($p = 0.0097$ and 0.0462, respectively) than in the agricultural areas, and tetrachloroethene also had significantly higher detections for urban areas relative to undeveloped areas. Although no trichloroethylene was detected in samples from undeveloped areas, the fewer detections of trichloroethene (6) than tetrachloroethene (10) in urban areas were not sufficient to reject the null hypothesis (no differences in frequency of any VOC detection among land uses) for the contingency-table comparison with a sample size of only 22 wells for the undeveloped land-use category.

Point and nonpoint sources contribute to the occurrence of VOCs in ground water in the Connecticut, Housatonic, and Thames River Basins. At least three of the wells in urban areas had concentrations of VOCs such as tetrachloroethene (250 µg/L), trichloroethene (63 µg/L), benzene (73 µg/L), and total xylenes (300 µg/L) that are evidence of nearby solvent and hydrocarbon point sources. Most VOC detections (61 percent) in this study were at concentrations less than 1.0 µg/L that are more indicative of nonpoint sources.

Other conflicting evidence as to the source of some VOCs can be presented. For example, MTBE is only used as a gasoline additive, and a relatively small amount (2 to 10 percent by volume) has been added to some gasoline since 1979 to enhance the octane level (Garrett and others, 1986; Zogorski and others, 1996). It has been used as a fuel oxygenate (at 11 to 15 percent by volume) since 1988 to improve air quality in some metropolitan areas. Winter use was required by the 1990 Clean Air Act Amendments in all areas of noncompliance to reduce atmospheric concentrations of carbon monoxide. Since 1995, reformulated gasoline has been used year round in nine metropolitan areas to reduce ozone from automobile emissions (Squillace and others, 1996a). Yet, MTBE was the most frequently detected VOC in this study and was widely detected in shallow wells in urban areas of seven other NAWQA study units (Squillace and others, 1996b).

Many (61 percent) of the MTBE detections in this study have been in monitoring wells that are within 0.25 mi of gasoline stations or other known underground gasoline storage tanks that could act as point sources for MTBE and other hydrocarbon contaminants (Garrett and others, 1986). However, a substantial number (39 percent) of MTBE detections occur in similar wells where there are no gasoline stations or other potential point sources in close proximity. Also, few of the MTBE detections occur concurrently with benzene, toluene, ethylbenzene, or xylenes (BTEX) compounds, which are common indicators of gasoline contamination. In addition, there is little evidence of oxygen depletion in samples from wells with MTBE detections relative to wells without MTBE (fig. 26) as would likely be the case if concentrated hydrocarbon contaminant plumes were upgradient of these wells. This evidence and the relatively low concentrations (0.2 to 2.4 µg/L) of MTBE measured in 18 monitoring wells in the study area indicate that most MTBE detections in this study cannot be attributed to large leaks or spills at nearby point sources. Transport of nonpoint source, atmospheric MTBE through the unsaturated zone to a shallow water table has recently been simulated to produce dissolved MTBE concentrations in ambient ground water that are in the same range observed in this study (Pankow and others, 1996).

Similarly to the pesticides, a few VOCs show significant or nearly significant differences in the frequency of detection when compared by aquifer lithologic composition. These differences in VOC detections by aquifer composition are likely artifacts of regional VOC use patterns. Information from the USEPA's Toxic Release Inventory (TRI) (U.S. Environmental Protection Agency, 1995) on the

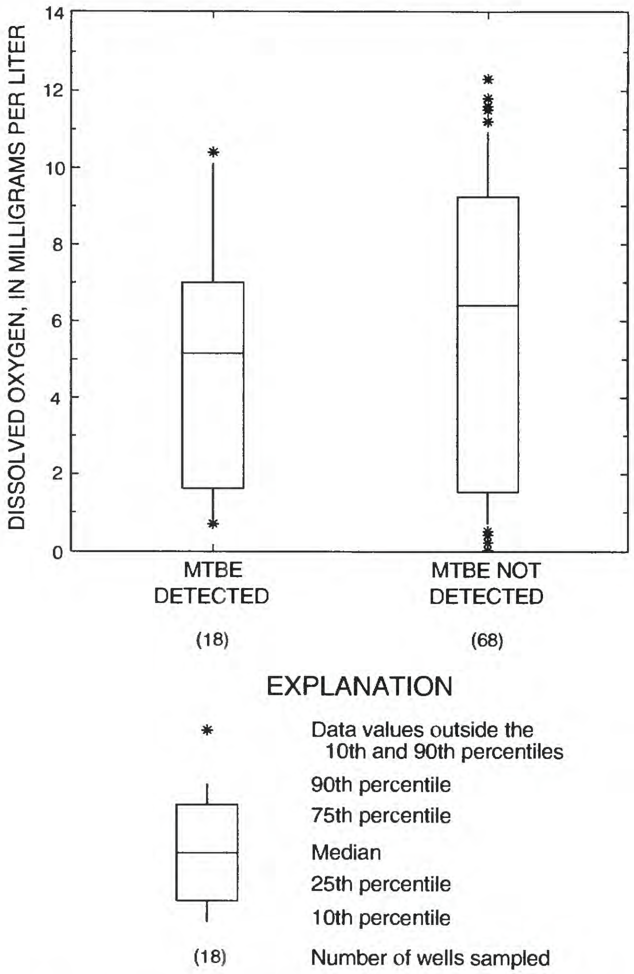


Figure 26. Dissolved oxygen concentrations in water samples from wells with and without detections of methyl *tert*-butyl ether (MTBE) in the Connecticut, Housatonic, and Thames River Basins.

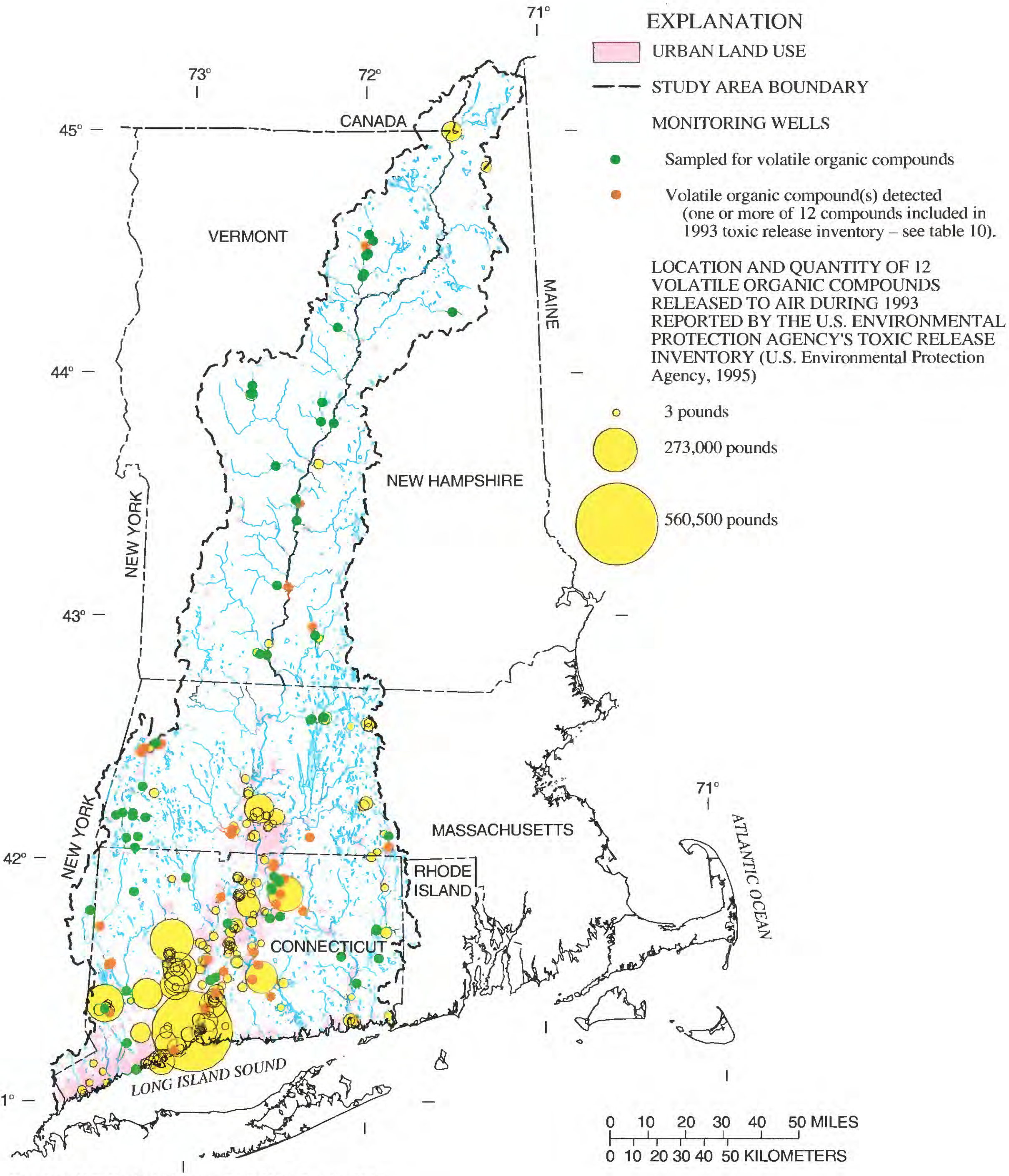
location and quantity of 12 VOCs (table 10) released to the air in 1993 is shown in figure 27. The compound 1,1,1-trichloroethane was detected only in water samples from wells in arkosic aquifers in the southern parts of the study area. The largest reported release for any VOC detected in ground water was more than 3 million lbs of 1,1,1-trichloroethane released into the air in the study unit in 1993. Most of the locations where VOCs were released (fig. 27) and nearly all of the larger releases were in or up wind (generally to the south and west) of the arkosic Mesozoic Basin in central Connecticut and south-central Massachusetts (see fig. 4). Although the 1993 TRI data does not include information on MTBE releases, its occurrence also reflects regional use patterns. MTBE was detected most frequently in arkosic aquifers, but nearly all (97 percent) of MTBE detections were in Connecticut and Massachusetts where statewide use of MTBE in reformulated gasoline is required by the 1990 Clean Air Act Amendments to reduce automobile emissions.

Table 10. Total quantity released to the air during 1987 and 1993 of 12 volatile organic compounds detected in water samples from surficial aquifers in the Connecticut, Housatonic, and Thames River Basins

[Data from U.S. Environmental Protection Agency's Toxic Release Inventory (U.S. Environmental Protection Agency, 1995); NR, not reported]

Volatile organic compound	Total quantity released to air (pounds)	
	1987	1993
1,1,1-Trichloroethane	12,149,753	3,039,217
Toluene	2,997,690	1,477,871
Tetrachloroethene	3,441,766	896,459
Trichloroethene	573,477	316,708
Xylenes (mixed isomers)	779,865	281,114
Dichlorodifluoromethane	NR	146,882
Chloroform	22,000	19,900
Ethylbenzene	15,710	13,715
Naphthalene	2,250	1,298
Carbon tetrachloride	263	624
Isopropylbenzene	NR	200
1,2,4-Trimethylbenzene	NR	67
Total	19,982,774	6,194,055

The TRI data (table 10) indicate, that in some cases, substantial quantities of 12 of the 25 compounds detected in ground water during this study have been released into the air in recent years. Other VOCs detected in this study also were likely released to the atmosphere in unreported quantities by industry, vehicle exhaust, or other urban and agricultural sources, and VOCs have been detected in outdoor air (Shah and Singh, 1988). The distribution of those monitoring wells with detections of 1 or more of the 12 VOCs reported in the TRI (fig. 27) demonstrates a fairly close association with the pattern of atmospheric releases in 1993. If atmospheric sources are partly responsible for the widespread low-level contamination of shallow ground water documented in this study, the large decrease (69 percent) in atmospheric releases of VOCs observed in the TRI data from 1987 to 1993 (table 10) may be an indication that there will be fewer detections of VOCs in the future.



