Effects of Land Use on Quality of Water in Stratified-Drift Aquifers in Connecticut

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Chapter B

Effects of Land Use on Quality of Water in Stratified-Drift Aquifers in Connecticut

By STEPHEN J. GRADY

U.S. GEOLOGICAL SURVEY WATER-SUPPLY PAPER 2381

ANALYSIS OF NONPOINT-SOURCE GROUND-WATER CONTAMINATION IN RELATION TO LAND USE

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
GORDON P. EATON, Director

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CONTENTS

FIGURES

TABLES

CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
acre	4,047	square meter
square mile (mi^2)	2.590	square kilometer
	Flow	
inch per year (in/yr)	25.4	millimeter per year
foot per day (ft/d)	0.3048	meter per day
	Hydraulic Conductivity	
foot per day (ft/d)	0.3048	meter per day

Temperature in degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) as follows:

$$°F = 1.8 \times °C + 32$$

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.

Effects of Land Use on Quality of Water in Stratified-Drift Aquifers in Connecticut

By Stephen J. Grady

Abstract

Human activities associated with agricultural, residential, commercial, and industrial land uses have affected the quality of water in the four stratified-drift aquifers examined in Connecticut. A study to evaluate quantitatively the effects of human activities, expressed as land use, on regional ground-water quality was initiated in 1984 as part of the U.S. Geological Survey's Toxic Waste–Ground-Water Contamination Program. Water-quality data were collected from 116 shallow stainless-steel wells installed beneath or immediately downgradient from seven types of land use areas within the Pootatuck, Pomperaug, Farmington, and Hockanum River valleys in Connecticut. Analysis of variance on the ranked concentrations of 21 largely uncensored or slightly censored constituents, and contingency-table analysis of the frequency of detection of 49 moderately to highly censored constituents indicate that 27 water-quality variables differ at the 0.05 level of significance for samples from at least one land use area.

For most constituents, concentrations or detection frequencies are lowest in samples from the undeveloped areas, which characterize background water-quality conditions. The effect of agricultural land use on ground-water quality reflects tillage practices; tilled areas affect the water quality to a greater degree than do untilled areas. Twenty percent of the wells in the tilled agricultural areas yielded water with concentrations of nitrate plus nitrite-nitrogen exceeding 10 milligrams per liter. Atrazine detections in one-third of the wells in areas of tilled agricultural land use were significantly more common than in the undeveloped areas.

Ground-water quality beneath sewered residential areas is more severely affected by inorganic and organic nonpoint-source contaminants than is water quality beneath unsewered residential areas. Median concentrations or detection frequencies of most physical properties and inorganic constituents of ground water are higher in sewered than in unsewered residential areas. Generally low concentrations (less than 1.0 microgram per liter) of one or more of 17 volatile organic compounds were detected in samples from 62 percent of the wells in the unsewered residential areas. Most of these compounds were detected in less than 10 percent of the ground-water samples from the unsewered residential areas, however, and consequently, their frequency of detections was not significantly different than in samples from other land use areas. The detection of chloroform in ground-water samples from 47 percent of the wells in the sewered residential areas is significantly higher than the frequency of detection of chloroform in samples from the undeveloped, tilled agricultural, and unsewered residential areas.

The quality of ground water is adversely affected beneath commercial areas more so than beneath all other land use areas. Median concentrations of sodium (22.5 milligrams per liter), chloride (36 milligrams per liter), and dissolved solids (286 milligrams per liter) are highest in ground-water samples in commercial areas. Detections of tetrachloroethylene, trichloroethylene, and 1,2-transdichloroethylene were significantly more common in ground-water samples from the commercial areas than in samples from one or more of the other land use areas. Tetrachloroethylene was detected in water samples from 50 percent of the observation wells in the commercial areas at concentrations of up to 1,300 micrograms per liter. Trichloroethylene and 1,2-transdichloroethylene were found at concentrations of up to 20 and 55 micrograms per liter, respectively, in samples from more than 40 percent of the wells in the commercial areas.

Although industrial areas occupy only a small part of each of the study areas, they have a disproportionately large effect on ground-water quality. One or more of 12 volatile organic compounds were detected in water samples from 91 percent of the observation wells in the industrial areas. Chloroform, the most commonly detected compound, was found at concentrations of 0.2–1.3 micrograms per liter in samples from more than half of the industrial-area wells. Thirty-six percent of these wells yielded water with detectable concentrations of tetrachloroethylene (0.2–4.9 micrograms per liter), and 95 percent contained 1,1,1-trichloroethane (0.2–180 micrograms per liter). The frequency of 1,1,1-trichloroethane, 1,1-dichloroethane, and 1,1-dichloroethylene detections at concentrations equal to or exceeding 1.0 microgram per liter was significantly higher for samples from the industrial areas than for samples from one or more of the other land use areas.

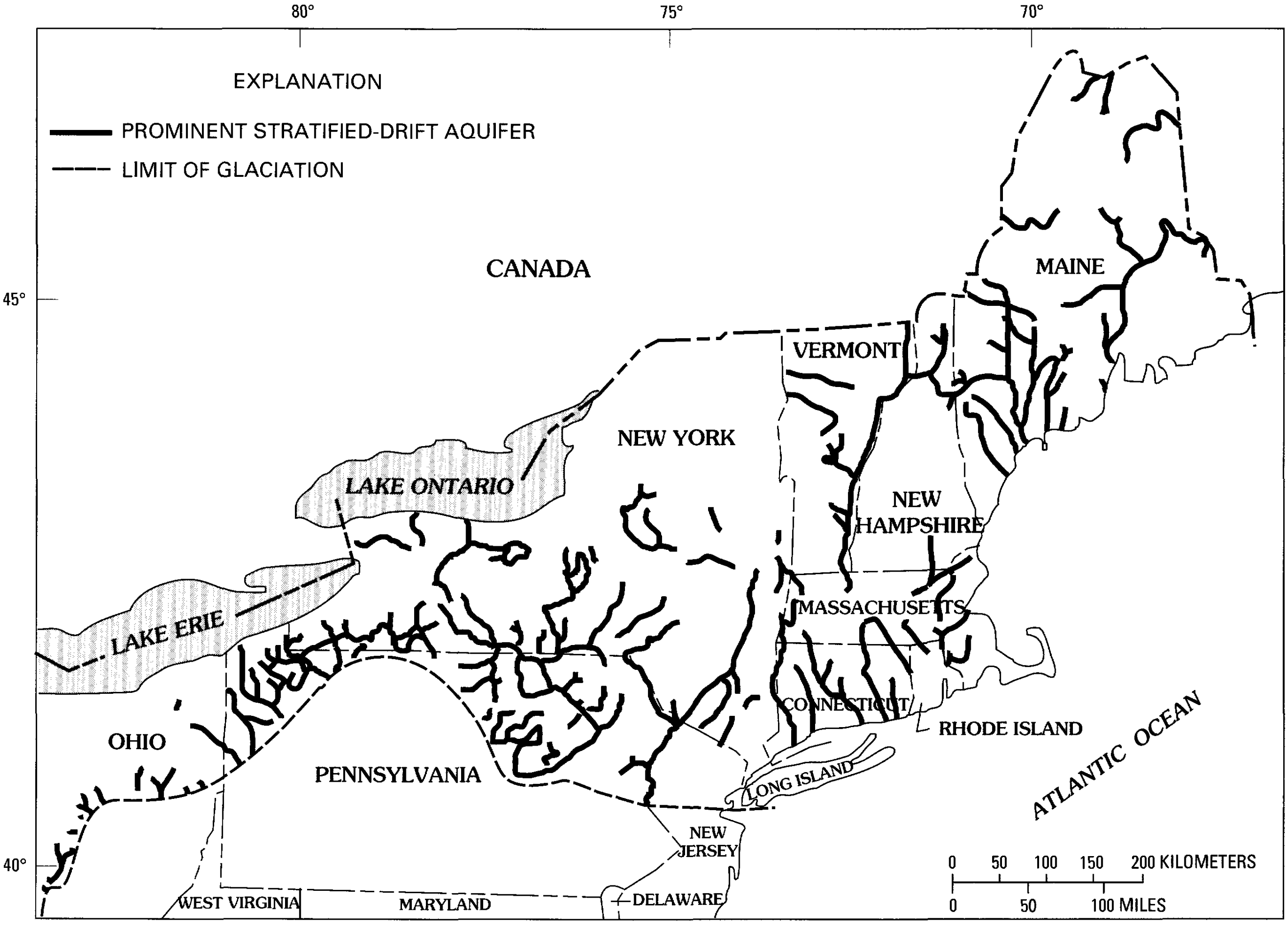


Figure 1. Prominent stratified-drift aquifers in the Northeastern United States (modified from McGuinness, 1964).

INTRODUCTION

Ground water is a vital resource for the Nation, supplying more than half of the population with drinking water, but its quality is being degraded by an increasing number and variety of contaminants. Incidents of ground-water contamination by toxic chemicals have been widely publicized, heightening concern for the protection of ground-water supplies. At present, only a very small part of the Nation's total ground-water resources is known to be contaminated. There are insufficient data, however, particularly about the occurrence of trace elements and synthetic organic chemicals, to assess adequately the full extent of ground-water contamination within the Nation's aquifers.

In 1984 the U.S. Geological Survey's Toxic Waste–Ground-Water Contamination Program initiated studies of the effects of human activities on the quality of ground water in 14 regions of the Nation (Ragone, 1984). Each study has endeavored to relate present ground-water quality to the hydrologic, climatic, and land use characteristics of that region and, by so doing, provides a basis for appraising ground-water quality in other areas of the Nation that have similar characteristics (Helsel and Ragone, 1984). The study in Connecticut has focused on unconsolidated glacial sand and gravel (stratified-drift) aquifers that are among the most productive sources of public-water supply in the glaciated Northeastern United States (fig. 1).

Stratified-drift aquifers that occupy many of the principal river valleys of Connecticut and the region are highly susceptible to contamination from human activities at the land surface. The same hydrologic characteristics that enable these aquifers to yield large quantities of water also facilitate the entry and migration of contaminants. These characteristics are a generally shallow water table, high permeability of predominantly coarse-grained sediments, and hydraulic connection with surface-water bodies.

Purpose and Scope

This report presents the final results of the study to determine the effects of land use activities on the quality of the water in four stratified-drift aquifers in Connecticut. The quality of ground water in the aquifers is described, and emphasis is placed on trace elements and synthetic organic compounds that have anthropogenic sources. The water chemistry is explained in terms of natural hydrogeologic factors and human factors. The hypothesis that human activities, as defined by a variety of land uses, affect ground-water quality is tested by statistical comparisons of water quality beneath land from seven use categories. The report identifies statistically significant relations between land use (or other causative factors) and ground-water quality that may be transferable to similar settings throughout the glaciated Northeast.

The report provides a compilation of information concerning the hydrogeology, land use, and sources of contaminants; description of the design of a sampling network consisting of 116 stainless-steel observation wells and a sample-collection protocol to obtain representative samples of ground water for field and laboratory analyses of 179 water-quality variables, including trace elements and organic chemical compounds; and a statistical analysis of the water-quality data using distribution-free, nonparametric statistical methods.

Previous Investigations

Grady and Weaver (1988) presented preliminary findings of this study based on selected historical data and limited sampling in two of the four aquifers studied. Their report described the methods used to define the hydrogeology, land use, and water quality of stratified-drift aquifers and the statistical methods used to evaluate relations between these factors. Information presented by Grady and Weaver (1988) was used in a review by Cain and others (1989) of the preliminary results of the regional nonpoint-source contamination studies conducted in New York (Eckhardt and others, 1989), New Jersey (Barton and others, 1987), Florida (Rutledge, 1987), Nebraska (Chen and Druliner, 1987), and Colorado (Cain and Edelmann, 1986) as well as Connecticut.

Grady (1989) and Grady and Weaver (1989) presented interim results of the study in Connecticut based on data collected in all four aquifers through 1988. Most of the preliminary and interim findings presented in the above reports are confirmed in this report; however, the additional data available at this time allow the author to refine the land use categories previously used.

Acknowledgments

The author wishes to acknowledge the cooperation, information, and assistance provided by public officials of the Towns of Avon, Ellington, Farmington, Granby, Manchester, Newtown, Plainville, Simsbury, Southbury, South Windsor, Vernon, and Woodbury that greatly facilitated the successful completion of this study. In addition, access was provided by the Connecticut Departments of Environmental Protection and Transportation to public lands for data collection. The author is also grateful to the numerous private citizens, corporations, and utilities that allowed access to their properties for data collection.

APPROACH

The regional nonpoint-source contamination studies followed a common five-step approach developed by Helsel and Ragone (1984), namely, (1) reconnaissance, (2) experimental design, (3) data collection, (4) data analysis, and (5) verification of results. During the reconnaissance phase of the study, all pertinent hydrogeologic, land use, and water-quality information on the study areas was compiled and analyzed, and limited additional data on water-quality were collected. Hypothetical relations among land use, hydrogeology, and water quality were proposed, and preliminary statistical comparisons were made of the water-quality data associated with different land uses. Grady and Weaver (1988) described the information obtained and the preliminary findings of the reconnaissance phase of the Connecticut study.

Information obtained during the reconnaissance phase directed the manner in which additional data were collected to test the hypothesis that human activities have a predictable, quantifiable effect on ground-water quality. Testing the hypothesis required (1) accurate characterization of hydrologic and land use conditions, (2) comprehensive chemical analyses of representative ground-water samples, and (3) valid statistical analysis.

DESCRIPTION OF STUDY AREAS

Four stratified-drift aquifers were selected for this study because their hydrogeologic characteristics and state of development are typical of glacial valley aquifers in Connecticut as well as much of the region. The location of the stratified-drift aquifers in the Pootatuck, Pomperaug, Farmington, and Hockanum River valleys is shown in figure 2.

Hydrogeologic Characteristics of Stratified-Drift Aquifers

A wealth of information is available on the hydrogeologic characteristics of stratified-drift aquifers in the Northeastern United States because many of these aquifers have been investigated for potential water supplies. Typically, these studies have focused on detailed definition of

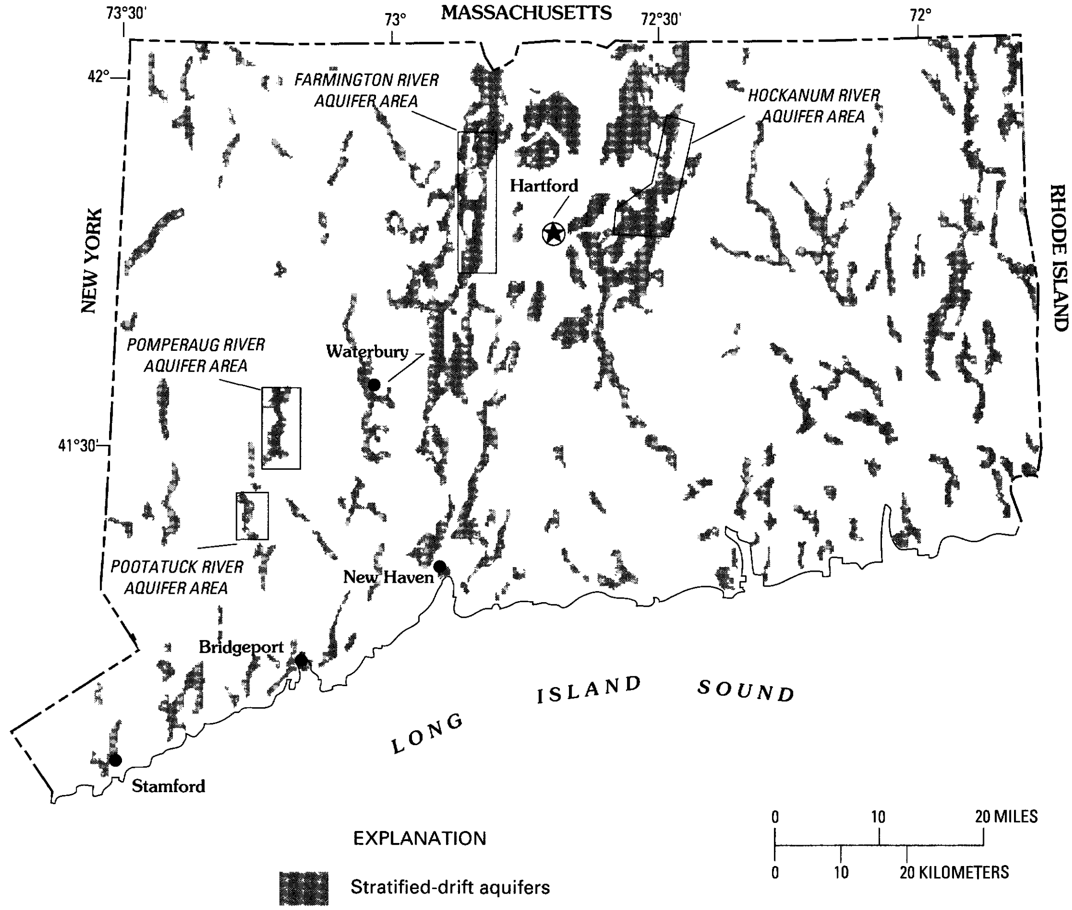


Figure 2. Location of four stratified-drift aquifers studied in Connecticut.

boundaries and hydraulic properties of the stratified-drift aquifers. Hydrogeologic information was obtained through test drilling, seismic refraction surveys, aquifer tests, and ground-water-flow models. Currently, the U.S. Geological Survey's Regional Aquifer-System Analysis Program is studying the hydrologic characteristics of glacial valley aquifers in the Northeastern United States (Lyford and others, 1984). Recent geological studies (Koteff and Pessl, 1981; Stone and Borns, 1986; Warren and Stone, 1986) have advanced the understanding of the deposition and sedimentology of glacial meltwater deposits that, in turn, control hydrologic characteristics.

Stratified-drift sediments—interbedded layers of generally well-sorted gravel, sand, silt, and clay—were deposited in most of the principal valleys of the Northeastern United States by meltwaters from continental glaciers that covered the region during the Pleistocene Epoch. The origin and depositional environment of these sediments strongly influence aquifer geometry, and thus, the aquifers are generally elongate, narrow, and relatively thin (fig. 3). Variations in the thickness and texture of stratified drift resulting from the pattern of deglaciation and topography of the land disrupt the continuity of the stratified-drift aquifers. Consequently, most major river valleys contain several individual aquifers that extend from a few hundred feet to several miles in length. The width of these aquifers is generally limited to a few thousand feet or less, and their maximum saturated thickness is generally less than 100 feet (ft). Stratified-drift aquifers underlie approximately 7.9 square miles (mi^2) of the Pootatuck River valley, 12.7 mi^2 of the Pomperaug River valley, 21.5 mi^2 of the Hockanum River valley, and 87.6 mi^2 of the Farmington River valley.

Stratified-drift deposits commonly exhibit abrupt horizontal and vertical changes in texture that reflect their complex depositional environment. However, except for some glaciolacustrine deposits, the stratified drift contains relatively little silt and clay, and the bulk of the aquifers consist of sand and gravel. Hydraulic conductivity primarily reflects the grain size and degree of sorting of the individual layers, and ranges from less than 1 foot per day to greater than 10,000 feet per day (ft/d) for stratified drift in the Northeastern United States (Lyford and others, 1984, p. 12). Average values of horizontal hydraulic conductivity in the range of 20–170 ft/d are typical of the four aquifers studied in Connecticut (Haeni, 1978; Ryder and others, 1981; Handman and others, 1986; Mazzaferro, 1986).

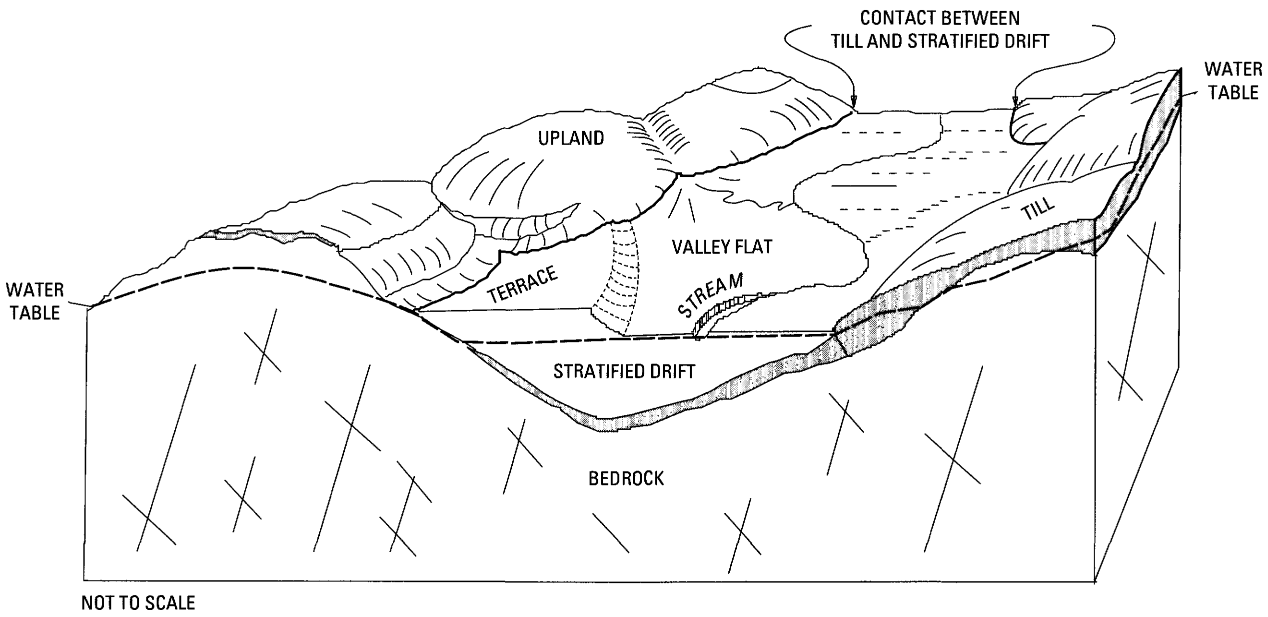


Figure 3. Idealized three-dimensional geometry of a typical glacial valley stratified-drift aquifer (modified from Frimpter, 1981, fig. 1).

Ground water in stratified-drift aquifers occurs mostly under unconfined conditions, and the water table is generally only a few feet to a few tens of feet below land surface. The mean depth to the water table measured in the 116 observation wells installed for this study was 11.2 ft. Natural recharge occurs directly through infiltration of precipitation upon the land surface above the aquifer, but more than half of the recharge to stratified-drift aquifers may be derived from upland runoff (Morrissey and others, 1988). The amount of recharge under natural (nonpumping) conditions averages about 25 inches per year (in/yr) for stratified-drift aquifers studied in Connecticut (Haeni, 1978; Mazzaferro, 1986). Seasonal variations in precipitation and evapotranspiration cause the depth to the water table to fluctuate from a few feet to more than 10 ft within the stratified-drift aquifers (fig. 4).

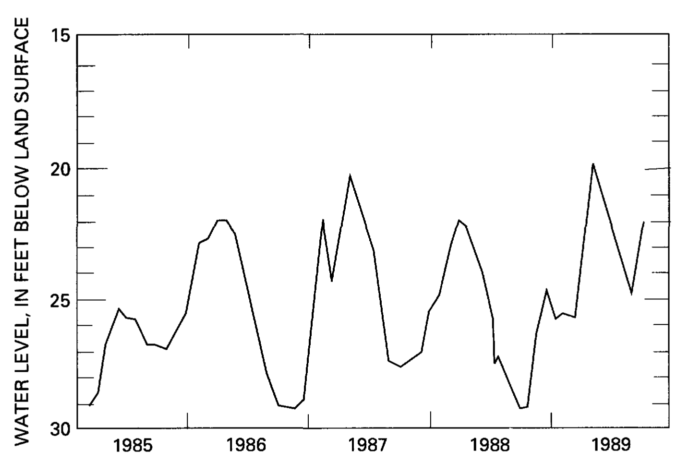


Figure 4. Water levels in an observation well in the stratified-drift aquifer within the Pomperaug River valley, 1985–89.

Ground water is in constant movement from areas of high water-table altitudes, which typically occur along the margins of the valleys, toward areas of lower water-table altitudes, which generally coincide with major streams, lakes, and wetlands within the central portions of the valleys. The rate of flow depends on the hydraulic gradient and the porosity and hydraulic conductivity of the aquifer. Grady and Weaver (1988, p. 13) have estimated the average linear velocity of ground-water flow from aquifer properties and hydraulic gradients in two stratified-drift aquifers in Connecticut. Values ranged from 0.01 to 10 ft/d; however, average linear velocities of 1–3 ft/d were considered to be most representative (Grady and Weaver, 1988, p. 13). Comparable velocity values of 0.3–1.3 ft/d were measured in natural-gradient tracer tests in glacial-outwash aquifers at Cape Cod, Massachusetts (LeBlanc, 1987, p. B-3), and Borden, Ontario, Canada (Mackay and others, 1986, p. 2027). Based upon these estimates of ground-water velocity, the residence time of water in stratified-drift aquifers must be brief, as the flow paths are commonly only a few hundred to a few thousand feet in length. Consequently, the residence time for most ground water in stratified-drift aquifers is likely to be less than 1 year to 2 decades (Grady and Weaver, 1988, p. 13–14).

The short temporal and spatial scales of the ground-water-flow systems in most stratified-drift, glacial valley aquifers strongly influenced the design of the water-quality sampling network. For those contaminants that move through the aquifer at the same rate as the water, the effects of only recent land use practices should be observed. Consequently, evaluation of the current pattern and recent history of land use development within the study areas was necessary. Land use information also was compiled at a scale comparable to the hydrogeologic scale in order to avoid misrepresenting possible associations between ground-water quality and land use.

Land Use

Information on both existing land use and recent changes in land use was compiled for each of the four aquifer areas. The 1970 statewide land use inventory (Connecticut Office of Policy and Management, 1970) was the principal source used for this study. Identified and mapped from 1:12,000-scale aerial photography flown in March 1970, the statewide land use inventory was compiled at a scale of 1:24,000 and therefore provides a level of resolution suitable for comparison with the hydrogeologic information. The 1970 land use inventory, outdated in some areas of the State, was updated using more recent aerial photography, local land use and zoning information, and field verification.

Sixty-nine land use categories were mapped in the 1970 Connecticut land use inventory that correspond to level III and IV categories of Anderson and others (1976). Reconnaissance-phase and interim-study evaluations (Grady and Weaver, 1988, 1989; Grady, 1989) used only four broadly defined land use categories, namely, undeveloped, agricultural, residential, and mixed industrial plus commercial, so that statistical comparisons of ground-water quality could be made from the small number of samples. Sufficient data were collected during the balance of the study to refine the land use classifications to seven categories: undeveloped, untilled agricultural, tilled agricultural, unsewered residential, sewered residential, commercial, and industrial.

The undeveloped land use category consists primarily of mixed deciduous woodlands that are generally second-growth forest on fields that were once cleared for agriculture but have been abandoned for at least 50 years. This category also contains all inactive, unused, unproductive, or abandoned open lands and areas cleared for construction prior to development, plus wetlands and surface-water bodies. In Connecticut the most extensive tracts of undeveloped land are frequently in the upland areas beyond the stratified-drift boundaries; however, in the study areas, some undeveloped land has been maintained as public reservoir watershed, parks, and wildlife preserves, or as private woodland recreational areas. Areas that are predominantly undeveloped may encompass some minor discordant land uses such as low-density residential development, secondary roads, and small agricultural plots, but the quality of ground water beneath such areas is assumed to be largely unaffected by human activities. Undeveloped areas therefore, provide background water-quality conditions with which to compare and evaluate the effects from human activities within other land use categories.

Untilled agricultural land use refers to alfalfa and hay production, pasture lands, ornamental shrub nurseries, and turf farms. Also in this category are recreational athletic fields and golf courses that, although not truly an agricultural use, receive applications of fertilizers, soil conditioners, and pesticides. The principal criterion for inclusion within this land use category, therefore, was that the land was used for the active production of some type of cover (hay, grass, shrubs) without any significant mechanical disturbance of the natural soil profile, and the probable (though not documented) use of agricultural chemicals. The most common chemical applications to untilled agricultural lands are nitrogen and phosphorous fertilizers; potash, borax, and lime for soil treatments; and a variety of pesticides (predominantly herbicides).

Tilled agricultural lands are primarily cultivated for silage and sweet-corn production. Some 73 percent of the active agricultural land in Connecticut is in corn production; other row crops are strawberries, tobacco, and a variety of vegetables. Little of the cultivated farmland is irrigated, and where irrigation is used, the source of water is most commonly a nearby surface-water body. Agricultural chemicals that are applied to tilled acreage are organic (manure) as well as inorganic fertilizers, soil treatments and micronutrients, and pesticides. The most common pesticides used on corn are the preemergent, broadleaf weed herbicides, atrazine and alachlor.

Residential land use encompasses any area of 5 acres or more where housing structures of any type predominate. The category covers a range of housing densities from high-density urban areas of more than eight dwellings per acre to single rural residences. Because population-density data are available only for census tracts that, in the study areas, are entire towns or large parts of the towns, it was not possible to subdivide the residential land use category by this criterion. However, information was readily available concerning which tracts of residential development are served by sanitary-sewer lines and which tracts utilize individual septic systems. Consequently, the residential land use category has been subdivided into unsewered residential and sewered residential categories. Although there is overlap in the housing densities within each of the two categories, the unsewered residential areas tend to have larger lot sizes (generally greater than 1 acre), are commonly underlain by coarse-grained stratified drift, and underlie areas where depth to the water table is greater. The sewered residential areas, conversely, tend to have higher housing densities, are more likely to have commercial structures within the area mapped as residential, and are more common where fine-grained materials or shallow depths to the water table predominate.

A variety of potential sources of contaminants are associated with unsewered and sewered residential areas. A prominent source of inorganic and organic contaminants in unsewered areas is the individual septic systems that receive domestic wastes, wastewaters, and discarded household chemicals. Exfiltration from leaky sanitary sewer lines may provide a source for similar contaminants within the sewered residential areas. Other contaminant sources associated with residential areas are the infiltration of street runoff carrying deicing chemicals, metals, and hydrocarbons. Use of lawn and garden chemicals and wastes from domestic animals provide sources for additional nutrients and pesticides. Leaky household fuel tanks may contaminate ground water with fuel oil or gasoline.

Commercial land use in the study areas consists of a variety of trades and services such as gas stations and automobile repair shops, dry cleaners, printers and photographic finishers, restaurants, retail outlets, and offices. Commercial areas have been mapped as such when they extend over an area of 5 acres or more. Generally, they fall within three characteristic patterns: (1) the central business section or downtown areas of a city or town; (2) shopping centers, frequently in outlying areas; and (3) commercial strip developments along major highways or streets. Much of the land surface in commercial land use areas is impervious, covered either by the buildings themselves, parking lots, storage "yards," or the network of streets and roads that facilitate vehicular access. A variety of nonpoint-source contaminants may originate from commercial areas as a result of leaks from gasoline, fuel oil, or chemical storage tanks; inadvertent leaks and spills or improper disposal of chemicals and wastes; infiltration of street and parking lot runoff; disposal of wastes and wastewaters to on-site septic systems in unsewered commercial areas; and exfiltration from sanitary sewers in areas served by municipal wastewater-treatment systems.

The industrial land use category consists of a complex mixture of individual types of industrial facilities that can collectively be described as light manufacturing. The term "light manufacturing" is used in the context of industries devoted to designing, assembling, finishing, and packaging of products rather than "heavy" manufacturing that involves the extraction and processing of basic or raw materials or producing heavy machinery. In Connecticut, light manufacturing is largely made up of small modern (often high-technology) facilities for the fabrication of electronic equipment and components (motors and generators, switchgear and controls, electric housewares, communication equipment, lighting and wiring, semiconductors, capacitors, coils, and transformers); metal products (cutlery, hand tools, hardware, plumbing and heating equipment, and springs, valves, and wire products); metal plating or polishing; textile and apparel; lumber and wood products; chemicals and allied products; and food processing, warehousing, and distribution. Individual industrial facilities or, more commonly, industrial parks have been mapped where they extend over areas of 5 acres or more. These facilities are office, warehouse, plant and laboratory buildings, parking and storage areas, ancillary buildings, roadways, and open areas.

Ground-water contamination has frequently been associated with industrial point sources. Generally, however, the multiple sources of contaminants that arise from manufacturing operations within diffuse areas of industrial land use can be considered as nonpoint sources. These multiple sources are industrial pits, ponds, and lagoons that receive wastes or wastewater discharges; leaks, spills, and improper discharges of hydrocarbons and other chemicals; infiltration of runoff from parking lots, storage areas, and roadways; effluent from on-site septic systems or exfiltration from leaky sanitary sewers; and atmospheric deposition of industrial air pollutants. The most common contaminants associated with industrial sources are trace metals, volatile organic compounds from solvents and cleaners, and other synthetic organic chemicals.

COLLECTION AND ANALYSIS OF WATER-QUALITY DATA

In addition to knowledge of the hydrogeologic and land use conditions within the study areas, accurate water-quality data are needed to ascertain relations between land use and ground-water quality. Grady and Weaver (1988, p. 18–20) have shown how the historical information available on ground-water quality for the selected aquifers was too limited, largely outdated, and inappropriate for the purpose here. Consequently, an observation-well network, sampling protocol, and statistical analysis program were designed to provide sufficient numbers of representative ground-water samples for comprehensive chemical analyses of nonpoint-source contaminants and valid statistical inference.

Observation-Well Network

The principal consideration in designing the observation-well network was to enable collection of ground-water samples that would provide an accurate representation of water-quality conditions within an aquifer that reflects a particular land use. To accomplish this, it was necessary to (1) locate wells within or immediately downgradient from well-defined and areally extensive land use areas, (2) construct shallow wells with short screened intervals open to the uppermost part of the ground-water-flow system, (3) install the wells with the minimum amount of disturbance to the natural aquifer materials and without introducing any foreign materials, and (4) avoid the use of casing and screen materials that could alter the chemistry of the water samples.

Land use maps and water-table contour maps were overlain to locate potential observation wells at sites within or along the downgradient side of target land use polygons. Because the extent of all land use polygons was 5 acres or more, and generally was a few tens of acres, a single land use commonly would overlie all or most of the length of a typical ground-water-flow path. Consequently, it was possible to locate sites for observation wells within or immediately downgradient from polygons of target land use areas such that the quality of ground water could be ascribed to a particular land use. An example of the positioning of the observation wells that demonstrates the compatibility of land use and hydrogeology is illustrated in figure 5. The appendix identifies the land use associated with each of the 116 observation wells.

When appropriate downgradient locations for observation wells were selected, other hydrogeologic siting criteria and requirements also needed to be satisfied. Wells were not installed where the depth to the water table exceeded 50 ft because a thick unsaturated zone could impede downward migration of contaminants introduced at or near the land surface. If predominantly fine-grained sediments (clay and silt) that could adsorb contaminants or otherwise retard their movement were encountered in the aquifer zone to be sampled, a well was not installed at the site. Also, there could be no known major point sources of contaminants in the vicinity of the observation well, so as not to complicate determination of the contaminant source. Finally, it was necessary to have access to the site for the drill rig and the permission of the landowner to install the well.

Well installation was accomplished with a truck-mounted hollow-stem auger that was used to drill a hole to depths of generally 5–10 ft below the water table. Type 304 stainless-steel, flush-joint casing (2-inch (in.) nominal inside diameter) and 2-ft-long wire-wound, continuous-slot screened wellpoints were then driven an additional several feet into undisturbed aquifer materials. All casing and screens were precleaned and packaged in polyethylene tubing to prevent contamination. The annulus around the casing above the water table was filled with cuttings brought to the surface by the augers. No cements or grouts were used in an effort to avoid introducing any materials that could affect the water quality.

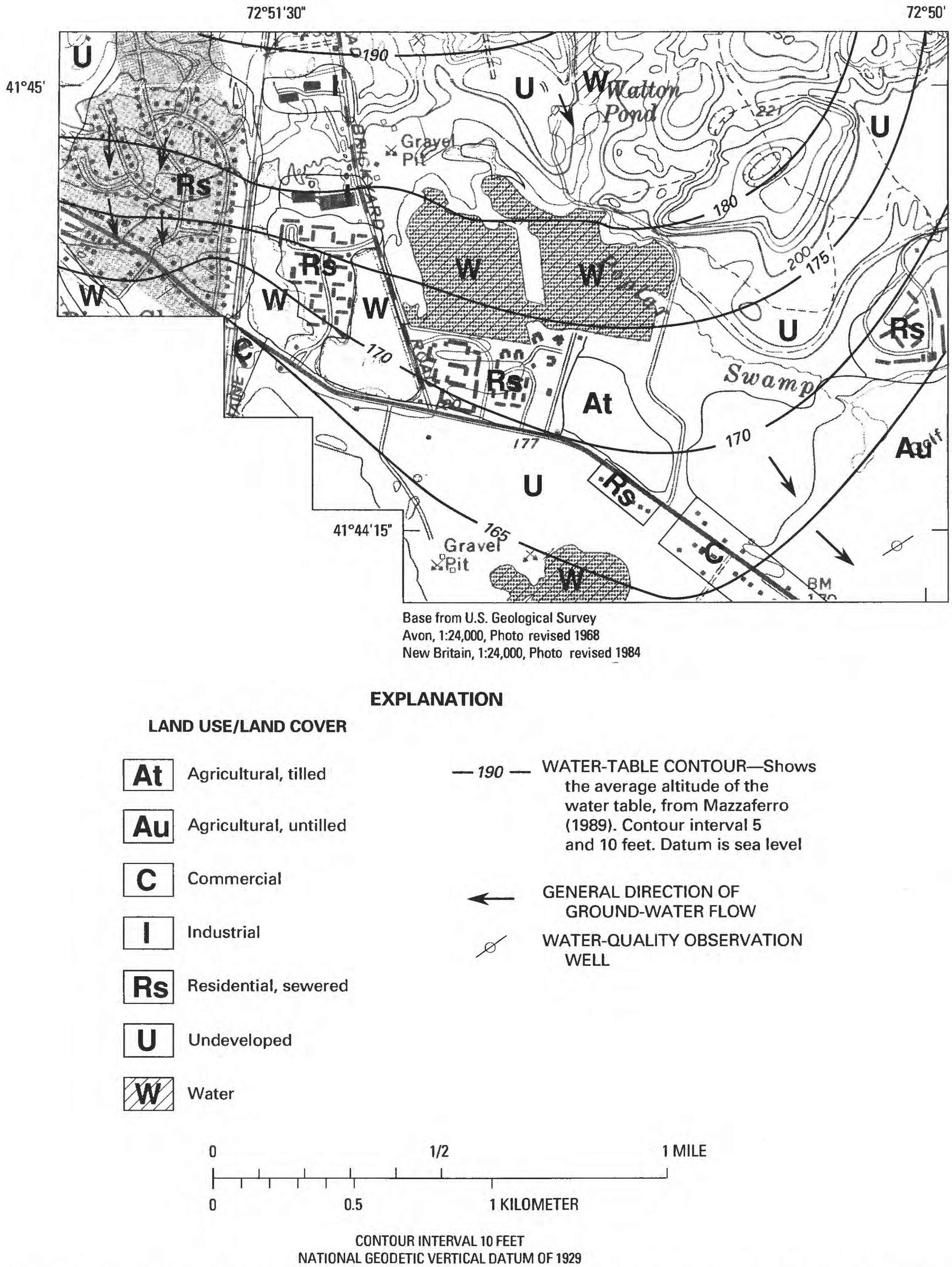
The distribution, by land use category and aquifer, of the 116 wells installed for this study is identified in table 1. Although the number of wells is sufficient to compare water quality by land use statistically, it was not possible to apportion the wells evenly in each aquifer. Only three of the seven land use categories were sampled by the six wells installed in the Pootatuck River aquifer, and one land use category, sewered residential, is not represented in the Pomperaug River aquifer (table 1). These inequities mainly reflect the fact that there is little or no occurrence of certain land use categories within these aquifers.