Base from U.S. Geological Survey Digital Line Graphs, 1989
Universal Transverse Mercator
1:100,000 scale

Figure 27. Distribution of monitoring wells in surficial aquifers where 1 or more of 12 volatile organic compounds were detected, and the locations and quantities released to the air in the Connecticut, Housatonic, and Thames River Basins during 1993.

CONCLUSIONS

Differences in the quality of shallow ground water in unconsolidated surficial (sand and gravel) aquifers in the Connecticut, Housatonic, and Thames River Basins of New England and eastern New York are related to natural factors that can be represented by the lithologic composition of the aquifer materials and to human factors that are associated with the principal land uses in the study area. Data for 177 water-quality variables in 172 water samples collected from some or all of 120 randomly located monitoring wells in surficial aquifers were compared by nonparametric statistical methods whenever one or more analyte was detected. Statistically significant differences in the concentration or frequency of detection for 32 water-quality variables were observed for comparisons among four aquifer-lithologic-composition and three land-use categories at the 0.05 level of significance; 10 variables differed just by land use, 6 variables differed only by aquifer-lithologic composition, and 16 variables differed significantly by both factors.

Among the physical and chemically related properties of water and the inorganic constituents, measurements of specific conductance and water temperature, and concentrations of DO, calcium, magnesium, hardness as $CaCO_3$, sodium, potassium, bicarbonate, alkalinity, nitrite plus nitrate, sulfate, bromide, silica, and dissolved solids are significantly related to aquifer-lithologic composition and land use. Noncarbonate hardness, chloride, and manganese concentrations are significantly related to land use only, whereas pH is significantly related to aquifer-lithologic composition only. A multifactor ANOVA on ranked data for each of these 18 continuous (or weakly censored) water-quality variables shows that only potassium displayed a significant interaction effect between aquifer-lithologic composition and land use. Lack of a significant interaction effect for 17 water-quality variables with significant aquifer-lithologic-composition and (or) land-use effects demonstrates that the two factors are independent. Consequently, differences in water quality produced by human activities associated with each land-use category are consistent within each aquifer-lithologic composition category, and the effects of aquifer-lithologic composition occur equally for all three land uses.

Regional differences in the mineralogical (lithologic) composition of surficial aquifers reflect the regional distribution of four major lithologic-composition categories of bedrock in the study area. The primary difference is the percentage of carbonate minerals in the bulk composition of the rock matrix. Surficial aquifers in the study area are classified as crystalline, arkosic, calcareous, or carbonate on the basis of the areal distribution of parent bedrock units of similar composition and knowledge of the direction and extent of glacial and meltwater transport of the sediments that make up the surficial aquifers.

Differences in water type are evident among the four aquifer-lithologic-composition categories. The very fresh (containing less than 100 mg/L dissolved solids), slightly acidic ground water characteristic of crystalline surficial aquifers is a result of the low solubility of their predominantly aluminosilicate mineralogy. The acidity of this water reflects the low buffering capacity that results from lack of a carbonate mineral source. Calcium and bicarbonate were the dominant ions in all water samples from the carbonate surficial aquifers. The predominance of calcium and bicarbonate decreased somewhat to 90 percent of all water samples from calcareous surficial aquifers and 80 percent of samples from arkosic surficial aquifers, but they were still the dominant ions in 60 percent of water samples from crystalline surficial aquifers. Sulfate and chloride replaced bicarbonate, and sodium was more prevalent than calcium in some water samples from crystalline surficial aquifers, even in natural, undeveloped (forested) settings. The most pervasive water type observed in this study was fresh (from 100 to 1,000 mg/L dissolved solids), slightly alkaline ground water that is associated with the carbonate and calcareous aquifers, and to a lesser degree with the arkosic aquifers.

Generally, the lowest concentrations or detection frequencies of inorganic water-quality variables were evident in water from crystalline surficial aquifers and the highest, particularly for carbonate dissolution products, were in samples from the carbonate surficial aquifers. Measurements of specific conductance and pH, and concentrations of dissolved solids, calcium, hardness (as $CaCO_3$), bicarbonate, and alkalinity concentrations were significantly lower in water samples from crystalline aquifers than from the three other surficial aquifers. Magnesium concentrations were three to six times higher in waters from carbonate aquifers than other surficial aquifers. Low calcium to magnesium ratios (less than 5.2:1) for water samples from carbonate aquifers reflect the predominance of dolomite in the carbonate mineralogy, whereas a median ratios of 14:1 for the calcareous waters is more representative of dissolution of calcite. Detections of fluoride and orthophosphate, and concentrations of silica, sodium, sulfate, nitrite plus nitrate, bromide, and DO, plus water temperatures were significantly higher in water samples from the arkosic aquifers relative to one or more of the other surficial aquifers.

Natural water-quality problems associated with one or more surficial aquifer-lithologic-composition categories include elevated concentrations of iron (to 22,000 µg/L) and manganese (to 5,800 µg/L) that exceeded SMCL's in 12 and 48 percent of all wells, respectively. Values of pH less than the 6.5 lower limit SMCL were measured for more than 90 percent of the water samples from the crystalline surficial aquifers. Although dissolved radon concentrations in water from the surficial aquifers (median radon-222 activity of 440 pCi/L) were substantially less than the elevated concentrations associated with crystalline bedrock aquifers (median radon-222 activity of 2,150 pCi/L), 82 percent of the samples from 17 monitoring wells sampled exceeded the 300-pCi/L proposed MCL.

The quality of water in surficial aquifers also is highly affected by human activities and practices associated with major land uses—undeveloped (forested), agricultural, and urban. Water-quality data for undeveloped areas provide a valid indicator of natural, background conditions with which the magnitude of human effects on ground water beneath agricultural and urban areas can be compared and quantified.

Median concentrations of 15 inorganic water-quality variables were lowest in water samples from undeveloped areas and highest in samples from urban areas. DO concentrations, which were highest in undeveloped areas and lowest in urban areas, also reflect degradation of water quality in developed areas relative to natural settings. Dissolved-solids concentrations were significantly higher in ground water beneath urban areas than undeveloped and agricultural areas. In addition, dissolved-solids concentrations were significantly higher in agricultural areas than undeveloped areas. The median dissolved-solids concentration for ground-water samples from urban areas (217 mg/L) was more than twice that of the undeveloped areas (98 mg/L), and 15 percent of the samples from urban areas exceeded the 500-mg/L SMCL. The median chloride concentration for undeveloped areas (3.1 mg/L) was significantly less than medians for the agricultural (12 mg/L) and urban (29 mg/L) ground-water samples. More than 25 percent of the urban samples exceeded 50 mg/L of chloride, and one sample exceeded the 250-mg/L SMCL.

The median nitrite plus nitrate concentration was similarly lowest in ground-water samples from undeveloped areas, whereas median nitrogen concentrations were highest in samples from agricultural areas. The median nitrite plus nitrate concentration of water in undeveloped areas was 0.14 mg/L, and only two samples (5 percent) contained more than 1.0 mg/L. The median nitrite plus nitrate concentration for the ground-water samples from wells in agricultural areas was 3.8 mg/L, and nearly 13 percent of these samples exceeded the 10-mg/L MCL. Nitrogen concentrations in ground-water samples from urban areas were significantly higher than undeveloped areas, but were significantly less than samples from agricultural areas. The median nitrite plus nitrate concentration for ground water from urban areas was 1.1 mg/L, and concentrations ranged as high as 9.7 mg/L.

Twenty-four pesticide compounds or their metabolites were detected in 1 or more of the 103 monitoring wells sampled for pesticides. The frequency of pesticide detections was significantly higher in water samples from monitoring wells in agricultural areas (80 percent) than in samples from wells in undeveloped areas (48 percent). Sixty percent of wells in urban areas also contained one or more pesticide compound. Herbicides were most frequently detected (90 percent of all pesticide detections), and the triazine herbicides, widely used in both agricultural and urban settings, were most prevalent. Detections of atrazine and its metabolite desethylatrazine accounted for 53 percent of all pesticide detections. Nearly all pesticide detections (96 percent) were at concentrations less than 1.0 µg/L, and 41 percent were at concentrations less than 0.01 µg/L. Only one pesticide detection, atrazine at 3.6 µg/L in one well in an agricultural area in Simsbury, Connecticut, exceeded a MCL or MCLG.

Detection frequencies for four compounds, atrazine, desethylatrazine, metolachlor, and prometon, were significantly different for one or more land-use categories. Atrazine (70 percent), desethylatrazine (72 percent), and metolachlor (28 percent) detections were significantly more frequently detected in water samples from agricultural wells than in samples from undeveloped and urban areas. Atrazine and metolachlor, applied to corn fields for preemergent control of broadleaf weeds, were the most and the third-most heavily used pesticides in the study area during 1982-85. Prometon was detected in 32 percent of wells from urban areas, but it was not detected in ground-water samples from undeveloped areas and was detected only once in an agricultural area. Prometon is one of the most commonly used herbicides on railroad, powerline, pipeline, and roadway rights-of-way.

Twenty-five VOCs were detected in one or more of the 86 monitoring wells. Concentrations of VOCs detected in the study area ranged from 0.2 to 300 μg/L. The USEPA has issued, drafted, or proposed MCLs or HAs for 23 of the 25 VOCs detected in ground-water samples, and 5 of the 25 detected compounds—benzene, 1,2-dibromoethane, naphthalene, tetrachloroethene, and trichloroethene—were measured at concentrations exceeding MCLs or HAs. The USEPA also has identified 8 of the 25 detected compounds as either known, probable, or possible human carcinogens.

The frequency of VOC detections was significantly different among the three land-use categories with detections in 62 percent of wells in urban areas and in 38 percent of wells in agricultural areas being significantly higher than the infrequent detections (9 percent of wells) in undeveloped areas. VOC detections among all 86 monitoring wells sampled also were related significantly to population density, but when data for the 40 urban wells were segregated into two population-density classes (less than and more than 1,000 persons/mi^2), no significant difference was evident. VOCs were detected in 70 percent of water samples from wells in areas of more than 1,000 persons/mi^2 but also were detected in 53 percent of wells in areas with lower population densities.

The frequency of detection of MTBE, chloroform, tetrachloroethene, and trichloroethene differed significantly by land use. MTBE, a gasoline oxygenate widely used in the Northeast, was the most commonly detected VOC, present in nearly 21 percent of the monitoring wells overall. MTBE detections in 40 percent of wells in urban areas were significantly higher than detections in undeveloped and agricultural areas. MTBE concentrations ranged from 0.2 to 2.4 μg/L and were substantially less than the 20-μg/L lower limit of the USEPA draft lifetime HA.