Differences in the nature and intensity of land use are also reflected in the distribution of wells. For example, much of the residential development in the Farmington River aquifer is new, relatively low-density, suburban housing built upon well-drained soils where the use of on-site septic systems is widespread. Consequently, there are three times as many wells in unsewered residential areas as in sewered residential areas. In the Hockanum River aquifer, however, nearly all the residential land use consists of high-density housing that was constructed on poorly drained soils and is served by sanitary sewers. Only 1 of the 15 wells installed in residential areas of the Hockanum River aquifer is in an unsewered area. Finally, the differences in the number of wells per aquifer are in part due to the areal extent of the aquifers; specifically, the fewest wells were emplaced in the smallest aquifer, the Pootatuck, and the most wells were installed in the most extensive aquifer, the Farmington River aquifer.

Well depth, measured from the land surface to the bottom of the well screen, of the 116 observation wells ranged from 6.4 to 55.6 ft and averaged 20.9 ft. Depth to the water table, measured at each of the 116 wells on several occasions, ranged from 2.3 to 44.0 ft and averaged 11.2 ft. The depths of wells and the depths to the water table are listed in the appendix and are compared in the seven land use categories in figure 6. Wells in the agricultural areas are slightly shallower than wells in the other land use areas. This reflects the fact that many agricultural fields occur within the valley floodplains, where the depth to the water table is typically shallow. Other land uses encompass a larger variety of topographic settings where the depth to the water table commonly ranges from 10 ft to greater than 40 ft. However, no statistically significant differences in the depth of wells or the depth to the water table were observed among the land use categories using analysis of variance (ANOVA) on the ranks of the well-depth and water-level data (Sokal and Rohlf, 1969; Conover and Iman, 1981; Helsel, 1983).

Sampling Protocol

Ground-water samples were collected using an all-Teflon and stainless-steel, positive-displacement gas-bladder pump pressurized with an oilless air compressor. Pumps of this design and construction have been found superior to other mechanisms for retrieving ground-water samples because they minimize (1) loss of volatile organic chemicals by degassing, (2) sorptive interaction of dissolved chemical species with solid surfaces, and (3) contamination of samples by leaching of pump materials (Barcelona and others, 1983, 1984; Devlin, 1986).



Base from U.S. Geological Survey
Avon, 1:24,000, Photo revised 1968
New Britain, 1:24,000, Photo revised 1984

CONTOUR INTERVAL 10 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

Figure 5. Location of selected observation wells within or immediately downgradient from polygons of target land use areas.

Table 1. Distribution of wells by land use category and aquifer

Land use category	Aquifer				Total number of wells
	Pootatuck River	Pomperaug River	Farmington River	Hockanum River	
Undeveloped	0	3	7	5	15
Agricultural, untilled	1	1	5	4	11
Agricultural, tilled	0	7	6	2	15
Residential, unsewered	2	7	21	1	31
Residential, sewered	0	0	7	14	21
Commercial	0	4	3	5	12
Industrial	3	1	4	3	11
Total number of wells	6	23	53	34	116

Prior to sample collection, the pump was cleaned with a detergent wash and deionized-water rinse, and then a solution of 1:10 acetone (or methanol) to deionized water was flushed through the pump, followed by several additional volumes of deionized water. Three or more well volumes were removed from each observation well, and specific conductance, pH, and water temperature were monitored until they stabilized before samples were collected. Sample collection and preservation were performed according to methods prescribed by Wood (1976), Classen (1982), Wershaw and others (1987), and Fishman and Friedman (1989).

Most ground-water samples were collected during four periods: April 1985, July–September 1986, June–September 1987, and June–July 1988. A few samples were collected during October–December 1988 to complete analytical coverage for all wells. Seven wells, however, were sampled monthly from June 1987 through June 1988 to determine the seasonal variability of selected water-quality constituents. The appendix gives the date and time of all samples collected for this study.

Analytical determinations of 3 physical properties, 8 major inorganic chemical species, 3 nutrient species, 19 trace elements, 36 volatile organic compounds, 24 pesticides, and 4 other organic compounds were performed on water samples from at least 110 of the 116 observation wells (see table 2). Twenty-seven additional pesticide compounds were analyzed in a more limited set of samples from 82 to 97 wells, and analyses for four other pesticide compounds were performed on samples from 12 or fewer wells. Finally, samples from all 116 wells were analyzed by gas chromatography using a flame-ionization detector (GC/FID) as a tool for screening the samples for the presence of a wide variety of organic compounds. Where the GC/FID results indicated a substantial presence of one or more unknown organic compounds, gas chromatography/mass spectrometric (GC/MS) analysis was performed to identify and quantify individual base-neutral and acid-extractable (BNA) organic compounds. Samples from 24 wells were analyzed by GC/MS. All laboratory analytical determinations were performed by the U.S. Geological Survey. All quantitative water-quality data are published in the annual hydrologic data report for Connecticut (Cervione, Weiss, and others, 1987, 1988, 1989; Cervione, Davies, and others, 1989, 1990). GC/FID results and other semiquantitative chromatographic data are on file at the Connecticut Office, U.S. Geological Survey, Hartford, Conn.

Statistical Analysis

Nonparametric statistical procedures have been used to test for relations between water-quality variables and land use categories because these data are typically not normally distributed and sample size is small. The water-quality data are bounded at zero or some detection limit, commonly are highly skewed, and consist of infrequent extreme values or "outliers." When traditional methods of statistical inference that assume a normal distribution are applied to such data sets, the results are generally invalid (Helsel, 1987). Nonparametric statistical procedures are robust, that is, the power of the test to detect differences between groups of data is high, regardless of the underlying population distribution. Rank transformation of the data, replacing each of the data points by its respective rank when all of the observations are ordered from smallest to largest, is a commonly used nonparametric procedure (Conover, 1980, p. 337; Helsel, 1987, p. 185).

Four statistical procedures have been used to describe the data and to test for differences between water-quality variables that were segregated by land use. First, descriptive statistics have been used to identify the central tendency (median) and variation of the data (interquartile range) within each group. The median, or 50th percentile, of the data's distribution is the preferred measure of central tendency for nonnormally distributed data because, unlike the mean, the median is not influenced by the magnitude of extreme values. Similarly, the interquartile range—the difference between the 75th percentile (or 3d quartile) and the 25th percentile (1st quartile)—provides a measure of sample variability that is less influenced by outliers than is the standard deviation for nonnormal data. For censored data distributions—that is, if some of the data are reported

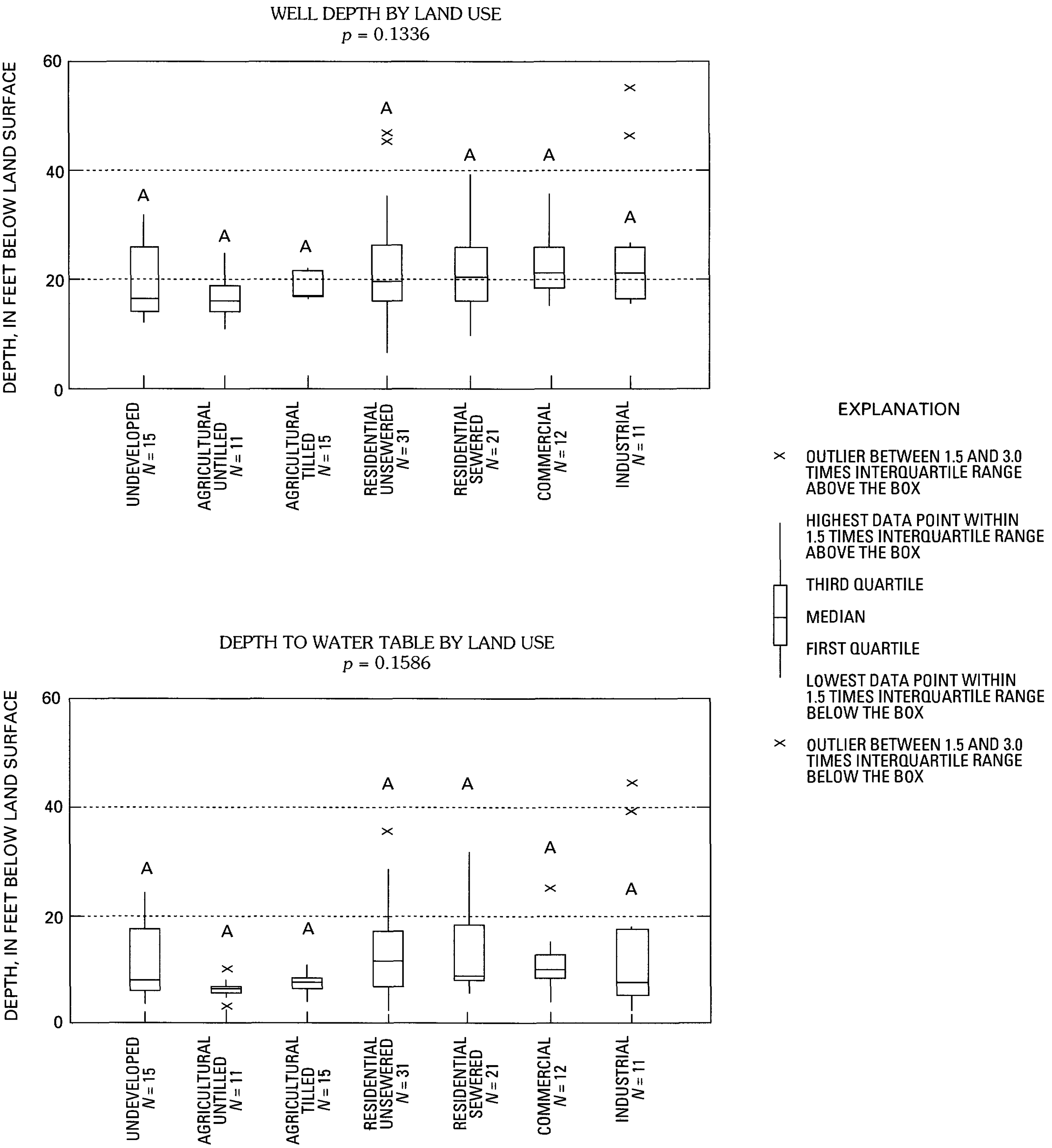


Figure 6. Statistical comparison by land use of depth of observation wells and depth to the water table in four stratified-drift aquifers in Connecticut. The *p* value is the attained significance level for that statistical comparison; *N* is the number of wells sampled per land use category; sample populations are designated by letter symbol A; sample populations that share the same letter are not significantly different at the 0.05 level of significance.

as less than a specified detection level—descriptive statistics were sometimes estimated by the method of Helsel and Gilliom (1986) and Gilliom and Helsel (1986). If more than 25 percent of the data for a variable are below the analytical detection limit, the interquartile range was estimated; if more than 50 percent of the data are below the detection limit, the median was also estimated, if possible. For some variables there were too few detections, or all detections

Table 2. Water-quality properties or constituents analyzed and detected in ground-water samples

[Detection limit is the lowest detectable constituent concentration or water-quality property unit of measurement that could routinely be achieved by the field or laboratory analytical methods. When analytical conditions resulted in multiple detection limits for any property or constituent, the detection limit reported below is the lowest detection limit common to the analytical methods used. Units: °C, degrees Celsius; μS/cm, microsiemens per centimeter at 25 °C; mg/L, milligrams per liter; μg/L, micrograms per liter. Number of detections is the number of wells in which the property or constituent was measured at or above the reported detection limit (when more than one analysis was available for a well, the median value was used). Values in parentheses indicate the number of wells in which the constituent was reported at concentrations below the lowest common analytical detection limit]

Table 2. Water-quality properties or constituents analyzed and detected in ground-water samples—Continued

Water-quality property or constituent	Detection limit	Number of wells	Number of detections
PHYSICAL PROPERTIES			
pH	0.1 units	115	115
Specific conductance	1.0 μS/cm	116	116
Temperature	.5 °C	115	115
MAJOR INORGANIC COMPOUNDS			
Calcium	.1 mg/L	115	115
Chloride	.1 mg/L	116	116
Dissolved solids	.1 mg/L	116	116
Hardness, as $CaCO_3$	.1 mg/L	115	115
Magnesium	.1 mg/L	115	115
Silica, as SiO_2	.1 mg/L	115	115
Sodium	.1 mg/L	115	115
Sulfate	.1 mg/L	116	116
NUTRIENTS			
Ammonia, as NH_4	.01 mg/L	116	67
Nitrate plus nitrite, as N	.1 mg/L	116	100
Orthophosphorus, as PO_4	.01 mg/L	116	47
TRACE ELEMENTS			
Arsenic	1.0 μg/L	116	25
Barium	1.0 μg/L	115	115
Beryllium	0.5 μg/L	115	17
Boron	20.0 μg/L	116	80
Cadmium	1.0 μg/L	115	11
Chromium	1.0 μg/L	116	26
Cobalt	3.0 μg/L	115	9
Copper	10.0 μg/L	115	6
Iron	3.0 μg/L	115	110
Lead	10.0 μg/L	115	15
Lithium	4.0 μg/L	115	50
Manganese	1.0 μg/L	115	112
Mercury	.1 μg/L	115	19
Molybdenum	10.0 μg/L	115	4
Nickel	1.0 μg/L	116	99
Silver	1.0 μg/L	116	12
Strontium	1.0 μg/L	115	115
Vanadium	6.0 μg/l	115	2
Zinc	3.0 μg/L	115	108
PESTICIDES			
Alachlor	.1 μg/L	85	0
Aldicarb	.5 μg/L	82	0
Aldicarb sulfone	.5 μg/L	82	0
Aldicarb sulfoxide	.5 μg/L	82	0
Aldrin	.01 μg/L	113	0
Ametryne	.1 μg/L	85	0
PESTICIDES—Continued			
Atrazine	0.1 μg/L	85	7
Carbaryl	.5 μg/L	82	0
Carbofuran	.5 μg/L	82	0
Chlordane	.1 μg/L	113	3
Chlorpyrifos	.01 μg/L	88	0
Cyanazine	.1 μg/L	85	1
2,4-D	.01 μg/L	97	5
DDD	.01 μg/L	113	1
DDE	.01 μg/L	113	0(2)
DDT	.01 μg/L	113	0
DEF	.01 μg/L	86	0
2,4-DP	.01 μg/L	97	1
Diazinon	.01 μg/L	113	2
Dicamba	.01 μg/L	12	0
Dieldrin	.01 μg/L	113	5(1)
Disulfoton	.01 μg/L	88	0
Endosulfan	.01 μg/L	113	0
Endrin	.01 μg/L	113	0
Ethion	.01 μg/L	113	0
Fonofos	.01 μg/L	88	0
Heptachlor	.01 μg/L	113	0
Heptachlor epoxide	.01 μg/L	113	0
3-Hydroxycarbofuran	.5 μg/L	82	0
Lindane	.01 μg/L	113	0
Malathion	.01 μg/L	113	0
Methomyl	.5 μg/L	82	0
Methoxychlor	.01 μg/L	112	0
Methyl parathion	.01 μg/L	113	0
Methyl trithion	.01 μg/L	113	0
Metolachlor	.1 μg/L	85	0
Metribuzin	.1 μg/L	85	0
Mirex	.01 μg/L	112	0
1-Naphthal	.5 μg/L	82	0
Oxamyl	.5 μg/L	82	0
Parathion	.01 μg/L	113	0
Perthane	.1 μg/L	113	0
Phorate	.01 μg/L	88	1
Picloram	.01 μg/L	10	0
Prometone	.1 μg/L	85	2
Prometryn	.1 μg/L	85	0
Propazine	.1 μg/L	85	1
Propham	.5 μg/L	82	0
Silvex	.01 μg/L	110	2
Simazine	.1 μg/L	85	2
Simetryn	.1 μg/L	85	0
2,4,5-T	.01 μg/L	111	3
Toxaphene	1.0 μg/L	113	0
Trifluralin	.1 μg/L	85	0
Trithion	.01 μg/L	113	0
OTHER ORGANIC CONSTITUENTS			
Gross polychlorinated biphenyls	.1 μg/L	113	0
Gross polychlorinated naphthalenes	.1 μg/L	113	0
Methylene-blue-active substances	.01 mg/L	116	115
Total organic carbon	.1 mg/L	116	112

Table 2. Water-quality properties or constituents analyzed and detected in ground-water samples—Continued