Many of the MTBE detections (61 percent) were in monitoring wells that are within 0.25 mi of gasoline stations or other known underground gasoline storage tanks that could be point sources for MTBE. However, a substantial number of MTBE detections (39 percent) occurred in similar wells where there are no gasoline stations or other potential point sources in close proximity. Few of the MTBE detections occurred concurrently with BTEX compounds, which are common indicators of gasoline contamination, and there is no evidence of oxygen depletion in wells with MTBE detections relative to wells without MTBE. The lack of concurrent BTEX or DO depletion, and the low MTBE concentrations measured in 18 randomly sited monitoring wells indicate that most MTBE detections in this study cannot be attributed to large, nearby gasoline leaks and spills. Nonpoint sources of MTBE from automobile exhaust and refueling emissions, leaks and spills of small amounts of gasoline from vehicles and motorized appliances, and infiltration of urban runoff through the unsaturated zone to shallow water tables are likely mechanisms for the widespread detection of MTBE in this study.

Chloroform, a trihalomethane by-product of the process of disinfecting drinking-water supplies, was the second most frequently detected VOC. Low concentrations (0.3 to 3.1 μg/L) of chloroform were present in 19 percent of the all wells sampled, but most widely detected (32 percent) in the urban areas. Chloroform detection frequencies were significantly higher in ground water from urban areas than from undeveloped and agricultural areas. Tetrachloroethene and trichloroethene, solvents commonly used in a variety of industrial and commercial activities, were detected only in ground water beneath urban areas. Concentrations of tetrachloroethene and trichloroethene, as high as 130 to 250 μg/L and 63 μg/L, respectively, were measured in water samples from two monitoring wells in urban areas of Milford and New Milford, Connecticut.

The geographic distribution of some VOCs detected in ground-water samples in this study differs regionally and may reflect regional use patterns and the distribution of sites where these compounds were released to the air during 1993. For example, the compound 1,1,1-trichloroethane was detected only in samples from wells in the arkosic surficial aquifers in south-central Massachusetts and central Connecticut. More than 3 million pounds of 1,1,1-trichloroethane were released into the air in the study area in 1993, and most of the reported releases were in central Connecticut and south-central Massachusetts, within or up wind of the area underlain by arkosic surficial aquifers. There were no reported air releases of MTBE, but 97 percent of MTBE detections in ground water were in Connecticut and Massachusetts where its use in reformulated gasoline is required to reduce automobile emissions.

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Table 11. Land-use category, aquifer-lithologic composition, date sampled, and analytical coverage for 120 monitoring wells in surficial aquifers in the Connecticut, Housatonic, and Thames River Basins

[Site identification No. is latitude and longitude plus two-digit sequence number. Local well number is sequential number assigned to wells inventoried by the U.S. Geological Survey. Analytical coverage: C, dissolved organic carbon; I, physical properties and inorganic chemical constituents; P, pesticides; R, radionuclides; V, volatile organic compounds. Chemical analyses of water samples collected on the dates indicated for the wells are published annually (by State) in the series of U.S. Geological Survey Water-Data Reports containing water-resources data for Connecticut, Massachusetts, New York, and New Hampshire —Vermont. These data also are maintained in the U.S. Geological Survey's Computer Water Data Storage and Retrieval System (WATSTORE), and are on file in the U.S. Geological Survey's East Hartford, Conn. office]

Map reference No. (fig. 6)	Site identification No.	Local well No.	Land-use category	Aquifer-lithologic composition	Date sampled	Time sampled	Analytical coverage
1	410813073160201	FF 29	Urban	Crystalline	08-06-93	1115	C,I,P,V
2	411314073033501	MI 315	Urban	Crystalline	08-06-93	1410	C,I,P,V
					02-07-94	1220	I,V
3	411449073190401	E 32	Undeveloped	Crystalline	09-02-93	1010	C,I,P,V
4	411806073163201	MO 64	Undeveloped	Crystalline	08-16-93	1330	C,I
5	412210073251501	BT 50	Urban	Carbonate	08-12-93	1345	C,I,P,V
					04-05-94	1310	I,V
6	412306073264101	DY 92	Urban	Carbonate	08-12-93	1145	C,I,P,V
					06-27-94	1310	I,V
7	412314073241101	BT 51	Undeveloped	Carbonate	08-24-93	1105	C,I
8	412328072533801	HM 453	Urban	Arkosic	07-29-94	1100	C,I,P,V
9	412422072460401	NBR 118	Undeveloped	Arkosic	08-27-93	1130	C,I
10	412643072314301	HD 472	Undeveloped	Crystalline	08-04-93	1300	C,I,P
					07-01-94	0945	I
					04-24-95	1500	V
11	412722072495701	WLD 279	Urban	Arkosic	08-05-94	1100	C,I,P,V
12	412730072551401	HM 451	Undeveloped	Arkosic	08-23-93	1235	C,I
					10-07-93	1045	I
13	412733073193601	NT 104	Undeveloped	Crystalline	09-02-93	1215	C,I,P,V
					04-20-94	1020	I,V
14	413001072025701	PS 137	Agricultural	Crystalline	08-10-93	1410	C,I,P,V
					04-21-94	1235	I,V
15	413031072513401	CS 206	Undeveloped	Arkosic	09-01-93	0940	C,I,P,V
					04-20-94	1326	I,V
16	413044072375701	MT 394	Agricultural	Arkosic	08-13-93	1345	C,I,P,V
					06-24-94	1310	I,V
17	413114072495401	ME 219	Urban	Arkosic	07-28-94	1330	C,I,P,V
18	413239072472701	ME 218	Urban	Arkosic	07-28-94	1042	C,I,P,V
19	413322073114101	WY 63	Agricultural	Crystalline	08-09-93	1314	C,I,P
20	413354073253901	NMI 32	Agricultural	Carbonate	08-26-93	1210	C,I,P,V
					06-30-94	1035	I,V
21	413427072355501	P 117	Undeveloped	Arkosic	07-29-94	1415	C,I,P,V
22	413434073245301	NMI 38	Urban	Carbonate	08-26-93	1530	C,I,P,V
					04-05-94	1145	I,V
23	413536072525301	S 387	Urban	Arkosic	09-01-93	1140	C,I,P,V
					07-01-94	1250	I
					09-15-94	1030	I,V
24	413619071553201	GS 93	Undeveloped	Crystalline	08-10-93	1115	C,I,P,V
					04-21-94	1030	I,V
25	413644072080501	FR 23	Agricultural	Crystalline	08-07-93	1120	C,I,P,V
					03-29-94	1440	I,V
26	413652072483601	B 403	Undeveloped	Arkosic	08-19-93	1200	C,I
27	413731072373403	P 112	Agricultural	Arkosic	08-13-93	1035	C,I,P,V
					06-23-94	1320	I,V

Table 11. Land-use category, aquifer-lithologic composition, date sampled, and analytical coverage for 120 monitoring wells in surficial aquifers in the Connecticut, Housatonic, and Thames River Basins—*Continued*

Map reference No. (fig. 6)	Site identification No.	Local well No.	Land-use category	Aquifer-lithologic composition	Date sampled	Time sampled	Analytical coverage
28	414200073295301	KT 46	Undeveloped	Carbonate	07-21-95	1150	C,I
29	414258071562701	PL 471	Undeveloped	Crystalline	08-02-93	1130	C,I,P,V
					03-29-94	1120	I,V
30	414306071562802	PL 441	Agricultural	Crystalline	08-02-93	1410	C,I,P,V
31	414327073285201	KT 45	Urban	Carbonate	07-21-95	1000	C,I,P,V
32	414435072461201	WH 142	Urban	Arkosic	08-03-93	1125	C,I,P,V
					06-22-94	1520	I,V
33	414557072320301	M 190	Urban	Arkosic	06-14-94	1110	C,I,P,V
34	414624072283301	M 160	Undeveloped	Arkosic	09-02-94	1510	C,I,P,V
35	414723073320601	3223	Agricultural	Carbonate	08-25-93	1445	C,I,P,V
36	414745072210101	CV 38	Agricultural	Crystalline	07-29-93	1235	C,I,P,V
					05-04-94	0940	I,V
37	414926072300801	V 96	Urban	Arkosic	07-26-94	1300	C,I,P,V
38	414942072265601	V 97	Agricultural	Arkosic	07-17-95	1015	C,I,P
39	415105072482201	SI 456	Agricultural	Crystalline	08-05-93	1120	C,I,P,V
					06-22-94	1100	I,V
40	415155072284601	V 92	Urban	Arkosic	07-26-94	1520	C,I,P,V
41	415209073173101	CRN 27	Undeveloped	Carbonate	08-25-93	1235	C,I,P,V
					06-30-94	1310	I,V
42	415249073215901	SR 21	Undeveloped	Carbonate	07-18-95	1330	C,I
43	415300072311601	EW 139	Undeveloped	Arkosic	08-20-92	1020	I,R
					08-27-93	1410	C,I,P,V
					05-05-94	1025	I,V
44	415329072313501	EW 140	Agricultural	Arkosic	08-20-92	1220	I,R
					08-31-93	1100	C,I,P,V
45	415441072274101	EL 86	Agricultural	Arkosic	09-02-94	1011	C,I,P
46	415450072285301	EL 141	Agricultural	Arkosic	07-27-94	1110	C,I,P,V
47	415458072291901	EL 82	Agricultural	Arkosic	09-02-94	1200	C,I,P
48	415504073213601	CRN 26	Undeveloped	Carbonate	08-25-93	1000	C,I
49	415530072290201	EL 133	Agricultural	Arkosic	08-14-93	1115	C,I,P,V
					05-04-94	1140	I,V
50	415542072273601	EL 142	Agricultural	Arkosic	07-27-94	1430	C,I,P,V
51	415545073000601	BA 104	Undeveloped	Crystalline	08-05-93	1515	C,I,P,V
52	415616072303801	EL 81	Undeveloped	Arkosic	07-26-94	1000	C,I,P,V
53	415811073212901	CN 31	Agricultural	Carbonate	07-18-95	1045	C,I,P
54	415837072305501	EF 125	Agricultural	Arkosic	09-03-92	1305	I,R
					08-30-93	1320	C,IP,V
					05-05-94	1320	I,V
55	415847072301201	EF 127	Undeveloped	Arkosic	08-11-93	1200	C,I
56	415856072263101	SO 110	Undeveloped	Arkosic	09-03-92	1520	I,R
					08-30-93	1520	C,I,P,V
57	415924072304401	EF 126	Urban	Arkosic	08-30-93	1100	C,I,P,V
					06-23-94	0930	I,V
58	420033073165401	NOC 37	Agricultural	Carbonate	08-24-93	1530	C,I,P
59	420302073171501	NKW 54	Agricultural	Carbonate	08-17-92	1200	I,R
					08-24-93	1100	C,I,P,V
60	420347071521801	WLW 72	Urban	Crystalline	08-02-94	1100	C,I,P,V
61	420351073034201	SCW 1	Undeveloped	Crystalline	08-17-93	1135	C,I

Table 11. Land-use category, aquifer-lithologic composition, date sampled, and analytical coverage for 120 monitoring wells in surficial aquifers in the Connecticut, Housatonic, and Thames River Basins—*Continued*

Map reference No. (fig. 6)	Site identification No.	Local well No.	Land-use category	Aquifer-lithologic composition	Date sampled	Time sampled	Analytical coverage
62	420527073201301	SJW 79	Agricultural	Carbonate	08-20-93	1015	C,I,P,V
					07-12-94	1140	I,V
63	420545073162201	NKW 55	Undeveloped	Carbonate	08-23-93	1245	C,I,P,V
64	420555073023001	TPW 3	Undeveloped	Crystalline	09-02-93	1230	C,I
65	420558072185301	M4W 129	Urban	Crystalline	08-24-94	1510	C,I,P,V
66	420624071521101	OXW 93	Urban	Crystalline	08-23-94	1200	C,I,P,V
67	420637072451401	WVW 172	Urban	Crystalline	08-11-93	1145	C,I,P,V
					06-28-94	1210	I,V
68	420651072132401	BOW 72	Agricultural	Crystalline	08-27-93	1100	C,I,P
69	420718073222401	SJW 78	Undeveloped	Carbonate	08-18-92	1400	I,R
					08-23-93	1545	C,I
70	420730073211401	SJW 77	Agricultural	Carbonate	08-17-92	1330	I,R
					08-19-93	1500	C,I,P
71	420744072451001	WVW 171	Urban	Crystalline	08-11-93	1445	C,I,P,V
					06-28-94	1010	I,V
72	420914073213601	SJW 76	Agricultural	Carbonate	08-18-92	1145	I,R
					08-19-93	1000	C,I,P
73	421030073135901	M6W 24	Undeveloped	Carbonate	08-19-92	0815	I,R
					08-17-93	0925	C,I,P,V
					07-12-94	1650	I,V
74	421047073182001	GMW 67	Undeveloped	Carbonate	08-19-92	0925	I,R
					08-17-93	1145	C,I,P,V
75	421101073235201	GMW 68	Agricultural	Carbonate	08-17-92	1545	I,R
					08-18-93	1110	C,I,P,V
76	421120073235901	GMW 69	Agricultural	Carbonate	08-18-92	1535	I,R
					08-18-93	1230	C,I,P
77	421134073213901	GMW 70	Urban	Carbonate	08-18-93	1545	C,I,P,V
					07-12-94	1440	I,V
78	421813073150101	LOW 78	Urban	Carbonate	08-25-94	1050	C,I,P,V
79	422404072402701	XKW 37	Undeveloped	Calcareous	07-24-95	1415	C,I
80	422633073155501	PTW 55	Urban	Carbonate	08-25-94	1400	C,I,P,V
81	422737073150901	PTW 54	Urban	Carbonate	08-26-94	0830	C,I,P,V
82	422831073100101	DAW 37	Urban	Carbonate	08-17-93	1730	C,I,V
					08-18-93	0800	P
					07-13-94	1110	I,V
83	422850073091501	DAW 36	Urban	Carbonate	08-16-93	1310	C,I,P,V
					07-13-94	1335	I,V
84	422903073105701	DAW 38	Undeveloped	Carbonate	08-16-93	1510	C,I,P,V
85	423511072183801	ORW 70	Urban	Crystalline	08-22-94	1230	C,I,P,V
86	423543072141401	ARW 73	Urban	Crystalline	08-24-94	1100	C,I,P,V
87	424105072412001	CSW 46	Agricultural	Calcareous	07-24-95	1100	C,I,P
88	424738072395301	GXW 1	Undeveloped	Calcareous	07-28-95	1015	C,I
89	425103072333501	BTW 10	Urban	Calcareous	07-25-95	1105	I,P,V
90	425117072355901	BTW 11	Urban	Calcareous	07-25-95	1345	C,I,P,V
91	425558072171701	KEW 118	Urban	Crystalline	07-31-95	1345	C,I,P,V
92	425801072182001	KEW 119	Agricultural	Crystalline	07-31-95	1155	C,I,P,V
93	430746072263701	RKW 120	Urban	Calcareous	08-12-94	1015	C,I,P,V
94	430813072301901	RKW 121	Urban	Calcareous	07-27-95	1015	C,I,P,V

Table 11. Land-use category, aquifer-lithologic composition, date sampled, and analytical coverage for 120 monitoring wells in surficial aquifers in the Connecticut, Housatonic, and Thames River Basins—*Continued*

Map reference No. (fig. 6)	Site identification No.	Local well No.	Land-use category	Aquifer-lithologic composition	Date sampled	Time sampled	Analytical coverage
95	432325072242101	WMW 128	Undeveloped	Calcareous	07-27-95	1330	C,I
96	432413072235001	CRW 41	Agricultural	Calcareous	08-09-94	0945	C,I,P,V
97	432826072230901	X2W 17	Urban	Calcareous	08-09-94	1700	C,I,P,V
98	432859072234201	X2W 16	Undeveloped	Calcareous	08-09-94	1300	C,I,P,V
99	433607072333001	X8W 13	Agricultural	Calcareous	08-08-94	1400	C,I,P
100	433740072305801	X8W 14	Urban	Calcareous	08-08-94	1800	C,I,P,V
101	434819072110901	TFW 13	Agricultural	Calcareous	08-10-94	0930	C,I,P,V
102	434844072153101	TFW 14	Undeveloped	Calcareous	08-10-94	1320	C,I,P,V
103	435332072151101	TFW 15	Agricultural	Calcareous	08-10-94	1615	C,I,P,V
104	435523072393101	RAW 15	Urban	Calcareous	08-11-94	1110	C,I,P,V
105	435731072391501	RAW 16	Agricultural	Calcareous	08-11-94	1450	C,I,P,V
106	440011072164201	CPW 1	Undeveloped	Calcareous	08-04-95	0920	C,I
107	441202072095701	RYW 12	Agricultural	Calcareous	08-15-94	1515	C,I,P,V
108	441502071465201	SUW 2	Agricultural	Crystalline	08-18-94	1415	C,I,P
109	441558071301401	CFW 18	Undeveloped	Crystalline	08-18-94	1055	C,I,P,V
110	442439072012001	SDW 12	Urban	Calcareous	08-16-94	1150	C,I,P,V
111	442519072004301	SDW 13	Urban	Calcareous	08-16-94	0900	C,I,P,V
112	442948072000601	SDW 2	Agricultural	Calcareous	09-02-92	0855	I,R
					09-08-93	1045	C,I,P,V
113	443015071592201	LYW 14	Undeveloped	Calcareous	08-16-94	1615	C,I,P,V
114	443017071590301	LYW 15	Agricultural	Calcareous	08-17-94	0930	C,I,P
115	443209072002901	LYW 16	Urban	Calcareous	08-17-94	1240	C,I,P,V
116	443327071574101	LYW 1	Undeveloped	Calcareous	09-01-92	1500	I,R
					09-07-93	1530	C,I,P,V
					08-17-94	1515	I,V
117	443503071585701	LYW 2	Undeveloped	Calcareous	09-01-92	1620	I,R
					09-07-93	1330	C,I,P,V
118	443534072055201	SJW 1	Agricultural	Calcareous	09-02-92	1045	I,R
					09-08-93	0835	C,I,P
119	443704071234801	SNW 1	Agricultural	Crystalline	08-19-94	1000	C,I,P
120	443855071532301	EAW 1	Undeveloped	Calcareous	09-01-92	1315	I,R
					09-07-93	1705	C,I

Table 12. Statistical summary of hydrogeologic and water-quality data by land use and aquifer-lithologic composition at 120 monitoring wells in surficial aquifers in the Connecticut, Housatonic, and Thames River Basins, August 17, 1992 through August 4, 1995

[All water-quality constituents are dissolved except as indicated. When multiple values are available from one well, the median value is used to calculate the statistic; when multiple samples were collected from a well, any detection of the target analyte was counted as a detection for summary statistics. Negative depth to water values indicate water levels above land-surface datum. Sample populations are designated by letter symbols (A, B, C, and D); sample populations that share the same letter symbol are not significantly different at $\alpha = 0.05$. Asterisk (*) indicates some constituent concentrations are less than the reporting limit, and, therefore the statistic is estimated using the method of Helsel and Cohn (1988). E, value estimated by analyst; <, actual value is less than value shown; >, actual value is greater than value shown. µS/cm at 25 °C, microsiemen per centimeter at 25 degrees Celsius; mg/L, milligram per liter; µg/L, microgram per liter; pCi/L, picocurie per liter. --,insufficient data to calculate the statistic]

Hydrogeologic or water-quality variable, units, and statistic	Land use			Aquifer-lithologic composition			
	Undeveloped	Agricultural	Urban	Crystalline	Arkosic	Calcareous	Carbonate
HYDROGEOLOGIC VARIABLES							
Depth to water (feet)							
Number of wells	40	40	40	30	30	30	30
Maximum	26.0	29.3	45.9	23.8	38.5	45.9	23.4
Median	7.78	8.51	9.35	8.59	9.35	8.38	8.38
Minimum	-10	3.32	-.44	2.02	3.32	-10	1.22
Interquartile range	5.21	6.42	7.20	7.22	6.55	7.30	6.90
Population	A	A	A	A	A	A	A
Depth of well (feet)							
Number of wells	40	40	40	30	30	30	30
Maximum	54.0	50.5	53.6	50.5	49.9	54.0	29.4
Median	16.8	20.7	21.8	18.1	24.0	22.4	18.7
Minimum	7.0	9.0	9.7	8.5	9.1	9.7	7.0
Interquartile range	11.2	11.6	9.9	8.8	14.5	10.9	6.5
Population	B	AB	A	A	A	A	A
WATER-QUALITY VARIABLES—PHYSICAL PROPERTIES							
Specific conductance (µS/cm at 25°C)							
Number of wells	40	40	40	30	30	30	30
Maximum	808	1,060	2,240	546	1,060	975	2,240
Median	170	276	361	158	300	331	390
Minimum	36	66	139	36	66	39	83
Interquartile range	190	233	303	148	180	241	316
Population	C	B	A	B	A	A	A
pH (standard units)							
Number of wells	40	40	40	30	29	30	29
Maximum	8.7	8.1	8.2	7.2	8.4	8.7	8.1
Median	6.9	6.6	6.8	6.1	6.8	7.2	7.3
Minimum	5.4	5.2	5.1	5.1	5.5	6.1	6.0
Interquartile range	1.4	1.3	1.1	.6	1.2	.9	.8
Population	A	A	A	B	A	A	A
Temperature (°C)							
Number of wells	39	40	40	30	29	30	30
Maximum	19.0	14.0	15.5	13.0	19.0	15.5	14.0
Median	9.5	10.2	11.5	10.5	11.5	9.2	10.1
Minimum	6.0	6.5	8.0	6.5	9.0	6.5	6.0
Interquartile range	2.5	2.9	2.0	2.25	2.0	3.0	2.0
Population	B	AB	A	AB	A	B	AB

Table 12. Statistical summary of hydrogeologic and water-quality data by land use and aquifer-lithologic composition at 120 monitoring wells in surficial aquifers in the Connecticut, Housatonic, and Thames River Basins, August 17, 1992 through August 4, 1995—*Continued*