Water-quality property or constituent	Detection limit	Number of wells	Number of detections
VOLATILE ORGANIC COMPOUNDS			
Benzene	0.2 μg/L	113	3
Bromoform	.2 μg/L	113	0
Carbon tetrachloride	.2 μg/L	113	0
Chlorobenzene	.2 μg/L	113	0
Chlorodibromomethane	.2 μg/L	113	0
Chloroethane	.2 μg/L	113	1
2-Chloroethylvinylether	.2 μg/L	113	0
Chloroform	.2 μg/L	113	27
Chloromethane	.2 μg/L	113	0
1,2-Dibromoethane	.2 μg/L	113	0
1,2-Dichlorobenzene	.2 μg/L	114	3
1,3-Dichlorobenzene	.2 μg/L	113	0
1,4-Dichlorobenzene	.2 μg/L	113	0
Dichlorobromomethane	.2 μg/L	113	0
Dichlorodifluoromethane	.2 μg/L	113	5
1,1-Dichloroethane	.2 μg/L	113	7
1,2-Dichloroethane	.2 μg/L	113	1
1,1-Dichloroethylene	.2 μg/L	113	5
1,2-transDichloroethylene	.2 μg/L	113	18
1,2-Dichloropropane	.2 μg/L	113	6
1,3-Dichloropropene	.2 μg/L	113	0
1,3-cisDichloropropene	.2 μg/L	113	0
1,3-transDichloropropene	.2 μg/L	113	0
Ethylbenzene	.2 μg/L	113	1
Methylbromide	.2 μg/L	113	0
Methylene chloride	3.0 μg/L	115	2
Styrene	.2 μg/L	113	0
1,1,2,2-Tetrachloroethane	.2 μg/L	113	1
Tetrachloroethylene	.2 μg/L	113	18
Toluene	.2 μg/L	113	15
1,1,1-Trichloroethane	.2 μg/L	113	22
1,1,2-Trichloroethane	.2 μg/L	113	1
Trichloroethylene	.2 μg/L	113	11
Trichlorofluoromethane	.2 μg/L	113	9
Vinyl chloride	.2 μg/L	113	2
Xylene	.2 μg/L	112	3
BASE-NEUTRAL AND ACID-EXTRACTABLE COMPOUNDS			
Acenaphthene	5.0 μg/L	24	0(1)
Acenaphthylene	5.0 μg/L	24	0
Anthracene	5.0 μg/L	24	0
Benzo(a)anthracene	10.0 μg/L	24	0
Benzo(b)fluoranthene	10.0 μg/L	24	0
Benzo(k)fluoranthene	10.0 μg/L	24	0
Benzo(a)pyrene	10.0 μg/L	24	0
BASE-NEUTRAL AND ACID-EXTRACTABLE COMPOUNDS—Continued			
Benzo(g,h,i)perylene	10.0 μg/L	24	0
Bis(2-chloroethyl)ether	5.0 μg/L	24	0
Bis(2-chloroethoxy)methane	5.0 μg/L	24	0
Bis(2-chloroisopropyl)ether	5.0 μg/L	24	0
Bis(2-ethylhexyl)phthalate	5.0 μg/L	24	7(2)
4-Bromophenyl phenylether	5.0 μg/L	24	0
Butyl benzyl phthalate	5.0 μg/L	24	0
2-Chloronaphthalene	5.0 μg/L	24	0
2-Chlorophenol	5.0 μg/L	24	0
4-Chlorophenyl phenylether	5.0 μg/L	24	0
4-Chloro-3-methylphenol	30.0 μg/L	24	0
Chrysene	10.0 μg/L	24	0
Dibenz(a,h)anthracene	10.0 μg/L	24	0
2,4-Dichlorophenol	5.0 μg/L	24	0
Diethyl phthalate	5.0 μg/L	24	1
Dimethyl phthalate	5.0 μg/L	24	0
2,4-Dimethylphenol	5.0 μg/L	24	0
2,4-Dinitrophenol	20.0 μg/L	24	0
4,6-Dinitro-2-methylphenol	30.0 μg/L	24	0
2,4-Dinitrotoluene	5.0 μg/L	24	0
2,6-Dinitrotoluene	5.0 μg/L	24	0
Di-n-butyl phthalate	5.0 μg/L	24	0(2)
Di-n-octyl phthalate	10.0 μg/L	24	0(1)
Fluoranthene	5.0 μg/L	24	0(1)
Fluorene	5.0 μg/L	24	0(1)
Hexachlorobenzene	5.0 μg/L	24	0
Hexachlorobutadiene	5.0 μg/L	24	0
Hexachlorocyclopentadiene	5.0 μg/L	24	0
Hexachloroethane	5.0 μg/L	24	0
Ideno(1,2,3-cd)pyrene	10.0 μg/L	24	0
Isophorone	5.0 μg/L	24	0
Naphthalene	5.0 μg/L	24	0(1)
Nitrobenzene	5.0 μg/L	24	0
2-Nitrophenol	5.0 μg/L	24	0
4-Nitrophenol	30.0 μg/L	24	0
n-Nitrosodimethylamine	5.0 μg/L	24	0
n-Nitrosodiphenylamine	5.0 μg/L	24	0
n-Nitrosodipropylamine	5.0 μg/L	24	0
Pentachlorophenol	30.0 μg/L	24	0
Phenanthrene	5.0 μg/L	24	0
Phenol	5.0 μg/L	24	0(2)
Pyrene	5.0 μg/L	24	0
1,2,4-Trichlorobenzene	5.0 μg/L	24	0
2,4,6-Trichlorophenol	20.0 μg/L	24	0

were at the same concentration, and estimates of median and interquartile range could not be made. Box plots are used to display the population distribution of water-quality variables that have 75 percent or more of the data at or above the analytical detection limit.

For 20 uncensored or slightly censored water-quality variables, analysis of variance of rank-transformed data was used to test for significant differences in water quality among land uses (one-way ANOVA) and among land uses and underlying aquifers (two-way ANOVA) (Sokal and Rohlf, 1969; Conover and Iman, 1981; Helsel, 1983). The uncensored or slightly censored variables—those with 75 percent or more of the values equal to or greater than the analytical detection level—were generally the physical properties, major inorganics, and some of the trace elements. An ANOVA of the ranked boron concentrations was also performed, although only 69 percent of the boron observations were at or above the detection limit. Nearly half of the censored boron observations were for samples from two land use categories. The null hypothesis tested by ANOVA states that there is no significant difference in the mean rank—a measure of the central tendency of the sample population of each water-quality variable—for any land use. Rejection of the null hypothesis at the 0.05 level of significance is considered evidence of a relation between land use and ground-water quality, or aquifer and ground-water quality, or some interaction of land use and aquifer with ground-water quality. An unbalanced ANOVA design is required because the number of wells in each of the land use categories is not the same. The SAS Systems general linear models (GLM) procedure was used (SAS Institute Inc., 1985).

Where the GLM procedure indicated that land use had a significant effect on a water-quality variable, a multiple-comparison procedure, namely, Tukey's honest significant-difference test (Sokal and Rohlf, 1969; Stoline, 1981) can be used to discriminate the land uses that differ. The Tukey test uses the within-group variance to calculate, for all possible pairwise comparisons, the minimum difference in mean rank between groups of data that is required to consider the groups significantly different (Helsel and Ragone, 1984). As with the ANOVA, a 0.05 level of significance (α), or the probability of falsely detecting differences that are the result of chance rather than the independent variable (land use), was chosen for the Tukey tests. Tukey's honest significant-difference test was used because it controls the overall error rate at $\alpha = 0.05$, and it is applicable to the uneven sample sizes.

Many of the water-quality variables, especially trace elements and organic compounds, are moderately censored; fewer than 75 percent of the samples have detectable concentrations. For many of these variables, the level of censoring is severe; fewer than 25 percent of the samples have concentrations above the detection level. For these variables, the only statistical test that was applicable was contingency-table analysis (Conover, 1980; Helsel and Ragone, 1984). Contingency-table analysis compares the frequency of detection, or the frequency of exceeding some designated concentration, for the variable by land use category. The procedure is to tabulate the observations by row according to land use category, and by column according to some measure of the water quality, such as whether the concentration of a variable is above or below the detection limit or some other concentration threshold, or whether the concentration falls within a specified range of values. The null hypothesis tested by the contingency table is that the probability of an observation being classified into one of the column categories is independent of the classification (row) it belongs to. Rejection of the null hypothesis at the 0.05 level of significance is evidence that the frequency of detection of a water-quality variable is associated with land use.

Multiway (7×2) contingency tables were first computed using an exact probability determination on the basis of a multinomial distribution (Sokal and Rohlf, 1969, p. 590; Conover, 1980, p. 160). The exact probability computed by the contingency-table analysis is the probability of obtaining the observed cell counts or more extreme cell counts (greater deviations from expected) given the marginal totals; this probability is used in preference to the chi-square approximation because of the low to zero cell frequencies for some water-quality variables. If a significant difference in the frequency of detection was noted by this procedure, separate 2×2 contingency tables of all possible two-row combinations of land uses were computed using Fisher's exact test (Sokal and Rohlf, 1969, p. 595) to determine which pairs of populations differ (Iman and Conover, 1983, p. 309).

EFFECTS OF LAND USE ON GROUND-WATER QUALITY

The chemistry of ground water is affected by natural factors and human activities. As water moves through the hydrologic cycle, its composition is modified by a number of chemical, physical, and biological processes. Particles of dust and atmospheric gases dissolve to produce low concentrations of most major inorganic constituents in the precipitation that falls on the land surface. Near saltwater sources, precipitation commonly contains increased concentrations of sodium and chloride. Industrial and automobile emissions produce elevated levels of nitrate and sulfate and the low pH characteristic of acid rain.

The composition of water moving through the soil and the unsaturated zone is further modified by evapotranspiration and reactions with the porous media, interstitial water and gases, and organic matter. The duration of contact between water molecules and earth materials, as well as the solubility, sorptive, and ion-exchange properties of those materials, controls the chemistry of natural waters. Although the texture of stratified-drift sediments can vary greatly, the mineral composition is predominantly siliceous, and only minor calcite, sodic plagioclase and potassium feldspars, and accessory minerals are reactants (Rogers, 1987, p. 1531). The short flow paths and brief residence time of ground water in stratified-drift aquifers also influence the extent of natural geochemical evolution, such that the dissolved solids concentrations rarely exceed 300 milligrams per liter (mg/L) (Rogers, 1987; p. 1531; Melvin and others, 1988, p. 192).

The quality of ground water can be impaired by human activities, such as those commonly associated with agriculture, industrialization, and urbanization. The common causes of ground-water contamination in Connecticut are applied pesticides, improper handling and disposal of solvents, leachate from solid-waste disposal sites, leakage from petroleum storage tanks, and improperly stored road salt (Melvin and others, 1988). During 1979–86, these causes accounted for 882 of the 928 incidents of public- and private-well contamination reported by the Connecticut Department of Environmental Protection (1986, p. 35). Generally, contamination is restricted to an area within a few hundred to a few thousand feet of a readily identifiable point source, such as a landfill, surface impoundment, underground storage tank, known chemical spill, or injection well. However, degradation of water quality from nonpoint sources that introduce contaminants over an area of a few acres to tens or even hundreds of acres may be a more pervasive problem and is the focus of this report. Nonpoint sources of contaminants are the application of agricultural pesticides and fertilizers, discharge of wastewater to septic tanks and cesspools, leakage from sewage pipelines, road salt applications, and infiltration of runoff from paved areas, as well as the aggregate effect of multiple, small point sources (for example, leaks, spills, and discharges of hydrocarbons or other chemicals within an industrial park).

Land use is a convenient framework for describing the prevailing activities within a relatively uniform demographic area, although it may have little relation to the severity and magnitude of ground-water degradation within or generated from that area. A host of other causative factors affect the amount of contaminants generated from areal sources: population density; septic-system density; percentage of impervious area; traffic patterns; street-cleaning practices; nature and density of storm sewers; age and density of underground storage tanks; application rates of deicing chemicals; design, construction characteristics, and condition of sanitary (or combined sanitary and storm) sewers; vegetation cover; tillage practices; agricultural-chemical application rates; and irrigation practices. Because many of these factors cannot be quantified and are highly varied in the study areas, land use is used as a collective surrogate for nonpoint-contaminant sources of differing type and intensity.

Ground-Water Quality Beneath Land Use Areas

Table 2 shows that 80 of the 179 water-quality variables analyzed for in ground water from the four stratified-drift aquifers have been detected or measured in at least one sample. Detections were made of all 33 of the inorganic constituents and physical properties but only 47 of the 146 organic constituents tested (including 8 constituents reported at concentrations below the lowest common analytical detection limit). The statistical procedures previously described were performed for all water-quality variables given in table 2 that were detected in ground-water samples, except the BNA organic compounds. Only 24 samples were analyzed by the GC/MS method for the target BNA organic compounds listed in table 2. Other nontarget BNA compounds were identified and quantified if mass spectra could be matched to National Bureau of Standards library reference spectra.[1] Those analyses were performed to identify and quantify both target and nontarget BNA compounds subsequent to detection of unknown compounds by GC/FID scans.

Attained significance levels (*p* values), or the probability that observed differences are due to chance rather than the tested effect, are shown in table 3 for the 21 water-quality variables compared by ANOVA, and are listed in table 4 for the 49 variables compared by contingency-table analysis. Only 23 of the 70 tested water-quality variables have significantly different populations for one or more types of land use. While inorganic chemical constituents and a few organic constituents have both natural and manmade sources, statistically significant differences in sample populations for data segregated by land use are due to human sources rather than natural factors. Table 5 is a statistical summary by land use category of all detected water-quality variables, except the BNA organic compounds, showing the sample size, number of detections, median and interquartile range, and letter symbols that identify similarities and differences in sample populations.

Undeveloped Land

The quality of ground water in undeveloped areas is largely unaffected by human activities and is considered to represent background conditions. The effects of human activities on ground-water quality in other land use areas are generally quantified by comparison with values measured in the sample population from the undeveloped areas. The only probable nonpoint sources of contaminants in undeveloped areas are minor tracts of discordant land uses situated within the more extensive undeveloped areas, and atmospheric deposition of contaminants.

Median concentrations and (or) frequencies of detection of 19 major inorganic constituents, nutrients, trace elements, and physical properties are lowest (or equally as low as for another type of land use) for ground-water samples from the undeveloped land use area (table 5). The mean rank of the sample population or the frequency of detection for 13 of these variables is significantly lower for the undeveloped area than for one or more of the other six land use areas. Also, variation within the sample population, as measured by the interquartile range, is smaller (or

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[1] Data for tentatively identified organic compounds (TIOCs) in this report are based on comparison of sample spectra with library spectra, followed by visual examination by GC/MS analysts. TIOC data have not been confirmed by direct comparison with reference standards. Therefore, TIOC identification is tentative, and reported concentrations are semiquantitative.

Table 3. Attained significance levels (*p* values) for two-way analysis of variance on the ranks of water-quality variables compared by land use and aquifer

[The *p* value is the probability that observed differences are due to chance rather than the tested effect. Asterisk indicates effect is significant at the 0.05 level]

Water-quality variable	*p* Value for the tested effect		
	Land use	Aquifer	Interaction
Magnesium	0.0001*	0.0001*	0.0386*
Sodium	.0001*	.0001*	.0857
Specific conductance	.0001*	.0035*	.0504
Dissolved solids	.0001*	.0061*	.0664
Hardness, as $CaCO_3$	.0001*	.0167*	.1704
Boron	.0001*	.0632	.5346
Nitrate plus nitrite, as N	.0001*	.0924	.1704
Calcium	.0002*	.0429*	.3170
Chloride	.0003*	.0264*	.7146
Strontium	.0003*	.4255	.1874
Methylene-blue-active substances	.0006*	.1578	.0014*
Sulfate	.0050*	.0007*	.2064
Silica, as SiO_2	.0166*	.4045	.0424*
Barium	.0180*	.0001*	.4859
Iron	.0327*	.9311	.2199
Nickel	.0477*	.6557	.0394*
pH	.0489*	.2542	.2914
Manganese	.0619	.7568	.1124
Temperature	.0864	.7078	.8194
Total organic carbon	.4023	.1862	.5694
Zinc	.8599	.8040	.2295

equally as small as for another land use) for samples from the undeveloped area for 12 of the 21 inorganic constituents and physical properties for which this statistic can be compared. The lowest pH (5.2) and temperature (6.1 degrees Celsius (°C)) were recorded for undeveloped-area samples, as were the lowest concentrations of barium (6 micrograms per liter (μg/L)), chloride (1.4 mg/L), and dissolved solids (30 mg/L). The frequency of detecting arsenic, lithium, molybdenum, and silver was lowest (or equally as low as for another land use area) for ground-water samples from the undeveloped areas. These findings are indicative of the dilute, slightly acidic, soft water that is characteristic of a short residence time within the dominantly silicate-mineral matrix of the stratified-drift aquifers.

Median iron concentration and interquartile range, however, are higher in the undeveloped area than in the other land use areas. This may reflect the depletion of dissolved oxygen during infiltration through soils with high organic-matter content, which are more prevalent in undeveloped areas. Where dissolved oxygen is depleted by the oxidation of organic material in wetland and forest soils, dissolution of iron oxides in the soil and aquifer materials is facilitated. The mean rank of iron concentrations in samples from the undeveloped land use category, however, is not significantly different from that of any of the other land use areas. The inability of the ANOVA to discern a significant difference between iron concentrations in the undeveloped areas and the other land use areas is due to the large variation of iron concentrations in the undeveloped area that range from less than 3.0 to 18,000 μg/L. Low concentrations of cobalt (3.0–6.0 μg/L) and lead (10–20 μg/L) were detected most often in the undeveloped areas; however, their detection frequencies are not significantly different from other land use areas. The infrequent detections of cobalt and lead may also be related to natural geochemical factors.

Median total organic carbon (TOC) and methylene-blue-active substance (MBAS) concentrations are also lowest (or equally as low as another land use) in the undeveloped areas. There were no detections of 26 of the 37 organic constituents listed in table 5 in ground-water samples from the undeveloped areas. Seven volatile organic compounds were detected, generally at trace-level concentrations, in some wells in the undeveloped area. The fluorocarbon trichlorofluoromethane and 1,2-transdichloroethylene, a breakdown product of widely used solvents, were each detected in two wells at concentrations of less than 1.0 μg/L. Toluene and benzene were present in the water from one undeveloped-area well at 2.2 and 0.7 μg/L, respectively. Neither compound was detected in a subsequent sample from this well, suggesting the possibility of a transitory source, such as a small hydrocarbon spill in the vicinity of the well. GC/FID analysis of a sample from this well reported an unidentified BNA compound, but the estimated concentration was considered to be too low for positive identification and quantification using GC/MS analysis. In addition, chloroform, dichlorodifluoromethane, and 1,2-dichloropropane have each been detected at con-

Table 4. Attained significance levels (*p* values) for contingency-table tests of water-quality variables compared by land use

[The *p* value is the probability that observed differences are due to chance rather than to the tested effect. Asterisk indicates effect is significant at 0.05 level]

Water-quality variable	*p* Value
Tetrachloroethylene	0.0013*
Chloroform	.0018*
Trichloroethylene	.0073*
Atrazine	.0131*
1,2-transDichloroethylene	.0382*
Ammonia, as NH_4	.0460*
Xylene	.0510
1,1,1-Trichloroethane	.0570
Lithium	.0614
Prometone	.0616
Beryllium	.0700
Silver	.1296
1,1-Dichloroethylene	.1450
1,1-Dichloroethane	.1494
Chloroethane	.1875
1,1,2-Trichloroethane	.1947
1,2-Dichloropropane	.2040
Cobalt	.2563
Orthophosphorus, as PO_4	.2807
Copper	.2940
Trichlorofluoromethane	.3239
Molybdenum	.3471
Toluene	.4495
2,4-D	.4640
Chromium	.4821
Cadmium	.4997
Cyanazine	.5176
Mercury	.5891
Benzene	.5926
Lead	.6378
Arsenic	.6513
Dichlorodifluoromethane	.6543
Propazine	.6588
Vinyl chloride	.7067
2,4-DP	.7423
Methylene chloride	.7666
1,2-Dichlorobenzene	.7970
2,4,5-T	.8826
Simazine	.8908
Diazinon	.8972
Dieldrin	.9739
DDD	.9999
1,2-Dichloroethane	.9999
Ethylbenzene	.9999
Silvex	.9999
1,1,2,2-Tetrachloroethane	.9999
Chlordane	1.0000
Phorate	1.0000
Vanadium	1.0000

centrations of 0.8, 0.6, and 1.8 μg/L, respectively, in the undeveloped area.

The herbicides simazine (0.2 μg/L) and 2,4-D (0.06 μg/L) were detected in water samples from two wells in undeveloped areas. Their source may have been applications to control weeds along powerline corridors that transect the areas. An alternative source for all or some of the trace-level organic compounds found in the undeveloped samples may be atmospheric deposition. Eisenreich and others (1981) and Shulters and others (1987) report that volatile, BNA, and pesticide compounds were found at nanogram to microgram per liter concentrations in precipitation samples collected downwind of both urban and agricultural areas.