Hydrogeologic or water-quality variable, units, and statistic	Land use			Aquifer-lithologic composition			
	Undeveloped	Agricultural	Urban	Crystalline	Arkosic	Calcareous	Carbonate
	WATER-QUALITY VARIABLES—PHYSICAL PROPERTIES—*Continued*						
Dissolved oxygen (mg/L)							
Number of wells	37	40	40	30	29	29	29
Maximum	11.8	12.3	10.5	10.9	11.8	12.3	10.6
Median	7.8	6.0	3.0	6.8	7.3	3.0	2.0
Minimum	.2	.0	.4	.4	.5	.4	.0
Interquartile range	5.2	5.7	5.0	5.6	3.3	7.1	4.6
Population	A	B	B	AB	A	BC	C
	INORGANIC CONSTITUENTS						
Hardness as $CaCO_3$ (mg/L)							
Number of wells	40	40	40	30	30	30	30
Maximum	290	560	460	130	560	390	460
Median	68	93	135	46	104	108	205
Minimum	4	20	10	4	18	18	24
Interquartile range	94	128	170	40	114	93	130
Population	B	A	A	C	B	AB	A
Noncarbonate hardness (mg/L)							
Number of wells	31	35	32	27	26	23	22
Maximum	180	480	140	110	480	180	120
Median	7	28	31	18	26	31	16
Minimum	1	1	3	2	3	1	1
Interquartile range	11	44	39	22	46	46	26
Population	B	A	A	A	A	A	A
Calcium (mg/L)							
Number of wells	40	40	40	30	30	30	30
Maximum	98	160	140	42	160	140	140
Median	20	30	42	14	30	38	46
Minimum	1.1	6.1	3.6	1.1	4.6	6.5	5.7
Interquartile range	28	35	38	12	34	29	33
Population	B	A	A	C	B	AB	A
Magnesium (mg/L)							
Number of wells	40	40	40	30	30	30	30
Maximum	30	39	38	14	39	13	38
Median	2.8	4.5	6.2	3.0	5.6	3.2	20
Minimum	.3	1.1	.4	.3	1.1	.4	2.4
Interquartile range	4.5	11	15	2.4	6.8	2.9	15
Population	B	A	A	C	B	C	A
Sodium (mg/L)							
Number of wells	40	40	40	30	30	30	30
Maximum	66	78	290	78	49	100	290
Median	4.2	5.2	17	5.5	11	5.6	4.8
Minimum	.6	1.2	1.9	1.2	3.5	.6	.8
Interquartile range	4.6	4.8	24	5.1	11.4	26.5	9.4
Population	B	B	A	B	A	AB	B

Table 12. Statistical summary of hydrogeologic and water-quality data by land use and aquifer-lithologic composition at 120 monitoring wells in surficial aquifers in the Connecticut, Housatonic, and Thames River Basins, August 17, 1992 through August 4, 1995—*Continued*

Hydrogeologic or water-quality variable, units, and statistic	Land use			Aquifer-lithologic composition			
	Undeveloped	Agricultural	Urban	Crystalline	Arkosic	Calcareous	Carbonate
INORGANIC CONSTITUENTS—*Continued*							
Potassium (mg/L)							
Number of wells	40	40	40	30	30	30	30
Maximum	6.4	15	9.6	5.8	6.2	11	15
Median	1.7	2.2	3.4	2.4	1.4	3.0	2.0
Minimum	.3	.2	.6	.3	.2	.7	.3
Interquartile range	1.8	2.3	3.6	2.1	1.2	2.6	2.8
Population	B	AB	A	A	B	A	A
Bicarbonate (mg/L)							
Number of wells	40	40	40	30	30	30	30
Maximum	330	280	640	53	270	310	640
Median	58	70	128	24	78	112	198
Minimum	4	7	5	4	6	14	28
Interquartile range	105	99	189	42	86	84	162
Population	B	B	A	D	C	B	A
Alkalinity as $CaCO_3$ (mg/L)							
Number of wells	40	40	40	30	30	30	30
Maximum	270	230	520	96	220	250	520
Median	48	58	104	20	98	92	162
Minimum	3	6	4	3	5	11	23
Interquartile range	86	81	156	34	70	69	132
Population	B	B	A	D	C	B	A
Sulfate (mg/L)							
Number of wells	40	40	40	30	30	30	30
Maximum	310	500	83	83	500	310	41
Median	10	15	16	12	15	13	12
Minimum	1.9	1.5	.6	1.3	7.0	1.5	.6
Interquartile range	5	12	16	14	11	7	10
Population	B	A	A	A	A	A	A
Chloride (mg/L)							
Number of wells	40	40	40	30	30	30	30
Maximum	43	130	500	130	110	170	500
Median	3.1	12	29	10	14	8.4	8.4
Minimum	.2	.9	2.1	.5	1.9	.2	.7
Interquartile range	8.8	10	49	14	21	49	14
Population	C	B	A	A	A	A	A
Fluoride (mg/L)							
Number of wells	40	40	40	30	30	30	30
Number of detections (= or > 0.1 mg/L)	12	6	10	2	10	6	10
Maximum	.3	.2	.4	.1	.3	.3	.4
Median	.047*	.030*	.041*	<.1	.052*	.025*	.042*
Minimum	<.1	<.1	<.1	<.1	<.1	<.1	<.1
Interquartile range	.076*	.041*	.081*	--	.073*	.046*	.080*
Population	A	A	A	A	A	A	A

Table 12. Statistical summary of hydrogeologic and water-quality data by land use and aquifer-lithologic composition at 120 monitoring wells in surficial aquifers in the Connecticut, Housatonic, and Thames River Basins, August 17, 1992 through August 4, 1995—*Continued*

Hydrogeologic or water-quality variable, units, and statistic	Land use			Aquifer-lithologic composition			
	Undeveloped	Agricultural	Urban	Crystalline	Arkosic	Calcareous	Carbonate
			INORGANIC CONSTITUENTS—*Continued*				
Bromide (mg/L)							
Number of wells	38	40	40	30	30	30	30
Number of detections (= or > 0.01 mg/L)	23	31	36	24	26	18	22
Maximum	.09	.10	.19	.10	.16	.07	.19
Median	.01	.02	.04	.02	.03	.02	.02
Minimum	<.01	<.01	<.01	<.01	<.01	<.01	<.01
Interquartile range	.014*	.02	.04	.02	.02	.021*	.034*
Population	B	BA	A	A	A	A	A
Silica (mg/L)							
Number of wells	40	40	40	30	30	30	30
Maximum	17	20	35	22	35	16	28
Median	9	10	11	11	15	9.4	8.0
Minimum	5.0	3.4	5.6	4.5	7.8	3.4	5.0
Interquartile range	5.2	6.3	6.9	3.9	5.0	2.9	4.7
Population	B	B	A	B	A	BC	C
Dissolved solids, residue at 180°C (mg/L)							
Number of wells	40	40	40	30	30	30	30
Maximum	572	832	1,190	286	832	572	1,190
Median	98	162	217	96	177	183	216
Minimum	22	44	80	22	44	28	36
Interquartile range	114	136	163	76	195	154	146
Population	C	B	A	B	A	A	A
Nitrite as N (mg/L)							
Number of wells	40	40	40	30	30	30	30
Number of detections (= or > 0.01 mg/L)	3	5	5	2	3	5	3
Maximum	.02	.07	.28	.04	.03	.28	.04
Median	<.01	.0038*	.0002*	<.01	<.01	.0004*	<.01
Minimum	<.01	<.01	<.01	<.01	<.01	<.01	<.01
Interquartile range	--	.0084*	.0020*	--	--	.0035*	--
Population	A	A	A	A	A	A	A
Nitrite plus nitrate as N (mg/L)							
Number of wells	40	40	40	30	30	30	30
Number of detections (= or > 0.01 mg/L)	30	37	32	27	27	23	22
Maximum	9.3	22	9.7	21	15	20	22
Median	.14	3.8	1.1	1.4	1.8	.23	.12
Minimum	<.05	<.05	<.05	<.05	<.05	<.05	<.05
Interquartile range	.80	6.2	2.5	3.9	3.8	1.8	2.4*
Population	C	A	B	A	A	AB	B

Table 12. Statistical summary of hydrogeologic and water-quality data by land use and aquifer-lithologic composition at 120 monitoring wells in surficial aquifers in the Connecticut, Housatonic, and Thames River Basins, August 17, 1992 through August 4, 1995—*Continued*

Hydrogeologic or water-quality variable, units, and statistic	Land use			Aquifer-lithologic composition			
	Undeveloped	Agricultural	Urban	Crystalline	Arkosic	Calcareous	Carbonate
			INORGANIC CONSTITUENTS—*Continued*				
Nitrogen, ammonia as N (mg/L)							
Number of wells	40	40	40	30	30	30	30
Number of detections (= or > 0.01 mg/L)	38	34	35	29	25	25	28
Maximum	.24	3.9	4.8	1.6	1.9	.58	4.8
Median	.02	.02	.03	.02	.02	.02	.03
Minimum	<.01	<.01	<.01	<.01	<.01	<.01	<.01
Interquartile range	.018	.035	.038	.04	.03	.04	.058
Population	A	A	A	A	A	A	A
Nitrogen, ammonia plus organic as N (mg/L)							
Number of wells	40	40	40	30	30	30	30
Number of detections (= or > 0.2 mg/L)	5	4	8	2	5	3	7
Maximum	.4	4.9	11	1.9	1.9	.6	11
Median	.046*	<.02	.006*	<.02	.008*	<.02	.009*
Minimum	<.02	<.02	<.02	<.02	<.02	<.02	<.02
Interquartile range	.074*	--	.076*	--	.046*	--	.153*
Population	A	A	A	A	A	A	A
Phosphorus as P (mg/L)							
Number of wells	40	40	40	30	30	30	30
Number of detections (= or > 0.01 mg/L)	14	11	15	5	19	8	8
Maximum	.05	.06	.13	.04	.13	.04	.05
Median	.015*	.006*	.005*	.003*	.02	.007*	.008*
Minimum	<.01	<.01	<.01	<.01	<.01	<.01	<.01
Interquartile range	.018*	.008*	.018*	.007*	.024*	.010*	.016*
Population	A	A	A	A	A	A	A
Orthophosphate as P (mg/L)							
Number of wells	40	40	40	30	30	30	30
Number of detections (= or > 0.01 mg/L)	19	13	12	9	20	5	10
Maximum	.06	.04	.15	.03	.15	.06	.06
Median	.010*	.006*	.002*	.005*	.02	.001*	.004*
Minimum	<.01	<.01	<.01	<.01	<.01	<.01	<.01
Interquartile range	.014*	.007*	.010*	.008*	.013*	.004*	.008*
Population	A	A	A	B	A	B	AB
Iron (μg/L)							
Number of wells	40	40	40	30	30	30	30
Number of detections (= or > 3.0 μg/L)	35	37	34	28	27	24	27
Maximum	3,200	22,000	17,000	22,000	17,000	2,700	4,300
Median	10	12	14	12	10	11	20
Minimum	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0
Interquartile range	16	28	44	14	14	30	79
Population	A	A	A	A	A	A	A

Table 12. Statistical summary of hydrogeologic and water-quality data by land use and aquifer-lithologic composition at 120 monitoring wells in surficial aquifers in the Connecticut, Housatonic, and Thames River Basins, August 17, 1992 through August 4, 1995—*Continued*

Hydrogeologic or water-quality variable, units, and statistic	Land use			Aquifer-lithologic composition			
	Undeveloped	Agricultural	Urban	Crystalline	Arkosic	Calcareous	Carbonate
			INORGANIC CONSTITUENTS—*Continued*				
Manganese (µg/L)							
Number of wells	40	40	40	30	30	30	30
Number of detections (= or > 1.0 µg/L)	35	34	39	30	25	28	25
Maximum	3,300	2,100	5,800	5,800	3,300	2,000	2,100
Median	34	21	120	40	17	70	94
Minimum	<1.0	<1.0	<1.0	1.0	<1.0	<1.0	<1.0
Interquartile range	252	110	453	420	316	242	718
Population	B	B	A	A	A	A	A
			RADIONUCLIDES				
Gross alpha radioactivity, dissolved (pCi/L)							
Number of wells	8	9	0	0	4	5	8
Number of detections (= or > 0.6 pCi/L)	2	3	--	--	0	2	3
Maximum	.8	7.2	--	--	<.6	.8	7.2
Median	<.6	.27*	--	--	<.6	<.6	.128*
Minimum	<.6	<.6	--	--	<.6	<.6	<.6
Interquartile range	--	1.43*	--	--	--	--	1.75*
Population	--	--	--	--	--	--	--
Gross alpha radioactivity, suspended (pCi/L)							
Number of wells	8	9	0	0	4	5	8
Number of detections (= or > 0.6 pCi/L)	3	3	--	--	2	1	3
Maximum	41	17	--	--	41	1.6	17
Median	.25*	.19*	--	--	<.6	<.6	.31*
Minimum	<.6	<.6	--	--	<.6	<.6	<.6
Interquartile range	4.64*	3.0*	--	--	--	--	5.81*
Population	--	--	--	--	--	--	--
Gross beta radioactivity, dissolved (pCi/L)							
Number of wells	8	9	0	0	4	5	8
Number of detections (= or > 0.6 pCi/L)	8	9	--	--	4	5	8
Maximum	4.8	12	--	--	5.6	12	2.5
Median	1.65	2.5	--	--	3.7	3.9	1.65
Minimum	.9	.9	--	--	.9	1.4	.9
Interquartile range	2.28	3.4	--	--	4.08	6.45	1.03
Population	--	--	--	--	--	--	--

Table 12. Statistical summary of hydrogeologic and water-quality data by land use and aquifer-lithologic composition at 120 monitoring wells in surficial aquifers in the Connecticut, Housatonic, and Thames River Basins, August 17, 1992 through August 4, 1995—*Continued*

Hydrogeologic or water-quality variable, units, and statistic	Land use			Aquifer-lithologic composition			
	Undeveloped	Agricultural	Urban	Crystalline	Arkosic	Calcareous	Carbonate
RADIONUCLIDES—*Continued*							
Gross beta radioactivity, total suspended (pCi/L)							
Number of wells	8	9	0	0	4	5	8
Number of detections (= or > 0.6 pCi/L)	3	5	--	--	1	2	4
Maximum	28	9.1	--	--	28	1.8	9.1
Median	.28*	.6*	--	--	<.6	<.6	.85*
Minimum	<.6	<.6	--	--	<.6	<.6	<.6
Interquartile range	4.24*	2.16*	--	--	--	--	4.41*
Population	--	--	--	--	--	--	--
Radon-222 (pCi/L)							
Number of wells	8	9	0	0	4	5	8
Number of detections (= or > 80 pCi/L)	8	9	--	--	4	5	8
Maximum	1,500	1,000	--	--	340	1,500	830
Median	580	440	--	--	260	1,000	440
Minimum	38	200	--	--	170	750	38
Interquartile range	760	410	--	--	160	490	310
Population	--	--	--	--	--	--	--
ORGANIC CONSTITUENTS							
Carbon, organic as C (mg/L)							
Number of wells	40	40	39	30	30	29	30
Number of detections (= or > 0.1 mg/L)	40	40	39	30	30	29	30
Maximum	11	9.1	11	3.3	11	6.2	9.1
Median	.7	.8	.8	.7	.6	.7	1.4
Minimum	.2	.2	.3	.3	.3	.2	.3
Interquartile range	1.2	.9	1.5	.5	1.6	.7	2.0
Population	A	A	A	A	A	A	A
PESTICIDES							
Aldicarb sulfoxide (µg/L)							
Number of wells	23	39	40	27	25	25	25
Number of detections (= or > 0.007 µg/L)	1	1	0	0	2	0	0
Maximum	E.007	1.8	<.021	<.021	1.8	<.021	<.021
Median	<.021	<.021	<.021	<.021	<.021	<.021	<.021
Minimum	<.021	<.021	<.021	<.021	<.021	<.021	<.021
Interquartile range	--	--	--	--	--	--	--
Population	A	A	A	A	A	A	A

Table 12. Statistical summary of hydrogeologic and water-quality data by land use and aquifer-lithologic composition at 120 monitoring wells in surficial aquifers in the Connecticut, Housatonic, and Thames River Basins, August 17, 1992 through August 4, 1995—*Continued*

Hydrogeologic or water-quality variable, units, and statistic	Land use			Aquifer-lithologic composition			
	Undeveloped	Agricultural	Urban	Crystalline	Arkosic	Calcareous	Carbonate
PESTICIDES—*Continued*							
Atrazine (µg/L)							
Number of wells	23	40	40	27	26	25	25
Number of detections (= or > 0.001 µg/L)	3	28	11	11	10	11	10
Maximum	.018	3.6	2.3	3.6	2.3	.12	.56
Median	<.001	.013*	<.001	.003*	<.001	<.001	.003*
Minimum	<.001	<.001	<.001	<.001	<.001	<.001	<.001
Interquartile range	.002*	.149*	.002*	.022*	.007*	.002*	.036*
Population	B	A	B	A	A	A	A
Atrazine, desethyl (µg/L)							
Number of wells	23	40	40	27	26	25	25
Number of detections (= or > 0.001 µg/L)	4	29	11	11	10	12	11
Maximum	E.034	E1.4	E.56	E1.4	E.56	E.42	E.70
Median	<.001	.014*	<.001	.005*	<.001	<.001	.003*
Minimum	<.001	<.001	<.001	<.001	<.001	<.001	<.001
Interquartile range	--	.163*	.002*	.050*	.004*	.004*	.027*
Population	B	A	B	A	A	A	A
Benfluralin (µg/L)							
Number of wells	23	40	40	27	26	25	25
Number of detections (= or > 0.002 µg/L)	0	1	0	0	0	1	0
Maximum	<.002	.004	<.002	<.002	<.002	.004	<.002
Median	<.002	<.002	<.002	<.002	<.002	<.002	<.002
Minimum	<.002	<.002	<.002	<.002	<.002	<.002	<.002
Interquartile range	--	--	--	--	--	--	--
Population	A	A	A	A	A	A	A
Bromacil (µg/L)							
Number of wells	23	40	40	27	26	25	25
Number of detections (= or > 0.035 µg/L)	0	0	1	0	0	0	1
Maximum	<.035	<.035	3.0	<.035	<.035	<.035	3.0
Median	<.035	<.035	<.035	<.035	<.035	<.035	<.035
Minimum	<.035	<.035	<.035	<.035	<.035	<.035	<.035
Interquartile range	--	--	--	--	--	--	--
Population	A	A	A	A	A	A	A
Carbaryl (µg/L)							
Number of wells	23	40	40	27	26	25	25
Number of detections (= or > 0.003 µg/L)	3	0	2	0	0	0	5
Maximum	E.020	<.003	<.003	<.003	<.003	<.003	E.020
Median	.011*	<.003	<.003	<.003	<.003	<.003	.004*
Minimum	<.003	<.003	<.003	<.003	<.003	<.003	<.003
Interquartile range	.005*	--	--	--	--	--	.005*
Population	A	A	A	B	B	B	A

Table 12. Statistical summary of hydrogeologic and water-quality data by land use and aquifer-lithologic composition at 120 monitoring wells in surficial aquifers in the Connecticut, Housatonic, and Thames River Basins, August 17, 1992 through August 4, 1995—*Continued*

Hydrogeologic or water-quality variable, units, and statistic	Land use			Aquifer-lithologic composition			
	Undeveloped	Agricultural	Urban	Crystalline	Arkosic	Calcareous	Carbonate
			PESTICIDES—*Continued*				
Carbofuran (μg/L)							
Number of wells	23	40	40	27	26	25	25
Number of detections (= or > 0.003 μg/L)	0	2	0	0	2	0	0
Maximum	<.003	1.3	<.003	<.003	1.3	<.003	<.003
Median	<.003	<.003	<.003	<.003	<.003	<.003	<.003
Minimum	<.003	<.003	<.003	<.003	<.003	<.003	<.003
Interquartile range	--	--	--	--	--	--	--
Population	A	A	A	A	A	A	A
Dacthal (μg/L)							
Number of wells	23	40	40	27	26	25	25
Number of detections (= or > 0.003 μg/L)	0	1	0	0	0	1	0
Maximum	<.002	E.001	<.002	<.002	<.002	E.001	<.002
Median	<.002	<.002	<.002	<.002	<.002	<.002	<.002
Minimum	<.002	<.002	<.002	<.002	<.002	<.002	<.002
Interquartile range	--	--	--	--	--	--	--
Population	A	A	A	A	A	A	A
Dichlobenil (μg/L)							
Number of wells	23	40	40	27	26	25	25
Number of detections (= or > 0.02 μg/L)	0	1	0	0	0	1	0
Maximum	<.02	E.13	<.02	<.02	<.02	E.13	<.02
Median	<.02	<.02	<.02	<.02	<.02	<.02	<.02
Minimum	<.02	<.02	<.02	<.02	<.02	<.02	<.02
Interquartile range	--	--	--	--	--	--	--
Population	A	A	A	A	A	A	A
Dichlorodiphenyl-dichloroethylene (μg/L)							
Number of wells	23	40	40	27	26	25	25
Number of detections (= or > 0.001 μg/L)	2	2	1	1	0	4	0
Maximum	E.002	.006	E.001	E.001	<.006	.006	<.006
Median	<.006	<.006	<.006	<.006	<.006	.002*	<.006
Minimum	<.006	<.006	<.006	<.006	<.006	<.006	<.006
Interquartile range	--	--	--	--	--	.002*	--
Population	A	A	A	AB	B	A	AB
Dichlorprop (μg/L)							
Number of wells	23	40	40	27	26	25	25
Number of detections (= or > 0.010 μg/L)	0	1	0	0	0	1	0
Maximum	<.032	E.010	<.032	<.032	<.032	E.010	<.032
Median	<.032	<.032	<.032	<.032	<.032	<.032	<.032
Minimum	<.032	<.032	<.032	<.032	<.032	<.032	<.032
Interquartile range	--	--	--	--	--	--	--
Population	A	A	A	A	A	A	A

Table 12. Statistical summary of hydrogeologic and water-quality data by land use and aquifer-lithologic composition at 120 monitoring wells in surficial aquifers in the Connecticut, Housatonic, and Thames River Basins, August 17, 1992 through August 4, 1995—*Continued*