Agricultural Land

Agricultural land use has been subdivided into untilled and tilled categories, as previously described in the section on land use. The principal difference between the two land use categories with respect to nonpoint-source contaminants is related to the intensity of agricultural practices. Wall and Magner (1988) found lower nitrate and chloride concentrations in ground water beneath areas of limited agricultural intensity with little row-crop production as compared with areas of moderate to intense agricultural activity with predominant row-crop cultivation. Hallberg (1986, p. 5) cites that a 3- to 60-fold increase in nitrate concentration between forested-pasture-grassland areas and intensely cultivated and fertilized areas has been documented by numerous investigators. Although data are sparse on the actual application rates, anecdotal information suggests that the untilled areas in this study receive lesser amounts of fertilizers and pesticides than tilled areas. Numerous macropores in the undisturbed soil profiles of untilled areas, however, may facilitate movement of contaminants to the water table (White, 1985; Dick and others, 1986; Hallberg, 1986, p. 38).

Untilled Areas

Ground-water quality beneath untilled agricultural areas is minimally affected by human activities. Although median concentrations of most inorganic constituents are somewhat elevated with respect to background levels (see table 5), only magnesium and hardness are significantly higher than in the undeveloped areas. Median ammonia-nitrogen and nitrate plus nitrite-nitrogen concentrations are about 10 times greater in ground water beneath the untilled agricultural land than the undeveloped land; however, the differences are not statistically significant. The highest reported concentration of sulfate (120 mg/L) was for a sample from the untilled agricultural area. Applications of fertilizers and inorganic chemical soil treatments, such as lime, are the most likely cause for elevated concentrations of these constituents.

Median iron, manganese, silica, and MBAS concentrations are lowest (or equally as low as for another land use) in ground-water samples from the untilled agricultural areas. The interquartile range of the concentrations of

(Text continues on page B26.)

Table 5. Statistical summary by land use of water-quality variables detected in 1 or more of 85–116 observation wells in four stratified-drift aquifers in Connecticut

[All constituents are dissolved except as indicated. When multiple analyses are available from one well, the median value is used to calculate the statistic. 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 below analytical detection limit and therefore statistic is estimated using method of Helsel and Gilliom (1986). Dashes indicate insufficient data to calculate statistic. Units: °C, degrees Celsius; μS/cm, microsiemens per centimeter at 25 °C; mg/L, milligrams per liter; μg/L, micrograms per liter]

Water-quality variable, units, and statistic	Land use category: Undeveloped	Agricultural		Residential		Commercial	Industrial
		Untilled	Tilled	Unsewered	Sewered		
			PHYSICAL PROPERTIES				
pH (standard units)							
Number of wells	15	11	15	30	21	12	11
Number of detections	15	11	15	30	21	12	11
Median	6.2	6.4	6.1	6.1	6.7	6.2	6.9
Interquartile range	.9	.8	.5	.7	1.0	.7	.8
Population	AB	AB	AB	A	AB	AB	B
Specific conductance (μS/cm at 25 °C)							
Number of wells	15	11	15	31	21	12	11
Number of detections	15	11	15	31	21	12	11
Median	97	167	191	182	280	319.5	364
Interquartile range	40	62	105.5	136.5	189.5	267.2	181
Population	A	AB	BC	BC	C	C	BC
Temperature (°C)							
Number of wells	15	10	15	31	21	12	11
Number of detections	15	10	15	31	21	12	11
Median	12	13	12.5	13	13	14	14
Interquartile range	2.5	1.6	1.4	2.6	1.6	2.8	2.0
Population	A	A	A	A	A	A	A
			MAJOR INORGANIC CONSTITUENTS				
Calcium (mg/L)							
Number of wells	15	11	15	30	21	12	11
Number of detections	15	11	15	30	21	12	11
Median	9.2	15	17	19	29	25.5	22
Interquartile range	8.9	19	14	21.6	40	22.3	31
Population	A	AB	B	B	B	B	B
Chloride (mg/L)							
Number of wells	15	11	15	31	21	12	11
Number of detections	15	11	15	31	21	12	11
Median	7.1	12	11.5	22	27	36	22
Interquartile range	15.4	4.0	5.5	21	20.5	50.5	21.8
Population	A	ABC	AB	BCD	CD	D	ABCD
Dissolved solids, residue at 180 °C (mg/L)							
Number of wells	15	11	15	31	21	12	11
Number of detections	15	11	15	31	21	12	11
Median	64	104	118	134	189	241.5	226
Interquartile range	38	52	74	119.5	115.5	147.4	120
Population	A	AB	BC	BC	C	C	BC
Hardness, as $CaCO_3$ (mg/L)							
Number of wells	15	11	15	30	21	12	11
Number of detections	15	11	15	30	21	12	11
Median	32	69	72.5	61	93	82	91
Interquartile range	26	56	49.5	57.8	90	66.2	108
Population	A	B	B	B	B	B	B

Table 5. Statistical summary by land use of water-quality variables detected in 1 or more of 85–116 observation wells in four stratified-drift aquifers in Connecticut—Continued

Water-quality variable, units, and statistic	Land use category						
	Undeveloped	Agricultural		Residential		Commercial	Industrial
		Untilled	Tilled	Unsewered	Sewered		
MAJOR INORGANIC CONSTITUENTS—Continued							
Magnesium (mg/L)							
Number of wells	15	11	15	30	21	12	11
Number of detections	15	11	15	30	21	12	11
Median	1.5	3.5	5.1	2.8	4.9	4.6	5.2
Interquartile range	1.0	3.3	3.7	3.2	4.3	4.7	4.4
Population	A	B	B	B	B	B	B
Silica, as SiO_2 (mg/L)							
Number of wells	15	11	15	30	21	12	11
Number of detections	15	11	15	30	21	12	11
Median	12	11	13	11	14	13	18
Interquartile range	4.5	2.3	6.4	5.1	4.5	3.5	8.0
Population	AB	A	AB	AB	AB	AB	B
Sodium (mg/L)							
Number of wells	15	11	15	30	21	12	11
Number of detections	15	11	15	30	21	12	11
Median	4.6	5.9	5.6	15	14	22.5	11
Interquartile range	4.8	9.9	2.4	21.4	8.0	28.3	13.7
Population	A	A	A	B	B	B	AB
Sulfate (mg/L)							
Number of wells	15	11	15	31	21	12	11
Number of detections	15	11	15	31	21	12	11
Median	11	15	19	15	20	19.5	15
Interquartile range	5.9	6.0	17	9.0	11	8.5	14
Population	A	AB	B	AB	B	B	AB
NUTRIENTS							
Ammonia, as NH_4 (mg/L)							
Number of wells	15	11	15	31	21	12	11
Number of detections	4	5	11	16	13	10	8
Median	.001*	.009*	.010	.010	.018	.035	.030
Interquartile range	.012*	.043*	.038*	.115*	.086*	.049	.041*
Population	A	AB	B	AB	B	B	B
Nitrate plus nitrite, as N (mg/L)							
Number of wells	15	11	15	31	21	12	11
Number of detections	8	11	14	29	19	10	9
Median	.11	1.5	4.7	2.4	2.3	3.4	1.3
Interquartile range	.56	3.0	6.5	4.4	2.3	1.9	3.0
Population	A	AB	B	B	B	B	AB
Orthophosphorus, as PO_4 (mg/L)							
Number of wells	15	11	15	31	21	12	11
Number of detections	7	4	3	10	11	6	6
Median	.009*	.008*	.002*	.007*	.010	.007*	.005*
Interquartile range	.004*	.004*	.006*	.006*	.024*	.011*	.019*
Population	A	A	A	A	A	A	A
TRACE ELEMENTS							
Arsenic (μg/L)							
Number of wells	15	11	15	31	21	12	11
Number of detections	2	2	2	9	3	3	4
Median	—	—	—	.28*	—	—	.55*
Interquartile range	—	—	—	.89*	—	—	.66*
Population	A	A	A	A	A	A	A

Table 5. Statistical summary by land use of water-quality variables detected in 1 or more of 85–116 observation wells in four stratified-drift aquifers in Connecticut—Continued

Water-quality variable, units, and statistic	Land use category						
	Undeveloped	Agricultural		Residential		Commercial	Industrial
		Untilled	Tilled	Unsewered	Sewered		
				TRACE ELEMENTS—Continued			
Barium (μg/L)							
Number of wells	15	11	15	30	21	12	11
Number of detections	15	11	15	30	21	12	11
Median	25	27	37	41.5	120	72.5	31
Interquartile range	40	73	69	56.6	143	104.9	161
Population	A	A	A	A	B	AB	AB
Beryllium (μg/L)							
Number of wells	15	11	15	30	21	12	11
Number of detections	1	0	2	5	1	4	4
Median	—	—	—	.10*	—	.25*	.55*
Interquartile range	—	—	—	.21*	—	.60*	.65*
Population	A	A	A	A	A	A	A
Boron (μg/L)							
Number of wells	15	11	15	31	21	12	11
Number of detections	3	6	11	22	19	11	8
Median	6.6*	20	30	20	30	40	50
Interquartile range	5.7*	10*	39.4*	29.1*	27.5*	37.5	137.3
Population	A	AB	BC	BC	C	C	C
Cadmium (μg/L)							
Number of wells	15	11	15	30	21	12	11
Number of detections	1	2	0	5	2	0	1
Median	—	—	—	.06*	—	—	—
Interquartile range	—	—	—	.28*	—	—	—
Population	A	A	A	A	A	A	A
Chromium (μg/L)							
Number of wells	15	11	15	31	21	12	11
Number of detections	4	2	1	6	8	3	2
Median	.27*	—	—	.15*	.62*	.75*	—
Interquartile range	.90*	—	—	.43*	1.73*	1.54*	—
Population	A	A	A	A	A	A	A
Cobalt (μg/L)							
Number of wells	15	11	15	30	21	12	11
Number of detections	3	0	0	2	2	0	2
Median	1.04*	—	—	—	—	—	—
Interquartile range	1.63*	—	—	—	—	—	—
Population	A	A	A	A	A	A	A
Copper (μg/L)							
Number of wells	15	11	15	30	21	12	11
Number of detections	2	0	0	1	3	0	0
Median	—	—	—	—	.61*	—	—
Interquartile range	—	—	—	—	2.72*	—	—
Population	A	A	A	A	A	A	A
Iron (μg/L)							
Number of wells	15	11	15	30	21	12	11
Number of detections	14	11	14	27	21	12	11
Median	37	9.0	10	11	32	31	23
Interquartile range	169	14	11.5	36	54	155	76
Population	AB	AB	A	AB	B	B	AB

Table 5. Statistical summary by land use of water-quality variables detected in 1 or more of 85–116 observation wells in four stratified-drift aquifers in Connecticut—Continued

Water-quality variable, units, and statistic	Land use category						
	Undeveloped	Agricultural		Residential		Commercial	Industrial
		Untilled	Tilled	Unsewered	Sewered		
	TRACE ELEMENTS—Continued						
Lead (μg/L)							
Number of wells	15	11	15	30	21	12	11
Number of detections	3	1	0	3	4	2	2
Median	2.53*	—	—	1.18*	.14*	—	—
Interquartile range	4.43*	—	—	2.58*	2.15*	—	—
Population	A	A	A	A	A	A	A
Lithium (μg/L)							
Number of wells	15	11	15	30	21	12	11
Number of detections	2	6	7	10	12	8	5
Median	—	6.0	3.8*	2.3	4.0	5.5	3.7*
Interquartile range	—	3.8*	3.2*	4.9	5.6*	3.6*	2.5*
Population	A	A	A	A	A	A	A
Manganese (μg/L)							
Number of wells	15	11	15	30	21	12	11
Number of detections	15	9	15	29	21	12	11
Median	45	4.0	22	61.5	149	93.2	45
Interquartile range	215.5	116.5	28	190	488	125.5	161.5
Population	A	A	A	A	A	A	A
Mercury (μg/L)							
Number of wells	15	11	15	30	21	12	11
Number of detections	3	4	2	6	2	1	1
Median	—	.018*	—	.001*	—	—	—
Interquartile range	—	.097*	—	.002*	—	—	—
Population	A	A	A	A	A	A	A
Molybdenum (μg/L)							
Number of wells	15	11	15	30	21	12	11
Number of detections	0	0	0	1	3	0	0
Median	—	—	—	—	.50*	—	—
Interquartile range	—	—	—	—	2.49*	—	—
Population	A	A	A	A	A	A	A
Nickel (μg/L)							
Number of wells	15	11	15	31	21	12	11
Number of detections	14	8	14	27	19	10	7
Median	2.0	2.0	3.0	3.0	4.0	8.5	1.0
Interquartile range	2.0	2.6	6.0	9.5	5.0	13	3.7*
Population	A	A	A	A	A	A	A
Silver (μg/L)							
Number of wells	15	11	15	31	21	12	11
Number of detections	0	1	0	5	3	0	3
Median	—	—	—	.43*	—	—	—
Interquartile range	—	—	—	.39*	—	—	—
Population	A	A	A	A	A	A	A
Strontium (μg/L)							
Number of wells	15	11	15	30	21	12	11
Number of detections	15	11	15	30	21	12	11
Median	37	56	76	91	76	89	79
Interquartile range	25	23	45	90.8	80.5	42	57
Population	A	AB	B	B	B	B	B

Table 5. Statistical summary by land use of water-quality variables detected in 1 or more of 85–116 observation wells in four stratified-drift aquifers in Connecticut—Continued

Water-quality variable, units, and statistic	Land use category						
	Undeveloped	Agricultural		Residential		Commercial	Industrial
		Untilled	Tilled	Unsewered	Sewered		
TRACE ELEMENTS—Continued							
Vanadium (μg/L)							
Number of wells	15	11	15	30	21	12	11
Number of detections	0	0	0	1	1	0	0
Median	—	—	—	—	—	—	—
Interquartile range	—	—	—	—	—	—	—
Population	A	A	A	A	A	A	A
Zinc (μg/L)							
Number of wells	15	11	15	30	21	12	11
Number of detections	13	10	14	28	21	11	11
Median	6.0	7.0	7.0	8.0	7.0	8.2	7.0
Interquartile range	8.5	5.0	4.8	7.0	5.0	4.5	4.5
Population	A	A	A	A	A	A	A
ORGANIC COMPOUNDS							
Methylene-blue-active substances (mg/L)							
Number of wells	15	11	15	31	21	12	11
Number of detections	15	11	14	31	21	12	11
Median	.030	.030	.050	.045	.040	.050	.040
Interquartile range	.025	.025	.040	.030	.020	.030	.015
Population	A	AB	AB	AB	AB	B	AB
Total organic carbon (mg/L)							
Number of wells	15	11	15	31	21	12	11
Number of detections	14	11	14	31	20	11	11
Median	.60	1.20	.80	1.00	1.00	1.10	1.40
Interquartile range	.55	1.20	.70	.92	1.20	.75	1.30
Population	A	A	A	A	A	A	A
VOLATILE ORGANIC COMPOUNDS							
Benzene (μg/L)							
Number of wells	14	11	15	29	21	12	11
Number of detections	1	0	0	1	0	0	1
Median	—	—	—	—	—	—	—
Interquartile range	—	—	—	—	—	—	—
Population	A	A	A	A	A	A	A
Chloroethane (μg/L)							
Number of wells	14	10	15	29	21	12	11
Number of detections	0	1	0	0	0	0	0
Median	—	—	—	—	—	—	—
Interquartile range	—	—	—	—	—	—	—
Population	A	A	A	A	A	A	A
Chloroform (μg/L)							
Number of wells	14	11	15	29	21	12	11
Number of detections	1	3	0	5	10	2	6
Median	—	.11*	—	.02*	.14*	—	.20
Interquartile range	—	.13*	—	.09*	.29*	—	.34*
Population	A	AB	A	A	B	AB	B
Dichlorodifluoromethane (μg/L)							
Number of wells	14	11	15	29	21	12	11
Number of detections	1	0	1	1	0	1	1
Median	—	—	—	—	—	—	—
Interquartile range	—	—	—	—	—	—	—
Population	A	A	A	A	A	A	A

Table 5. Statistical summary by land use of water-quality variables detected in 1 or more of 85–116 observation wells in four stratified-drift aquifers in Connecticut—Continued

Water-quality variable, units, and statistic	Land use category						
	Undeveloped	Agricultural		Residential		Commercial	Industrial
		Untilled	Tilled	Unsewered	Sewered		
	VOLATILE ORGANIC COMPOUNDS—Continued						
1,2-Dichlorobenzene (μg/L)							
Number of wells	14	11	14	28	21	12	11
Number of detections	0	0	1	2	0	0	0
Median	—	—	—	—	—	—	—
Interquartile range	—	—	—	—	—	—	—
Population	A	A	A	A	A	A	A
1,1-Dichloroethane (μg/L)							
Number of wells	14	11	15	29	21	12	11
Number of detections	0	0	1	1	1	1	3
Median	—	—	—	—	—	—	.03*
Interquartile range	—	—	—	—	—	—	2.40*
Population	A	A	A	A	A	A	A
1,2-Dichloroethane (μg/L)							
Number of wells	14	11	15	29	21	12	11
Number of detections	0	0	0	1	0	0	0
Median	—	—	—	—	—	—	—
Interquartile range	—	—	—	—	—	—	—
Population	A	A	A	A	A	A	A
1,1-Dichloroethylene (μg/L)							
Number of wells	14	11	15	29	21	12	11
Number of detections	0	0	1	0	1	1	2
Median	—	—	—	—	—	—	—
Interquartile range	—	—	—	—	—	—	—
Population	A	A	A	A	A	A	A
1,2-Dichloropropane (μg/L)							
Number of wells	14	11	15	29	21	12	11
Number of detections	1	0	3	2	0	0	0
Median	—	—	—	—	—	—	—
Interquartile range	—	—	—	—	—	—	—
Population	A	A	A	A	A	A	A
Ethylbenzene (μg/L)							
Number of wells	14	11	15	29	21	12	11
Number of detections	0	0	0	1	0	0	0
Median	—	—	—	—	—	—	—
Interquartile range	—	—	—	—	—	—	—
Population	A	A	A	A	A	A	A
Methylene chloride (μg/L)							
Number of wells	15	11	15	30	21	12	11
Number of detections	0	0	0	2	0	0	0
Median	—	—	—	—	—	—	—
Interquartile range	—	—	—	—	—	—	—
Population	A	A	A	A	A	A	A
Tetrachloroethylene (μg/L)							
Number of wells	14	11	15	29	21	12	11
Number of detections	0	0	0	4	4	6	4
Median	—	—	—	.09*	—	.16*	.03*
Interquartile range	—	—	—	.13*	—	9.40*	.60*
Population	A	AB	A	AB	ABC	C	BC

Table 5. Statistical summary by land use of water-quality variables detected in 1 or more of 85–116 observation wells in four stratified-drift aquifers in Connecticut—Continued