Hydrogeologic or water-quality variable, units, and statistic	Land use			Aquifer-lithologic composition			
	Undeveloped	Agricultural	Urban	Crystalline	Arkosic	Calcareous	Carbonate
			PESTICIDES—*Continued*				
Ethalfluralin (µg/L)							
Number of wells	23	40	40	27	26	25	25
Number of detections (= or > 0.004 µg/L)	0	1	0	0	0	1	0
Maximum	<.004	.004	<.004	<.004	<.004	.004	<.004
Median	<.004	<.004	<.004	<.004	<.004	<.004	<.004
Minimum	<.004	<.004	<.004	<.004	<.004	<.004	<.004
Interquartile range	--	--	--	--	--	--	--
Population	A	A	A	A	A	A	A
Metolachlor (µg/L)							
Number of wells	23	40	40	27	26	25	25
Number of detections (= or > 0.002 µg/L)	0	11	3	4	7	0	3
Maximum	<.002	1.2	.009	1.2	.065	<.002	.013
Median	<.002	<.002	<.002	<.002	<.002	<.002	<.002
Minimum	<.002	<.002	<.002	<.002	<.002	<.002	<.002
Interquartile range	--	.003*	--	.002*	--	--	--
Population	B	A	B	AB	A	B	AB
Metribuzin (µg/L)							
Number of wells	23	40	40	27	26	25	25
Number of detections (= or > 0.002 µg/L)	0	0	2	0	1	1	0
Maximum	<.004	<.004	E.002	<.004	E.002	E.002	<.004
Median	<.004	<.004	<.004	<.004	<.004	<.004	<.004
Minimum	<.004	<.004	<.004	<.004	<.004	<.004	<.004
Interquartile range	--	--	--	--	--	--	--
Population	A	A	A	A	A	A	A
Napropamide (µg/L)							
Number of wells	23	40	40	27	26	25	25
Number of detections (= or > 0.003 µg/L)	0	1	0	0	1	0	0
Maximum	<.003	.010	<.003	<.003	.010	<.003	<.003
Median	<.003	<.003	<.003	<.003	<.003	<.003	<.003
Minimum	<.003	<.003	<.003	<.003	<.003	<.003	<.003
Interquartile range	--	--	--	--	--	--	--
Population	A	A	A	A	A	A	A
Permethrin, *cis*- (µg/L)							
Number of wells	23	40	40	27	26	25	25
Number of detections (= or > 0.004 µg/L)	0	2	0	0	0	2	0
Maximum	<.005	.007	<.005	<.005	<.005	.007	<.005
Median	<.005	<.005	<.005	<.005	<.005	<.005	<.005
Minimum	<.005	<.005	<.005	<.005	<.005	<.005	<.005
Interquartile range	--	--	--	--	--	--	--
Population	A	A	A	A	A	A	A

Table 12. Statistical summary of hydrogeologic and water-quality data by land use and aquifer-lithologic composition at 120 monitoring wells in surficial aquifers in the Connecticut, Housatonic, and Thames River Basins, August 17, 1992 through August 4, 1995—*Continued*

Hydrogeologic or water-quality variable, units, and statistic	Land use			Aquifer-lithologic composition			
	Undeveloped	Agricultural	Urban	Crystalline	Arkosic	Calcareous	Carbonate
			PESTICIDES—*Continued*				
Prometon (µg/L)							
Number of wells	23	40	40	27	26	25	25
Number of detections (= or > 0.009 µg/L)	0	1	13	3	1	6	4
Maximum	<.018	E.009	.17	.056	E.015	.17	.17
Median	<.018	<.018	.011*	.013*	<.018	.007*	.011*
Minimum	<.018	<.018	<.018	<.018	<.018	<.018	<.018
Interquartile range	--	--	.019*	.011*	--	.016*	.016*
Population	B	B	A	AB	B	A	AB
Propanil (µg/L)							
Number of wells	23	40	40	27	26	25	25
Number of detections (= or > 0.004 µg/L)	0	0	1	0	0	0	1
Maximum	<.004	<.004	.008	<.004	<.004	<.004	.008
Median	<.004	<.004	<.004	<.004	<.004	<.004	<.004
Minimum	<.004	<.004	<.004	<.004	<.004	<.004	<.004
Interquartile range	--	--	--	--	--	--	--
Population	A	A	A	A	A	A	A
Propargite (µg/L)							
Number of wells	23	40	40	27	26	25	25
Number of detections (= or > 0.009 µg/L)	0	1	0	0	0	1	0
Maximum	<.013	E.009	<.013	<.013	<.013	E.009	<.013
Median	<.013	<.013	<.013	<.013	<.013	<.013	<.013
Minimum	<.013	<.013	<.013	<.013	<.013	<.013	<.013
Interquartile range	--	--	--	--	--	--	--
Population	A	A	A	A	A	A	A
Simazine (µg/L)							
Number of wells	23	40	40	27	26	25	25
Number of detections (= or > 0.002 µg/L)	2	3	9	1	5	5	3
Maximum	.13	.023	.37	.009	.18	.37	.023
Median	<.005	<.005	.003*	<.005	<.005	.002*	.004*
Minimum	<.005	<.005	<.005	<.005	<.005	<.005	<.005
Interquartile range	--	--	.006*	--	.003*	.007*	.004*
Population	A	A	A	A	A	A	A
Tebuthiuron (µg/L)							
Number of wells	23	40	40	27	26	25	25
Number of detections (= or > 0.01 µg/L)	0	0	2	0	0	0	2
Maximum	<.01	<.01	.079	<.01	<.01	<.01	.079
Median	<.01	<.01	<.01	<.01	<.01	<.01	<.01
Minimum	<.01	<.01	<.01	<.01	<.01	<.01	<.01
Interquartile range	--	--	--	--	--	--	--
Population	A	A	A	A	A	A	A

Table 12. Statistical summary of hydrogeologic and water-quality data by land use and aquifer-lithologic composition at 120 monitoring wells in surficial aquifers in the Connecticut, Housatonic, and Thames River Basins, August 17, 1992 through August 4, 1995—*Continued*

Hydrogeologic or water-quality variable, units, and statistic	Land use			Aquifer-lithologic composition			
	Undeveloped	Agricultural	Urban	Crystalline	Arkosic	Calcareous	Carbonate
			PESTICIDES—*Continued*				
Terbacil (µg/L)							
Number of wells	23	40	40	27	26	25	25
Number of detections (= or > 0.007 µg/L)	0	2	0	0	1	1	0
Maximum	<.007	E.33	<.007	<.007	E.056	E.33	<.007
Median	<.007	<.007	<.007	<.007	<.007	<.007	<.007
Minimum	<.007	<.007	<.007	<.007	<.007	<.007	<.007
Interquartile range	--	--	--	--	--	--	--
Population	A	A	A	A	A	A	A
Triallate (µg/L)							
Number of wells	23	40	40	27	26	25	25
Number of detections (= or > 0.001 µg/L)	0	1	0	0	0	1	0
Maximum	<.001	.002	<.001	<.001	<.001	.002	<.001
Median	<.001	<.001	<.001	<.001	<.001	<.001	<.001
Minimum	<.001	<.001	<.001	<.001	<.001	<.001	<.001
Interquartile range	--	--	--	--	--	--	--
Population	A	A	A	A	A	A	A
Trifluralin (µg/L)							
Number of wells	23	40	40	27	26	25	25
Number of detections (= or > 0.002 µg/L)	0	2	0	0	0	2	0
Maximum	<.002	.004	<.002	<.002	<.002	.004	<.002
Median	<.002	<.002	<.002	<.002	<.002	<.002	<.002
Minimum	<.002	<.002	<.002	<.002	<.002	<.002	<.002
Interquartile range	--	--	--	--	--	--	--
Population	A	A	A	A	A	A	A
			VOLATILE ORGANIC COMPOUNDS				
Benzene (µg/L)							
Number of wells	22	24	40	23	22	21	20
Number of detections (= or > 0.2 µg/L)	0	1	1	0	1	0	1
Maximum	<.2	.6	73	<.2	.6	<.2	73
Median	<.2	<.2	<.2	<.2	<.2	<.2	<.2
Minimum	<.2	<.2	<.2	<.2	<.2	<.2	<.2
Interquartile range	--	--	--	--	--	--	--
Population	A	A	A	A	A	A	A
Bromobenzene (µg/L)							
Number of wells	22	24	40	23	22	21	20
Number of detections (= or > 0.2 µg/L)	0	1	0	0	1	0	0
Maximum	<.2	.4	<.2	<.2	<.2	<.2	<.2
Median	<.2	<.2	<.2	<.2	<.2	<.2	<.2
Minimum	<.2	<.2	<.2	<.2	<.2	<.2	<.2
Interquartile range	--	--	--	--	--	--	--
Population	A	A	A	A	A	A	A

Table 12. Statistical summary of hydrogeologic and water-quality data by land use and aquifer-lithologic composition at 120 monitoring wells in surficial aquifers in the Connecticut, Housatonic, and Thames River Basins, August 17, 1992 through August 4, 1995—*Continued*

Hydrogeologic or water-quality variable, units, and statistic	Land use			Aquifer-lithologic composition			
	Undeveloped	Agricultural	Urban	Crystalline	Arkosic	Calcareous	Carbonate
VOLATILE ORGANIC COMPOUNDS—*Continued*							
Bromodichloromethane (µg/L)							
Number of wells	22	24	40	23	22	21	20
Number of detections (= or > 0.2 µg/L)	1	0	0	0	1	0	0
Maximum	.2	<.2	<.2	<.2	.2	<.2	<.2
Median	<.2	<.2	<.2	<.2	<.2	<.2	<.2
Minimum	<.2	<.2	<.2	<.2	<.2	<.2	<.2
Interquartile range	--	--	--	--	--	--	--
Population	A	A	A	A	A	A	A
***n*-Butylbenzene (µg/L)**							
Number of wells	22	24	40	23	22	21	20
Number of detections (= or > 0.2 µg/L)	0	0	1	0	0	0	1
Maximum	<.2	<.2	6.8	<.2	<.2	<.2	6.8
Median	<.2	<.2	<.2	<.2	<.2	<.2	<.2
Minimum	<.2	<.2	<.2	<.2	<.2	<.2	<.2
Interquartile range	--	--	--	--	--	--	--
Population	A	A	A	A	A	A	A
***sec*-Butylbenzene (µg/L)**							
Number of wells	22	24	40	23	22	21	20
Number of detections (= or > 0.2 µg/L)	0	0	1	0	0	0	1
Maximum	<.2	<.2	4.4	<.2	<.2	<.2	4.4
Median	<.2	<.2	<.2	<.2	<.2	<.2	<.2
Minimum	<.2	<.2	<.2	<.2	<.2	<.2	<.2
Interquartile range	--	--	--	--	--	--	--
Population	A	A	A	A	A	A	A
Carbon tetrachloride (µg/L)							
Number of wells	22	24	40	23	22	21	20
Number of detections (= or > 0.2 µg/L)	0	0	1	0	0	0	1
Maximum	<.2	<.2	.9	<.2	<.2	<.2	.9
Median	<.2	<.2	<.2	<.2	<.2	<.2	<.2
Minimum	<.2	<.2	<.2	<.2	<.2	<.2	<.2
Interquartile range	--	--	--	--	--	--	--
Population	A	A	A	A	A	A	A
Chloroform (µg/L)							
Number of wells	22	24	40	23	22	21	20
Number of detections (= or > 0.2 µg/L)	1	2	13	6	6	1	3
Maximum	2.6	.4	3.1	3.1	2.9	.3	1.4
Median	<.2	<.2	.081*	.080*	.024*	<.2	.008*
Minimum	<.2	<.2	<.2	<.2	<.2	<.2	<.2
Interquartile range	--	--	.354*	.380*	.221*	--	.050*
Population	B	B	A	A	A	A	A