Water-quality variable, units, and statistic	Land use category						
	Undeveloped	Agricultural		Residential		Commercial	Industrial
		Untilled	Tilled	Unsewered	Sewered		
	VOLATILE ORGANIC COMPOUNDS—Continued						
1,1,2,2-Tetrachloroethane (μg/L)							
Number of wells	14	11	15	29	21	12	11
Number of detections	0	0	0	1	0	0	0
Median	—	—	—	—	—	—	—
Interquartile range	—	—	—	—	—	—	—
Population	A	A	A	A	A	A	A
Toluene (μg/L)							
Number of wells	14	11	15	29	21	12	11
Number of detections	1	1	0	6	3	3	1
Median	—	—	—	.12*	.07*	—	—
Interquartile range	—	—	—	.08*	.08*	—	—
Population	A	A	A	A	A	A	A
1,2-transDichloroethylene (μg/L)							
Number of wells	14	11	15	29	21	12	11
Number of detections	2	3	2	1	2	5	3
Median	—	.11*	—	—	—	.09*	.14*
Interquartile range	—	.13*	—	—	—	2.84*	.11*
Population	AB	AB	AB	A	AB	B	AB
1,1,1-Trichloroethane (μg/L)							
Number of wells	14	11	15	29	21	12	11
Number of detections	0	1	1	6	6	3	5
Median	—	—	—	.03*	.17*	.10*	.03*
Interquartile range	—	—	—	.16*	.13*	.56*	2.80*
Population	A	A	A	A	A	A	A
1,1,2-Trichloroethane (μg/L)							
Number of wells	14	11	15	29	21	12	11
Number of detections	0	0	0	0	0	0	1
Median	—	—	—	—	—	—	—
Interquartile range	—	—	—	—	—	—	—
Population	A	A	A	A	A	A	A
Trichloroethylene (μg/L)							
Number of wells	14	11	15	29	21	12	11
Number of detections	0	0	0	3	1	5	2
Median	—	—	—	—	—	.04*	—
Interquartile range	—	—	—	—	—	.65*	—
Population	A	A	A	A	A	B	AB
Trichlorofluoromethane (μg/L)							
Number of wells	14	11	15	29	21	12	11
Number of detections	2	2	1	1	1	0	2
Median	—	—	—	—	—	—	—
Interquartile range	—	—	—	—	—	—	—
Population	A	A	A	A	A	A	A
Vinyl chloride (μg/L)							
Number of wells	14	11	15	29	21	12	11
Number of detections	0	0	0	1	0	1	0
Median	—	—	—	—	—	—	—
Interquartile range	—	—	—	—	—	—	—
Population	A	A	A	A	A	A	A

Table 5. Statistical summary by land use of water-quality variables detected in 1 or more of 85–116 observation wells in four stratified-drift aquifers in Connecticut—Continued

Water-quality variable, units, and statistic	Land use category						
	Undeveloped	Agricultural		Residential		Commercial	Industrial
		Untilled	Tilled	Unsewered	Sewered		
VOLATILE ORGANIC COMPOUNDS—Continued							
Xylene (μg/L)							
Number of wells	14	11	15	29	21	12	10
Number of detections	0	0	1	0	0	2	0
Median	—	—	—	—	—	—	—
Interquartile range	—	—	—	—	—	—	—
Population	A	A	A	A	A	A	A
PESTICIDES							
Atrazine (μg/L)							
Number of wells	14	11	15	11	11	12	11
Number of detections	0	0	5	0	0	1	1
Median	—	—	.06*	—	—	—	—
Interquartile range	—	—	.06*	—	—	—	—
Population	A	AB	B	AB	AB	AB	AB
Chlordane (μg/L)							
Number of wells	13	10	15	31	21	12	11
Number of detections	0	0	0	2	1	0	0
Median	—	—	—	—	—	—	—
Interquartile range	—	—	—	—	—	—	—
Population	A	A	A	A	A	A	A
Cyanazine (μg/L)							
Number of wells	14	11	15	11	11	12	11
Number of detections	0	1	0	0	0	0	0
Median	—	—	—	—	—	—	—
Interquartile range	—	—	—	—	—	—	—
Population	A	A	A	A	A	A	A
2,4-D (μg/L)							
Number of wells	13	10	12	25	16	11	10
Number of detections	1	0	0	1	1	0	2
Median	—	—	—	—	—	—	—
Interquartile range	—	—	—	—	—	—	—
Population	A	A	A	A	A	A	A
DDD (μg/L)							
Number of wells	13	10	15	31	21	12	11
Number of detections	0	0	0	1	0	0	0
Median	—	—	—	—	—	—	—
Interquartile range	—	—	—	—	—	—	—
Population	A	A	A	A	A	A	A
2,4-DP (μg/L)							
Number of wells	13	10	12	25	16	11	10
Number of detections	0	0	0	0	1	0	0
Median	—	—	—	—	—	—	—
Interquartile range	—	—	—	—	—	—	—
Population	A	A	A	A	A	A	A
Diazinon (μg/L)							
Number of wells	13	10	15	31	21	12	11
Number of detections	0	0	0	2	0	0	0
Median	—	—	—	—	—	—	—
Interquartile range	—	—	—	—	—	—	—
Population	A	A	A	A	A	A	A

Table 5. Statistical summary by land use of water-quality variables detected in 1 or more of 85–116 observation wells in four stratified-drift aquifers in Connecticut—Continued

Water-quality variable, units, and statistic	Land use category						
	Undeveloped	Agricultural		Residential		Commercial	Industrial
		Untilled	Tilled	Unsewered	Sewered		
			PESTICIDES—Continued				
Dieldrin (μg/L)							
Number of wells	13	10	15	31	21	12	11
Number of detections	0	0	1	2	1	0	1
Median	—	—	—	—	—	—	—
Interquartile range	—	—	—	—	—	—	—
Population	A	A	A	A	A	A	A
Phorate (μg/L)							
Number of wells	13	5	11	18	19	11	11
Number of detections	0	0	0	0	1	0	0
Median	—	—	—	—	—	—	—
Interquartile range	—	—	—	—	—	—	—
Population	A	A	A	A	A	A	A
Prometone (μg/L)							
Number of wells	14	11	15	11	11	12	11
Number of detections	0	0	0	0	0	0	2
Median	—	—	—	—	—	—	—
Interquartile range	—	—	—	—	—	—	—
Population	A	A	A	A	A	A	A
Propazine (μg/L)							
Number of wells	14	11	15	11	11	12	11
Number of detections	0	0	0	0	0	1	0
Median	—	—	—	—	—	—	—
Interquartile range	—	—	—	—	—	—	—
Population	A	A	A	A	A	A	A
Silvex (μg/L)							
Number of wells	13	10	14	31	20	11	11
Number of detections	0	0	0	1	1	0	0
Median	—	—	—	—	—	—	—
Interquartile range	—	—	—	—	—	—	—
Population	A	A	A	A	A	A	A
Simazine (μg/L)							
Number of wells	14	11	15	11	11	12	11
Number of detections	1	0	0	0	0	1	0
Median	—	—	—	—	—	—	—
Interquartile range	—	—	—	—	—	—	—
Population	A	A	A	A	A	A	A
2,4,5-T (μg/L)							
Number of wells	13	10	14	31	20	12	11
Number of detections	0	0	0	1	1	1	0
Median	—	—	—	—	—	—	—
Interquartile range	—	—	—	—	—	—	—
Population	A	A	A	A	A	A	A

several inorganic constituents (chloride, silica, orthophosphorus, and strontium) is smallest for the untilled agricultural areas. Ground-water quality in the untilled agricultural areas resembles background conditions with respect to the generally low median concentrations and interquartile ranges for most inorganic ground-water constituents.

There are no significant differences in the mean rank of the concentrations or frequency of detection of any organic compound between the untilled agricultural and the undeveloped land (see table 5). Only six volatile organic compounds and one pesticide compound were detected in samples from the untilled areas. Trace-level concentrations

(0.2–0.3 μg/L) of chloroform and 1,2-transdichloroethylene were each detected three times. Two detections of trichlorofluoromethane (0.3 and 0.7 μg/L) and one detection each of chloroethane (0.3 μg/L), 1,1,1-trichloroethane (0.2 μg/L), and toluene (0.2 μg/L) were reported in ground-water samples from this land use category. Because 9 of the 11 detections of volatile organic compounds were in samples from three wells, and there is no known agricultural use for these compounds, their presence may reflect unknown anthropogenic factors in the vicinity of the anomalous wells, or perhaps atmospheric deposition. Similarly, detections of unidentified BNA compounds in three GC/FID scans cannot be related to known human activities in this land use area. GC/MS analyses performed on two of these samples were inconclusive. No BNA compounds were detected in one sample, and a trace-level concentration (0.7 μg/L) of one compound, methylbenzene (toluene), was reported in the other. Resampling the third well failed to confirm the GC/FID peaks reported in the initial sampling. The only pesticide detected in the untilled agricultural areas was cyanazine (0.1 μg/L), a herbicide commonly used on fallow agricultural lands.

Tilled Areas

Ground-water quality is more severely affected beneath tilled agricultural lands than beneath untilled areas because of the more intense agricultural practices associated with agricultural land use. The mean rank of the sample populations or the frequency of detection for specific conductance, calcium, magnesium, hardness, sulfate, dissolved solids, nitrate plus nitrite-nitrogen, ammonia-nitrogen, boron, and strontium is significantly higher for the tilled agricultural areas than the undeveloped areas (see table 5). Increased nitrate plus nitrite-nitrogen concentrations and ammonia-nitrogen detections can be attributed to widespread applications of inorganic and organic fertilizers on cultivated cropland. Applications of a variety of inorganic chemical compounds as soil treatments and micronutrients, such as lime, dolomite, anhydrite, gypsum, and borax, increase the concentrations of calcium, magnesium, hardness, sulfate, boron, and strontium. Increased specific conductance and dissolved solids reflect the aggregate effects of fertilizer and inorganic chemical applications.

The median nitrate plus nitrite-nitrogen concentration of 4.7 mg/L is higher for ground-water samples from the tilled agricultural areas than for all other land use areas (fig. 7). Twenty percent of the wells in the tilled agricultural areas yielded water that exceeded the 10-mg/L limit specified by the national primary drinking-water regulations (U.S. Environmental Protection Agency, 1986). In 11 samples collected from one well installed beneath a corn field that receives heavy applications of organic fertilizer (manure), nitrate plus nitrite-nitrogen concentrations ranged from 5.5 to 60 mg/L. Although the mean rank of the nitrate plus nitrite-nitrogen concentrations in water samples from the tilled agricultural areas is significantly higher than in those from the undeveloped areas, it is not significantly different from the untilled agricultural areas or any of the developed areas. The interquartile range of nitrate plus nitrite-nitrogen and sulfate concentrations is greater for samples from this land use area than for samples from all other land use areas. Large variation in the concentrations of these constituents may reflect differences in the quantity and composition of fertilizer and soil-treatment chemicals applied to different tilled crops by different farmers.

Although the use of phosphate fertilizers has increased the phosphorous content of agricultural drainage and contributed to algal growth problems in surface waters (Hem, 1985, p. 126–129), the low solubility of phosphorous and its use by biota as a nutrient generally result in low concentrations in ground waters. Both the estimated median concentration (0.002 mg/L) and the frequency of detection (20 percent) of orthophosphorus were lowest in water samples from the tilled agricultural areas but did not differ significantly from those of the other land use categories. Several trace elements (arsenic, cadmium, cobalt, copper, chromium, lead, molybdenum, silver, and vanadium) were also detected least frequently (or equally as frequent as for another land use) in the tilled agricultural areas.

Although the mean rank of the MBAS concentrations for ground-water samples from the tilled agricultural areas is not statistically different from that of the other land use areas, the median MBAS concentration, 0.05 mg/L, is elevated relative to five other land use areas and equally as large as the median MBAS concentration for samples from the commercial areas. Samples from wells in the tilled agricultural areas had both the lowest (<0.01 mg/L) and the highest (0.38 mg/L) MBAS concentrations. Elevated MBAS concentrations may relate to agricultural pesticide use because surfactants are used to aid dispersal of some pesticide compounds.

The herbicide atrazine, widely used for weed control in corn, was detected at low concentrations (0.1–0.2 μg/L) in one-third of the wells in the tilled agricultural areas (fig. 7). The frequency of atrazine detections was significantly higher in this land use category than in the undeveloped areas, where it was undetected. Although no atrazine was detected in ground water beneath the untilled agricultural, unsewered residential, and sewered residential land use areas either, the number of samples from these areas was too few to establish a valid statistical difference in the frequency of detection.

One additional pesticide and nine volatile organic compounds were detected in ground-water samples from the tilled agricultural areas. The insecticide dieldrin, commonly used to control corn pests prior to its prohibition in 1974, was detected at a concentration of 0.13 μg/L in water from one well. The extremely low volatility and low solubility of dieldrin, as well as its high affinity for organic matter, may

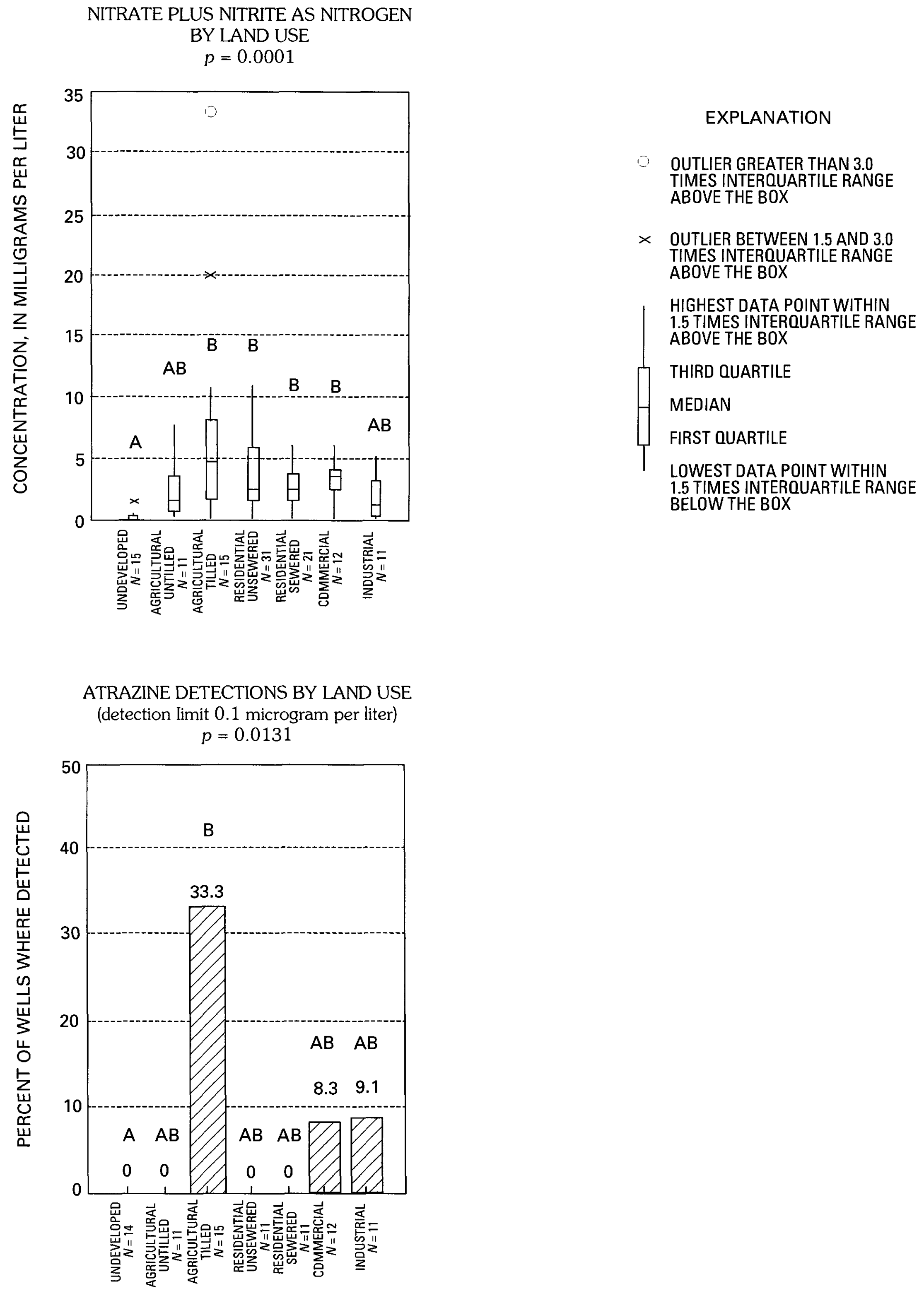


Figure 7. Statistical comparisons by land use of nitrate plus nitrite-nitrogen concentrations and frequency of atrazine detections in ground-water samples from four stratified-drift aquifers in Connecticut. The *p* value is the attained significance level for that statistical comparison; *N* is number of wells sampled per land use category; sample populations are designated by letter symbols A and B; sample populations that share the same letter are not significantly different at the 0.05 level of significance.

result in its residual occurrence and may account for the persistence of this compound in ground water more than a decade after all use presumably ceased. The most frequently detected volatile organic compound, 1,2-dichloropropane, is a soil fumigant and nematocide used on tobacco and strawberries in the study areas. It has been detected in water samples from three wells in the tilled areas at concentrations of 0.9–41 μg/L. The frequency of detection of 1,2-dichloropropane is highest in ground water from the tilled agricultural areas; however, it is not significantly higher than in the other land use areas, where it has been detected rarely or not at all (see table 5).

The occurrence of three volatile organic compounds, 1,1-dichloroethane, 1,1-dichloroethylene, and 1,1,1-trichloroethane at concentrations of 0.3, 1.4, and 25 μg/L, respectively, in the water from one tilled-area well is enigmatic. The lack of any known agricultural source for these compounds and the elevated concentration of the 1,1,1-trichloroethane suggest contamination from a nonagricultural source in the vicinity of the well. Trace-level concentrations (0.2–0.5 μg/L) of other volatile organic compounds, 1,2-dichlorobenzene, dichlorodifluoromethane, 1,2-transdichloroethylene, trichlorofluoromethane, and xylene, in one or two water samples may also originate from nonagricultural sources.

GC/FID analyses of water samples from four wells completed in the tilled agricultural area indicated that each sample contained one or more unidentified BNA organic compounds. Subsequent resampling and GC/FID analysis of water from three of the wells failed to detect any compounds in two of the samples, while the presence of organic compounds was confirmed in the third sample. GC/MS analysis was performed on the latter sample, as well as on the sample from the fourth well. One sample contained nine nontarget BNA organic compounds, of which five were aliphatic hydrocarbons and four were unidentified alkane compounds, at concentrations of less than 1.0–20 μg/L. The other sample contained 38 μg/L of an unidentified carboxylic acid ester and 5.8 μg/L of 1,3,5-cycloheptatriene. No agricultural source is apparent for any of the compounds identified in these samples.

Residential Land

Although several nonpoint sources may contribute to the degradation of ground-water quality in residential areas, the most important is perhaps on-site disposal of wastes through septic tanks and cesspools. Septic tanks represent the highest total volume of wastewater discharged directly to ground water and the most commonly recorded source of ground-water contamination (U.S. Environmental Protection Agency, 1977). Consequently, residential land use was differentiated into unsewered and sewered areas to evaluate if differences in ground-water quality exist between the two areas that may reflect the manner of sewage disposal.

Eckhardt and others (1989) observed statistically significant differences in the concentration or frequency of detection of several inorganic constituents and volatile organic compounds in ground water beneath sewered and unsewered areas of Long Island, N.Y. Ground water beneath sewered areas of Long Island was found to have higher total dissolved solids concentrations and greater frequency of volatile organic compound detections than unsewered areas. Nitrate and chloride concentrations were not significantly different between the two areas, although the implementation of sewering was anticipated to reduce levels of these constituents. Eckhardt and others (1989, p. 22–25) concluded that the higher population density of the sewered areas together with other sources of ground-water contamination complicated direct comparisons of ground-water quality between sewered and unsewered areas.