Table 12. Statistical summary of hydrogeologic and water-quality data by land use and aquifer-lithologic composition at 120 monitoring wells in surficial aquifers in the Connecticut, Housatonic, and Thames River Basins, August 17, 1992 through August 4, 1995—*Continued*

Hydrogeologic or water-quality variable, units, and statistic	Land use			Aquifer-lithologic composition			
	Undeveloped	Agricultural	Urban	Crystalline	Arkosic	Calcareous	Carbonate
VOLATILE ORGANIC COMPOUNDS—*Continued*							
1,2-Dibromoethane (µg/L)							
Number of wells	22	24	40	23	22	21	20
Number of detections (= or > 0.2 µg/L)	0	1	0	0	1	0	0
Maximum	<.2	1.4	<.2	<.2	1.4	<.2	<.2
Median	<.2	<.2	<.2	<.2	<.2	<.2	<.2
Minimum	<.2	<.2	<.2	<.2	<.2	<.2	<.2
Interquartile range	--	--	--	--	--	--	--
Population	A	A	A	A	A	A	A
Dichlorodifluoromethane (µg/L)							
Number of wells	22	24	40	23	22	21	20
Number of detections (= or > 0.2 µg/L)	0	0	1	0	0	1	0
Maximum	<.2	<.2	.8	<.2	<.2	.8	<.2
Median	<.2	<.2	<.2	<.2	<.2	<.2	<.2
Minimum	<.2	<.2	<.2	<.2	<.2	<.2	<.2
Interquartile range	--	--	--	--	--	--	--
Population	A	A	A	A	A	A	A
1,1-Dichloroethane (µg/L)							
Number of wells	22	24	40	23	22	21	20
Number of detections (= or > 0.2 µg/L)	0	0	4	0	1	2	1
Maximum	<.2	<.2	2.2	<.2	.4	1.0	2.2
Median	<.2	<.2	<.2	<.2	<.2	<.2	<.2
Minimum	<.2	<.2	<.2	<.2	<.2	<.2	<.2
Interquartile range	--	--	--	--	--	--	--
Population	A	A	A	A	A	A	A
***cis*-1,2-Dichloroethene (µg/L)**							
Number of wells	22	24	40	23	22	21	20
Number of detections (= or > 0.2 µg/L)	0	0	4	1	1	1	1
Maximum	<.2	<.2	.9	.2	.2	.2	.9
Median	<.2	<.2	<.2	<.2	<.2	<.2	<.2
Minimum	<.2	<.2	<.2	<.2	<.2	<.2	<.2
Interquartile range	--	--	--	--	--	--	--
Population	A	A	A	A	A	A	A
Ethylbenzene (µg/L)							
Number of wells	22	24	40	23	22	21	20
Number of detections (= or > 0.2 µg/L)	0	0	1	0	0	0	1
Maximum	<.2	<.2	270	<.2	<.2	<.2	270
Median	<.2	<.2	<.2	<.2	<.2	<.2	<.2
Minimum	<.2	<.2	<.2	<.2	<.2	<.2	<.2
Interquartile range	--	--	--	--	--	--	--
Population	A	A	A	A	A	A	A

Table 12. Statistical summary of hydrogeologic and water-quality data by land use and aquifer-lithologic composition at 120 monitoring wells in surficial aquifers in the Connecticut, Housatonic, and Thames River Basins, August 17, 1992 through August 4, 1995—*Continued*

Hydrogeologic or water-quality variable, units, and statistic	Land use			Aquifer-lithologic composition			
	Undeveloped	Agricultural	Urban	Crystalline	Arkosic	Calcareous	Carbonate
VOLATILE ORGANIC COMPOUNDS—*Continued*							
Isopropylbenzene (µg/L)							
Number of wells	22	24	40	23	22	21	20
Number of detections (= or > 0.2 µg/L)	0	0	1	0	0	0	1
Maximum	<.2	<.2	27	<.2	<.2	<.2	27
Median	<.2	<.2	<.2	<.2	<.2	<.2	<.2
Minimum	<.2	<.2	<.2	<.2	<.2	<.2	<.2
Interquartile range	--	--	--	--	--	--	--
Population	A	A	A	A	A	A	A
***p*-Isopropyltoluene (µg/L)**							
Number of wells	22	24	40	23	22	21	20
Number of detections (= or > 0.2 µg/L)	0	0	2	1	0	0	1
Maximum	<.2	<.2	6.3	.5	<.2	<.2	6.3
Median	<.2	<.2	<.2	<.2	<.2	<.2	<.2
Minimum	<.2	<.2	<.2	<.2	<.2	<.2	<.2
Interquartile range	--	--	--	--	--	--	--
Population	A	A	A	A	A	A	A
Methylene chloride (µg/L)							
Number of wells	22	24	40	23	22	21	20
Number of detections (= or > 0.2 µg/L)	0	1	2	2	1	0	0
Maximum	<.2	2.8	.9	.9	2.8	<.2	27
Median	<.2	<.2	<.2	<.2	<.2	<.2	<.2
Minimum	<.2	<.2	<.2	<.2	<.2	<.2	<.2
Interquartile range	--	--	--	--	--	--	--
Population	A	A	A	A	A	A	A
Methyl *tert*-butyl ether (µg/L)							
Number of wells	22	24	40	23	22	21	20
Number of detections (= or > 0.2 µg/L)	0	2	16	5	8	1	4
Maximum	<.2	.4	2.4	.5	.7	2.4	1.1
Median	<.2	<.2	.114*	.171*	.105*	<.2	.026*
Minimum	<.2	<.2	<.2	<.2	<.2	<.2	<.2
Interquartile range	--	--	.331*	.139*	.176*	--	.111*
Population	B	B	A	A	A	A	A
Naphthalene (µg/L)							
Number of wells	22	24	40	23	22	21	20
Number of detections (= or > 0.2 µg/L)	1	4	5	2	4	0	4
Maximum	.3	.3	70	.3	.9	<.2	70
Median	<.2	.01*	<.2	<.2	.02*	<.2	<.2
Minimum	<.2	<.2	<.2	<.2	<.2	<.2	<.2
Interquartile range	--	--	--	--	--	--	--
Population	A	A	A	A	A	A	A

Table 12. Statistical summary of hydrogeologic and water-quality data by land use and aquifer-lithologic composition at 120 monitoring wells in surficial aquifers in the Connecticut, Housatonic, and Thames River Basins, August 17, 1992 through August 4, 1995—*Continued*

Hydrogeologic or water-quality variable, units, and statistic	Land use			Aquifer-lithologic composition			
	Undeveloped	Agricultural	Urban	Crystalline	Arkosic	Calcareous	Carbonate
VOLATILE ORGANIC COMPOUNDS—*Continued*							
***n*-Propylbenzene (µg/L)**							
Number of wells	22	24	40	23	22	21	20
Number of detections (= or > 0.2 µg/L)	0	0	1	0	0	0	1
Maximum	<.2	<.2	47	<.2	<.2	<.2	47
Median	<.2	<.2	<.2	<.2	<.2	<.2	<.2
Minimum	<.2	<.2	<.2	<.2	<.2	<.2	<.2
Interquartile range	--	--	--	--	--	--	--
Population	A	A	A	A	A	A	A
Tetrachloroethene (µg/L)							
Number of wells	22	24	40	23	22	21	20
Number of detections (= or > 0.2 µg/L)	0	0	10	1	3	3	3
Maximum	<.2	<.2	250	250	6.5	.9	130
Median	<.2	<.2	.006*	<.2	.003*	.019*	<.2
Minimum	<.2	<.2	<.2	<.2	<.2	<.2	<.2
Interquartile range	--	--	.410*	--	.050*	.084*	.010*
Population	B	B	A	A	A	A	A
Toluene (µg/L)							
Number of wells	22	24	40	23	22	21	20
Number of detections (= or > 0.2 µg/L)	0	2	1	0	1	0	2
Maximum	<.2	2.2	23	<.2	1.5	<.2	23
Median	<.2	<.2	<.2	<.2	<.2	<.2	<.2
Minimum	<.2	<.2	<.2	<.2	<.2	<.2	<.2
Interquartile range	--	--	--	--	--	--	--
Population	A	A	A	A	A	A	A
1,1,1-Trichloroethane (µg/L)							
Number of wells	22	24	40	23	22	21	20
Number of detections (= or > 0.2 µg/L)	0	0	3	0	3	0	0
Maximum	<.2	<.2	1.1	<.2	1.1	<.2	<.2
Median	<.2	<.2	<.2	<.2	.004*	<.2	<.2
Minimum	<.2	<.2	<.2	<.2	<.2	<.2	<.2
Interquartile range	--	--	--	--	.031*	--	--
Population	A	A	A	A	A	A	A
Trichloroethene (µg/L)							
Number of wells	22	24	40	23	22	21	20
Number of detections (= or > 0.2 µg/L)	0	0	6	1	0	2	3
Maximum	<.2	<.2	63	63	<.2	1.8	4.8
Median	<.2	<.2	.001*	<.2	<.2	<.2	.014*
Minimum	<.2	<.2	<.2	<.2	<.2	<.2	<.2
Interquartile range	--	--	.030*	--	--	--	.120*
Population	AB	B	A	A	A	A	A

Table 12. Statistical summary of hydrogeologic and water-quality data by land use and aquifer-lithologic composition at 120 monitoring wells in surficial aquifers in the Connecticut, Housatonic, and Thames River Basins, August 17, 1992 through August 4, 1995—*Continued*

Hydrogeologic or water-quality variable, units, and statistic	Land use			Aquifer-lithologic composition			
	Undeveloped	Agricultural	Urban	Crystalline	Arkosic	Calcareous	Carbonate
VOLATILE ORGANIC COMPOUNDS—*Continued*							
1,2,4-Trimethylbenzene (µg/L)							
Number of wells	22	24	40	23	22	21	20
Number of detections (= or > 0.2 µg/L)	0	3	1	1	2	0	1
Maximum	<.2	.2	260	.2	.2	<.2	260
Median	<.2	<.2	<.2	<.2	<.2	<.2	<.2
Minimum	<.2	<.2	<.2	<.2	<.2	<.2	<.2
Interquartile range	--	--	--	--	--	--	--
Population	A	A	A	A	A	A	A
1,3,5-Trimethylbenzene (µg/L)							
Number of wells	22	24	40	23	22	21	20
Number of detections (= or > 0.2 µg/L)	0	0	1	0	0	0	1
Maximum	<.2	<.2	18	<.2	<.2	<.2	18
Median	<.2	<.2	<.2	<.2	<.2	<.2	<.2
Minimum	<.2	<.2	<.2	<.2	<.2	<.2	<.2
Interquartile range	--	--	--	--	--	--	--
Population	A	A	A	A	A	A	A
Xylenes, *meta-, para-, ortho-* (µg/L)							
Number of wells	22	24	40	23	22	21	20
Number of detections (= or > 0.2 µg/L)	0	0	1	0	0	0	1
Maximum	<.2	<.2	300	<.2	<.2	<.2	300
Median	<.2	<.2	<.2	<.2	<.2	<.2	<.2
Minimum	<.2	<.2	<.2	<.2	<.2	<.2	<.2
Interquartile range	--	--	--	--	--	--	--
Population	A	A	A	A	A	A	A

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