Unsewered Areas

The quality of ground water beneath unsewered residential lands is affected to about the same degree with respect to inorganic constituents as is the water quality in the tilled agricultural areas. The mean rank of the concentrations or the frequency of detection of specific conductance, calcium, magnesium, hardness, sodium, chloride, dissolved solids, nitrate plus nitrite-nitrogen, boron, and strontium is significantly higher in samples from the unsewered land than from the undeveloped areas (table 5). The mean rank of the sodium concentrations is also significantly higher in the unsewered residential areas than in both the untilled and tilled agricultural land areas, reflecting the absence of any substantial septic tank or road salt sources in those areas. Median concentrations of most inorganic constituents are intermediate; only strontium has a higher median concentration in water samples from the unsewered residential areas than in samples from all other land use areas (fig. 8). The most likely source of strontium is from septic tank effluents, inasmuch as the only documented domestic use of strontium known to the author is in toothpaste (Wennig and Kirsch, 1988, p. 632). Elevated levels of all 10 of the above water-quality variables could result from septic tank effluents; however, other nonpoint sources, such as applications of deicing chemicals and lawn and garden fertilizers, are likely as well.

Large variations in some water-quality constituents were found in unsewered residential areas, as evidenced by the fact that three inorganic constituents have their lowest and highest concentrations in water from this land category. Calcium concentrations ranged from 1.5 to 110 mg/L, strontium from 9 to 940 μg/L, and hardness from 5 to 270 mg/L (as calcium carbonate) in samples from wells in unsewered residential areas. Lowest magnesium (0.3 mg/L) and silica (3.4 mg/L) concentrations also were detected in this area, whereas the highest temperature (20 °C) and concentrations of barium (400 μg/L), cadmium (8 μg/L),

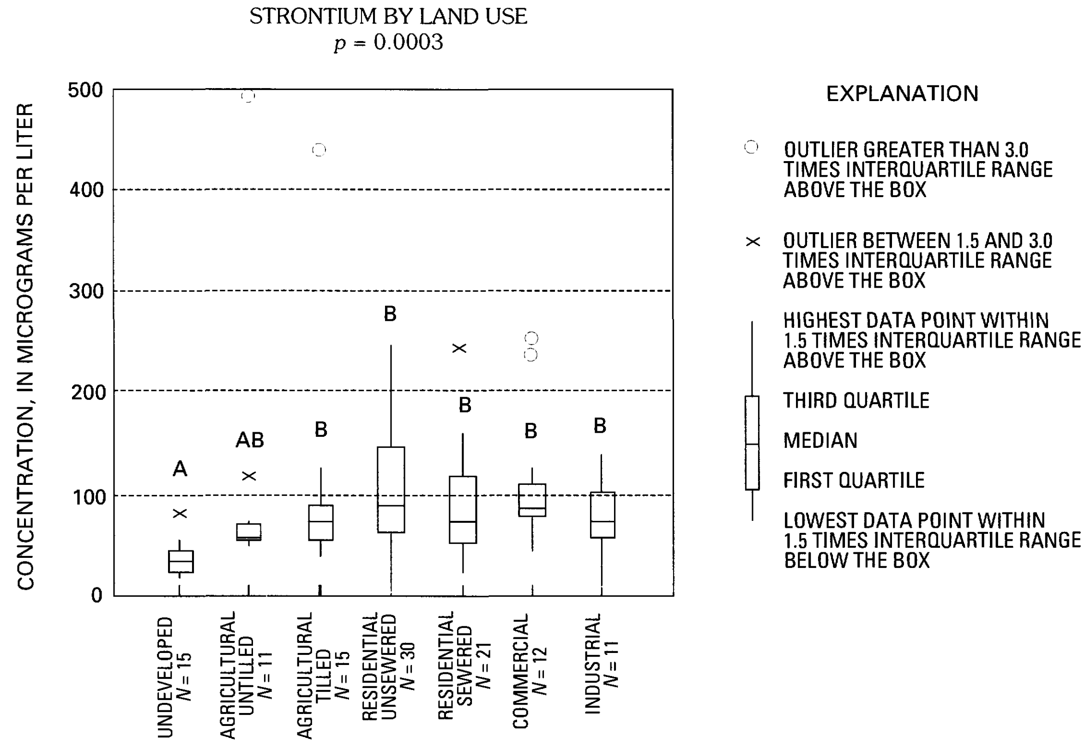


Figure 8. Statistical comparison by land use of strontium concentrations in ground-water samples from four stratified-drift aquifers in Connecticut. The p value is the attained significance level for that statistical comparison; N is the number of wells sampled per land use category; sample populations are designated by letter symbols A and B; sample populations that share the same letter are not significantly different at the 0.05 level of significance.

iron (20,000 µg/L), lithium (66 µg/L), manganese (7,400 µg/L), mercury (3.7 µg/L), and silver (1.8 µg/L) were reported in ground-water samples from the unsewered residential land. This large variation may be attributed, in part, to the wide range in housing densities encountered in unsewered areas.

Evidence of widespread presence of organic contaminants from human activities is provided by the detection of one or more volatile organic compounds in samples from 62 percent of the wells in the unsewered residential area. Seventeen volatile organic compounds have been detected in ground-water samples from the unsewered residential areas, and five of these compounds (1,2-dichlorobenzene, 1,2-dichloroethane, ethylbenzene, methylene chloride, and 1,1,2,2-tetrachloroethane) are found solely or most commonly in this area. However, the frequency of detection was not significantly higher for any of the compounds (table 5). The volatile organic compounds most commonly detected were toluene (0.2–0.3 µg/L) and 1,1,1-trichloroethane (0.2–2.1 µg/L), both of which were found in six wells. Chloroform was detected in samples from five wells at concentrations ranging from 0.2 to 1.3 µg/L, tetrachloroethylene in samples from four wells at trace-level concentrations of 0.2–0.3 µg/L, and trichloroethylene in water from three wells at concentrations ranging from 0.2 to 4.4 µg/L. Other volatile organic compounds were detected just once or twice, and except for methylene chloride (8.8–11.0 µg/L) and 1,2-dichlorobenzene (3.0 µg/L), all were present at concentrations of less than 1.0 µg/L. This group of synthetic chemicals consists of low-molecular-weight chlorinated hydrocarbons widely used as solvents, degreasers, refrigerants, fumigants, and insecticides and found in numerous household products. Disposal of these products through septic systems is a likely source for some of the detections, but spills, leaks, and improper disposal of gasoline and motor oils, paint, varnish, finish removers, disinfectants, and cleaning agents may also be sources.

Nearly half (48 percent) of the samples from wells in the unsewered residential areas submitted for GC/FID analyses contained one or more unidentified BNA organic compounds. GC/MS analyses were performed on 10 samples from wells with positive GC/FID results, and target BNA compounds (see table 2) were identified and quantified in 6 of these samples. These compounds were bis(2-

ethylhexyl)phthalate at concentrations of 2.9–8.5 μg/L in five of the samples, diethyl phthalate (1.9–5.5 μg/L) and phenol (2.4–2.6 μg/L) in two of the samples, and singular detections of di-n-butyl phthalate (2.6 μg/L) and naphthalene (2.3 μg/L). The above compounds are most commonly used as plasticizers, solvents, lubricants, and preservatives and are found in numerous household products such as perfumes, pharmaceuticals, and moth and mosquito repellents. Trace levels of the polynuclear aromatic hydrocarbons (PAH) acenaphthene, fluoranthene, and fluorene, all common combustion byproducts, were also reported in one sample. In addition, most of the samples contained one or more nontarget BNA compounds, principally high-molecular weight aliphatic hydrocarbons. Water from one well contained as many as 49 BNA compounds at concentrations ranging from less than 1.0 to 500 μg/L. The association of such compounds as fenchone (40 μg/L), benzenepropanoic acid (500 μg/L), trans-geraniol (10 μg/L), para-menthan-8-ol (400 μg/L), alpha-terpineol (200 μg/L), and benzeneacetic acid (150 μg/L) with various phenols and alkanes suggests contamination from an adjacent septic source that receives household products, such as cleaners, toiletries, pharmaceuticals, food additives, preservatives, and flavoring agents.

The seven pesticides detected in samples from the unsewered residential areas are the insecticides chlordane, diazinon, dieldrin, and DDD, and the herbicides 2,4-D, 2,4,5-T, and silvex (table 5). Chlordane (0.1–0.3 μg/L), diazinon (0.01–0.07 μg/L), and dieldrin (0.03–0.063 μg/L) were each detected twice, and DDD (0.01 μg/L) once. These insecticides have commonly been used in residential areas to control such pests as termites, ants, cockroaches, yellow jackets, and garden insects. The herbicides 2,4-D (0.03 μg/L), 2,4,5-T (0.01 μg/L), and silvex (0.01 μg/L) were all detected in water from one well, where they may have been used to control weeds in residential lawns and gardens. None of the above pesticides was detected in enough samples from wells in unsewered residential areas to be statistically different from other land use areas.

Sewered Areas

Ground-water quality beneath sewered residential areas is affected to a greater degree by human activities than is ground-water quality beneath the unsewered areas. The mean rank of the concentrations or the frequency of detection of specific conductance, calcium, magnesium, hardness, sodium, chloride, sulfate, dissolved solids, nitrate plus nitrite-nitrogen, ammonia-nitrogen, barium, boron, and strontium is significantly higher for samples from the sewered residential areas than for those from the undeveloped areas (table 5). The mean rank of the specific conductance of ground water, and the mean rank of the dissolved solids, sodium, barium, and boron concentrations are also significantly higher for the sewered areas than for the untilled agricultural areas. Mean ranks of sodium, chloride, barium, and iron concentrations are significantly higher for ground-water samples from the sewered residential areas than for those from the tilled agricultural areas. The mean rank of the barium concentrations is significantly higher for ground-water samples from the sewered residential areas than for samples from the unsewered residential areas.

Median concentrations or frequency of detection of most physical properties and inorganic constituents is higher in water samples from the sewered areas than in those from the unsewered areas. Figure 9 shows that median concentrations of calcium (29 mg/L), hardness (93 mg/L), and sulfate (20 mg/L) are higher in ground water beneath the sewered residential land than in the ground water beneath any other land use area. Median concentrations of orthophosphorus (0.01 mg/L) and manganese (149 μg/L) and detection frequencies of copper, chromium, and molybdenum are also highest in the sewered residential areas. Median nitrate plus nitrite-nitrogen concentrations are nearly identical for ground-water samples from sewered and unsewered areas. Although sewering may prevent nitrogen-rich septic effluents from reaching ground water, exfiltration from sewer lines is likely to occur in many places within the Northeast where soils are sandy and the water table may be less than 10 ft below sewer lines (Engineering Science, written commun., 1989). Effluents from leaking sewer lines could be contributing to the measured nitrate plus nitrite-nitrogen concentrations. Other sources of nitrogen, such as heavy use of lawn fertilizer in densely populated sewered areas, are masking any improvement in water quality that might result from use of sewers.

Highest reported concentrations of a number of inorganic constituents were measured in samples from the sewered residential areas. Extremely high specific conductance (3,530 microsiemens per centimeter at 25 degrees Celsius (μS/cm)) and concentrations of sodium (480 mg/L), chloride (1,100 mg/L), and dissolved solids (2,050 mg/L) were measured in one ground-water sample from a sewered residential area. These analytical results indicate contamination of the shallow aquifer at this site from a local, concentrated salt source. A pile of sand containing deicing chemicals was left uncovered near this well for use by motorists during the previous winter. The general similarity of sodium and chloride concentrations in samples from unsewered and sewered residential areas indicates that use of deicing chemicals may be a more important source of these constituents than septic tank effluents.

Ground-water samples from the sewered residential areas also had the highest reported concentrations of several other inorganic constituents that may be derived from nonpoint sources. The highest concentrations of five trace elements—arsenic (9 μg/L), chromium (6 μg/L), copper (37 μg/L), lead (210 μg/L), and molybdenum (40 μg/L)—were measured in samples from sewered residential

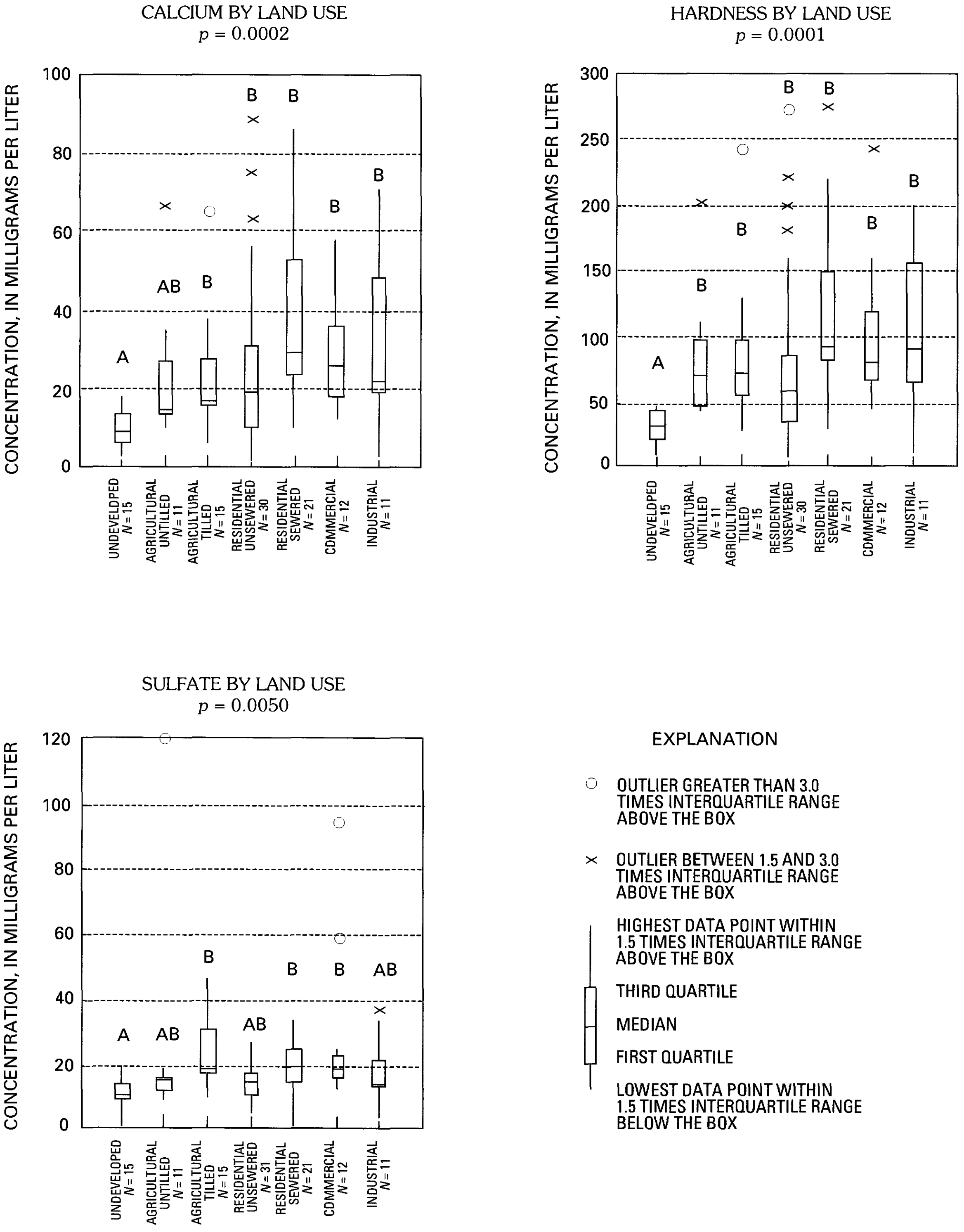


Figure 9. Statistical comparisons by land use of calcium, hardness, and sulfate concentrations in ground-water samples from four stratified-drift aquifers in Connecticut. The *p* value is the attained significance level for that statistical comparison; *N* is the number of wells sampled per land use category; sample populations are designated by letter symbols A and B; sample populations that share the same letter are not significantly different at the 0.05 level of significance.

areas. Concentrations of hardness (270 mg/L) and barium (400 µg/L) were equally as high as concentrations observed in samples from unsewered areas. The broad interquartile ranges for calcium, lithium, manganese, and orthophosphorus concentrations and pH measurements indicate that the sources of these constituents vary greatly within the sewered residential areas.

The frequency of detection of only one volatile organic compound, chloroform, in ground-water samples from the sewered residential areas differed significantly from the frequency of detection observed in other land use areas. Detection of low concentrations (0.2–1.0 µg/L) of chloroform in nearly 48 percent of the wells in the sewered residential areas was significantly higher than detections in the undeveloped, tilled agricultural, and unsewered residential areas (table 5). The widespread detection of chloroform may originate from domestic use of solvents and cleaning agents, exfiltration from water mains, or lawn irrigation with chlorinated municipal drinking water. Eight other volatile organic compounds were detected infrequently. Three compounds, namely, 1,1-dichloroethane (4.8 µg/L), tetrachloroethylene (2.9 µg/L), and trichloroethylene (19 µg/L), were found at elevated concentrations. Trace concentrations of 1,1-dichloroethylene (0.6 µg/L), 1,2-transdichloroethylene (0.2 and 0.3 µg/L), 1,1,1-trichloroethane (0.2 to 0.4 µg/L), trichlorofluoromethane (0.9 µg/L), and toluene (0.2 to 0.3 µg/L) have also been measured in samples from some wells in sewered residential areas.

More than half (52 percent) of the wells in the sewered residential areas contained one or more unidentified BNA organic compounds in samples analyzed by the GC/FID method. Of five samples selected for GC/MS analysis, no BNA compounds could be identified in two samples, while the plasticizer bis(2-ethylhexyl)phthalate was found in three samples at concentrations of 10–420 µg/L. No other target BNA compounds and few nontarget BNA compounds were reported in these samples.

Seven pesticides were also detected in ground-water samples from the sewered residential area. The insecticides chlordane (0.1 µg/L), dieldrin (0.02 µg/L), and phorate (0.01 µg/L) were each detected in one of three wells, while the herbicides 2,4-D (0.03 µg/L), 2,4-DP (0.09 µg/L), 2,4,5-T (0.06 µg/L), and silvex (0.02 µg/L) were all detected in one well. These herbicide compounds are often combined in mixtures used to control brush and weeds, and such a combination may have been applied in the vicinity of this well.

A large number of nonpoint sources of contamination and a high population density may explain the higher median concentrations and greater number of inorganic water-quality variables that are statistically significant in the sewered compared with the unsewered residential areas. Eckhardt and others (1989) found that specific conductance and concentrations of dissolved solids and chloride were highest in ground water on Long Island, N.Y., beneath high-density (more than five dwellings per acre) residential areas. Population density affects water quality because contaminant loadings are determined by factors such as percentage of impervious area, traffic patterns, street-cleaning practices, type of storm-water drainage system, and application rates of deicing chemicals, which differ in urban and suburban settings.

Sewered areas in this study tend to resemble an urban rather than suburban setting in that they are more populous and have more impervious area than unsewered areas. Pervious areas of the sewered residential land are more likely to be cultivated lawns and shrubbery than vacant fields or wooded lots, and sewered residential areas are more likely than unsewered areas to encompass small tracts of industrial and commercial land. The primary source of contaminants in these areas is chemicals leached from street refuse—the detritus, litter, and dust that accumulate on the impervious areas—that infiltrate to the water table in areas of natural (no storm or combined storm-sanitary sewers) storm drainage (Novotny and Chesters, 1981, p. 407). Street refuse commonly contains inorganic and organic matter derived from motor vehicle emissions and road wear, decaying vegetation and animal wastes, discarded litter and garbage, deicing chemicals, leaks and spills from vehicles transporting hydrocarbons and other chemicals through urban areas, and atmospheric deposition. Other nonpoint sources are exfiltration from sanitary sewers; application of lawn and garden chemicals; improper disposal of hydrocarbons and other chemicals onto pervious areas, seepage pits, dry wells, or old septic tanks not replaced during sewering; and leaks or spills from underground storage tanks or from commercial tanks and pipelines within or traversing residential areas.

Commercial Land

The quality of ground water beneath commercial areas is adversely affected more so than beneath all other land use areas. A variety of nonpoint sources contribute contaminants in commercial areas. Infiltration of runoff from streets, parking lots, and other impervious areas carries inorganic and organic contaminants, such as deicing chemicals, metals, grease, oil, and hydrocarbon fuels. Leaks and spills, particularly from underground storage tanks, and improper discharges of solvents, fuels, and other chemicals into drains, sumps, and dry wells may introduce contaminants directly into the subsurface, thereby facilitating their movement to the water table. Like the sewered residential areas, commercial areas within the stratified-drift aquifers studied are, with few exceptions, served by sanitary sewers. Removal of wastes and wastewater from commercial facilities by sanitary sewers tends to eliminate a major potential source of nonpoint contaminants. However, exfiltration from sanitary sewer lines can occur, contributing inorganic and organic contaminants to the ground water.

The mean rank of specific conductance measurements; the mean rank of concentrations of calcium, magnesium, hardness, sodium, chloride, sulfate, dissolved solids, nitrate plus nitrite-nitrogen, boron, and strontium; and the frequency of detection of ammonia-nitrogen are significantly higher for water samples from the commercial areas than from the undeveloped areas (table 5). Five of the above variables (specific conductance, sodium, chloride, dissolved solids, and boron) are also significantly higher in the commercial areas than in the untilled agricultural areas, and the mean ranks of sodium, chloride, and iron concentrations are significantly higher than in the tilled agricultural areas. Figure 10 shows that median concentrations of sodium (22.5 mg/L), chloride (36 mg/L), and dissolved solids (241.5 mg/L) are highest for the commercial areas. The use of highway deicing chemicals, a likely source for these constituents, is generally greater in commercial areas than in other land use areas because the major transportation routes often transect or are bounded by commercial areas. Fifty percent of the wells in the commercial areas yielded water with sodium concentrations that exceeded the State's drinking-water standard of 20 mg/L (Connecticut Department of Health Services, 1985).

Median water temperature (14 °C), and ammonia-nitrogen (0.035 mg/L) and zinc (8.2 μg/L) concentrations were also highest, but not significantly higher, in ground water from the commercial areas compared with other land use areas. Although the median nickel concentration (8.5 μg/L) was highest in the commercial areas, and the ANOVA indicated that nickel was significantly different for one or more land use categories (see table 3), Tukey's multiple-comparison test could not distinguish a difference at the 0.05 level of significance. The large variation of nickel concentrations in ground water beneath commercial areas appears to obscure the difference between the generally high concentrations in the commercial areas and low concentrations present in the undeveloped and the untilled agricultural areas. Ammonia-nitrogen detections, however, were significantly more common in the commercial areas than the undeveloped areas (fig. 11). The highest reported ammonia-nitrogen concentration (1.7 mg/L) was in the commercial area, as were highest reported magnesium (23 mg/L) and beryllium (1.8 μg/L) concentrations. Although low concentrations (less than 1.0 μg/L) of beryllium were detected in ground-water samples from most land use areas, the frequency of detections at concentrations equal to or greater than 1.0 μg/L was significantly higher in samples from the commercial areas than in samples from the sewered residential areas. Variation in the specific conductance of ground water and in the concentrations of magnesium, sodium, chloride, dissolved solids, and nickel is greatest for samples from the commercial land use areas.

Mean rank of the MBAS concentrations in water samples is significantly higher for the commercial area than for the undeveloped area. Median MBAS (0.05 mg/L) concentration is equally as high as for the tilled agricultural area (fig. 11). Use of anionic-surfactant detergents in commercial areas is the most likely source of elevated MBAS concentrations in the ground water.

The frequency of detection for 3 of 11 volatile organic compounds is significantly higher in ground-water samples from wells in the commercial areas than in the other land use areas (fig. 12). Tetrachloroethylene detections in water samples from 50 percent of the wells in the commercial area are significantly higher than tetrachloroethylene detections in samples from the unsewered residential and the undeveloped, untilled, and tilled agricultural areas. An extreme tetrachloroethylene concentration of 1,300 μg/L was reported for a sample from one well in a commercial area that apparently was contaminated by dry-cleaning fluid. Although not indicative of the degree of contamination most commonly associated with nonpoint sources, this incident demonstrates the magnitude of possible effects on ground-water quality from human activities.

Tetrachloroethylene concentrations of 0.3–26 μg/L were observed in other samples from the commercial areas. Detections of trichloroethylene, at concentrations ranging from 0.2 to 20 μg/L, were significantly more frequent in water samples from wells in the commercial areas than in samples from the undeveloped, untilled, and tilled agricultural areas and the unsewered and sewered residential areas (fig. 12). Because trace-level concentrations (0.2–0.4 μg/L) of 1,2-transdichloroethylene were detected in all land use areas, the frequency of detection was only significantly higher in the commercial areas than in the unsewered residential areas. However, comparison of detections of this compound at concentrations equal to or greater than 1.0 μg/L (fig. 12) shows that the frequency of detection of 1,2-transdichloroethylene at these concentrations in the commercial area, where four wells yielded water with concentrations of 1.8–55 μg/L, is significantly higher than that in the undeveloped, tilled agricultural areas and the unsewered and sewered residential areas (fig. 12).

Other volatile organic compounds found in ground-water samples from commercial land use areas at concentrations exceeding 1.0 μg/L are 1,1,1-trichloroethane (4.1 μg/L), xylene (3.9 μg/L), dichlorofluoromethane (2.5 μg/L), and toluene (1.6 μg/L). Trace concentrations of chloroform (0.2–0.8 μg/L), 1,1-dichloroethane (0.5 μg/L), 1,1-dichloroethylene (0.2 μg/L), and vinyl chloride (0.3 μg/L) have also been detected in ground-water samples from the commercial areas. Volatile organic compounds are used widely as solvents and degreasing agents, or are components of fuels used and stored in commercial areas.

GC/FID analyses indicated that water samples from 5 of the 12 wells (42 percent) in the commercial land use areas contained one or more unidentified BNA organic

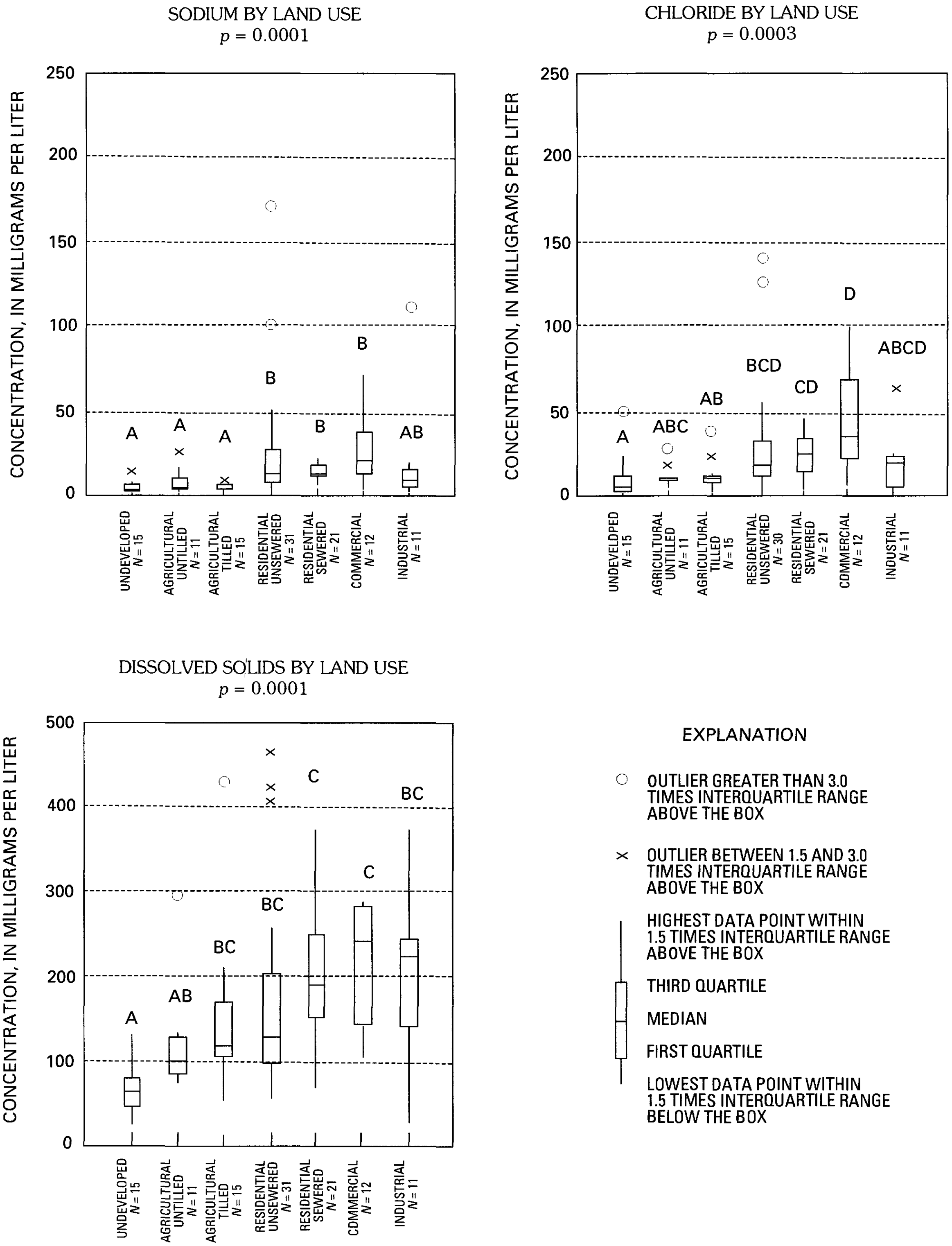
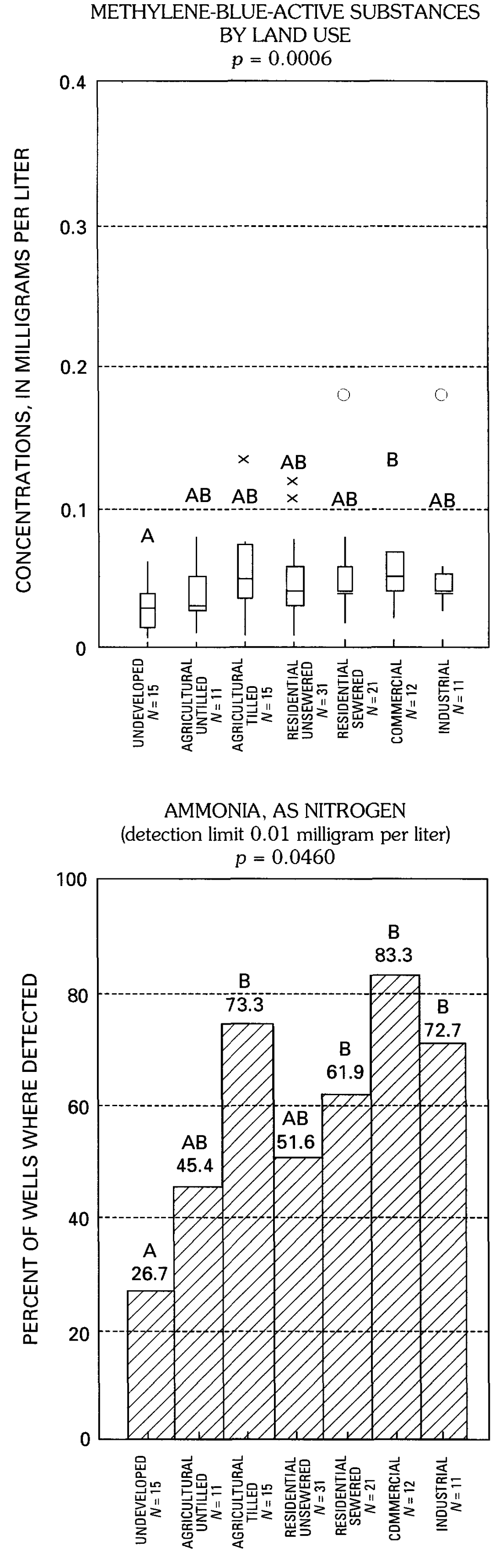


Figure 10. Statistical comparisons by land use of sodium, chloride, and dissolved solids concentrations in ground-water samples from four stratified-drift aquifers in Connecticut. The *p* value is the attained significance level for that statistical comparison; *N* is the number of wells sampled per land use category; sample populations are designated by letter symbols A, B, C, and D; sample populations that share the same letter are not significantly different at the 0.05 level of significance.



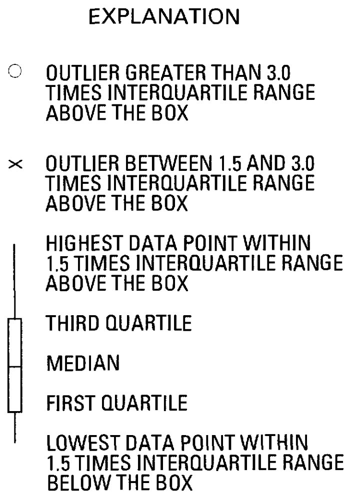


Figure 11. Statistical comparisons by land use of the frequency of ammonia-nitrogen detections and the concentration of methylene-blue-active substances in ground-water samples from four stratified-drift aquifers in Connecticut. The *p* value is the attained significance level for that statistical comparison; *N* is the number of wells sampled per land use category; sample populations are designated by letter symbols A and B; sample populations that share the same letter are not significantly different at the 0.05 level of significance.

compounds. GC/MS analyses were performed on three samples that appeared to have sufficiently high concentrations to enable identification of BNA compounds. Target or nontarget BNA compounds were identified in two of the three samples. The plasticizer bis(2-ethylhexyl)phthalate was reported in each sample at a concentration of 21 μg/L in one and 14,000 μg/L in the other. The extremely high concentration observed in the latter sample, however, is not likely related to use of this compound as a plasticizer, in which the phthalate ester is encased in a polymer matrix. The occurrence of two other phthalate esters, di-n-octyl phthalate (6.7 μg/L) and di-n-butyl phthalate (2.4 μg/L), and low concentrations of several nontarget BNA compounds (nonanoic acid, nonyl alcohol, 1,2-benzenedicarboxylic acid, and an unidentified alkane) in this sample may be related to a commercial source where the compounds have nonplasticizer uses such as pesticide carriers or insect repellents, or are used in cosmetics, fragrances, or oils (Peakall, 1975).

Four herbicide compounds, atrazine (2.0 μg/L), propazine (0.1 μg/L), simazine (0.4 μg/L), and 2,4,5-T (0.4 μg/L), were each detected once in ground-water samples from the commercial areas. The first three compounds, all triazine herbicides, were detected in one well adjacent to an interstate highway. It is possible that these compounds were used to control weed growth in turf areas along the highway. The observed atrazine concentration in this well exceeds concentrations measured in the tilled agricultural areas where this compound is used extensively on corn.

Industrial Land

Industrial areas occupy a smaller part of the land surface above the stratified-drift aquifers than do any of the other land use areas, but they have a disproportionate effect on ground-water quality. Several nonpoint sources of contaminants are associated with the typically high-technology, light-industry facilities prevalent in the study areas. These industries are substantial users or producers of industrial chemicals and byproducts. Commonly, such industries are clustered within industrial parks that are isolated from residential developments, and they are not served by sanitary sewers in some areas. Improper or inadvertent discharge of chemicals or wastes through on-site septic systems and (or) industrial pits, ponds, and lagoons have contaminated public-supply, domestic, and industrial wells (Handman and others, 1979, p. 46; Melvin and others, 1988, p. 196). Additional nonpoint sources of contaminants in industrial areas are leaks and spills of chemicals and hydrocarbons, infiltration of runoff from paved areas (roadways, parking lots, and storage yards), and the use of fertilizers and pesticides on lawns and ornamental shrubs within industrial properties.

The mean rank of the specific conductance measurements; the mean rank of the concentrations of calcium, magnesium, hardness, dissolved solids, boron, and strontium; and the frequency of detection of ammonia-nitrogen are significantly higher for ground-water samples from the industrial areas than for samples from the undeveloped areas (see table 5). In addition, the mean rank of the boron and silica concentrations is signficantly higher in samples from industrial-area wells than in ground-water samples from the untilled agricultural areas. The mean rank of pH measurements is significantly higher for ground-water samples from the industrial areas than for samples from the unsewered residential areas. Median pH (6.9) and specific conductance (364 μS/cm) of ground water are highest in the industrial areas (fig. 13). Median concentrations of magnesium (5.2 mg/L), silica (18 mg/L), and boron (50 μg/L) are also highest for water samples from the industrial land use areas (fig. 14).

The highest measured pH (9.2); the largest concentrations of silica (35 mg/L), boron (360 μg/L), orthophosphorus (6.6 mg/L), cobalt (25 μg/L), and nickel (630 μg/L); and the largest variation in concentrations of hardness, silica, barium, and boron were observed in ground-water samples from wells in the industrial land use areas. The frequency of detection of orthophosphorus, arsenic, beryllium, and silver is highest in ground-water samples from the industrial areas but is not significantly higher than for other land use areas. However, comparison of beryllium detections at concentrations equal to or greater than 1.0 μg/L (fig. 15) shows a significantly higher frequency of elevated beryllium concentrations in water samples from the industrial areas than for samples from the sewered residential areas.

Twelve volatile organic compounds have been detected in ground-water samples from 10 of the 11 wells (91 percent) in the industrial areas, and the frequency of detection of five of these compounds is significantly higher for this land use area than for other land use areas. Detections of chloroform at concentrations of 0.2–1.3 μg/L in water samples from more than 50 percent of the wells in the industrial area (fig. 15), and of tetrachloroethylene (0.2–4.9 μg/L) in 36 percent of the wells (see fig. 12), are significantly more frequent than in both the undeveloped and tilled agricultural areas. Chloroform detections were also significantly more frequent in samples from the industrial-area wells than from those in the unsewered residential areas.

Comparison of the frequency of detection of three other compounds at concentrations equal to or greater than 1.0 μg/L also demonstrates statistically significant differences between the industrial area and one or more of the other land use areas (fig. 16). Elevated concentrations of 1,1-dichloroethane (2.4–4.8 μg/L) and 1,1-dichloroethylene (1.4–1.8 μg/L) occur significantly more often in ground water beneath industrial areas than beneath unsewered residential land. Concentrations of 1,1,1-trichloroethane ranging from 1.0–180 μg/L were observed in samples from 36 percent of the wells in the industrial area—a frequency that was significantly higher than that in the undeveloped and the sewered residential areas. Use of these compounds as solvents and degreasing agents in industrial processes is the most probable source of their presence in ground water in this area.

Trichloroethylene was found in water samples from two wells in the industrial areas at concentrations of 3.3 and 14 μg/L. Two additional compounds, dichlorodifluoromethane and 1,1,2-trichloroethane, were detected at concentrations of 1 μg/L or more. Trace-level concentrations (0.2–0.6 μg/L) of benzene, 1,2-transdichloroethylene, trichlorofluoromethane, and toluene have also been detected in ground-water samples from the industrial areas. GC/FID analyses indicated that three samples contained one or more unidentified BNA organic compounds, but only one sample was judged to contain sufficient concentrations to warrant GC/MS analysis. Subsequent analysis indicated the presence of three nontarget compounds at concentrations less than 5 μg/L each.

Four pesticide compounds were detected in ground-water samples from the industrial land use area. The

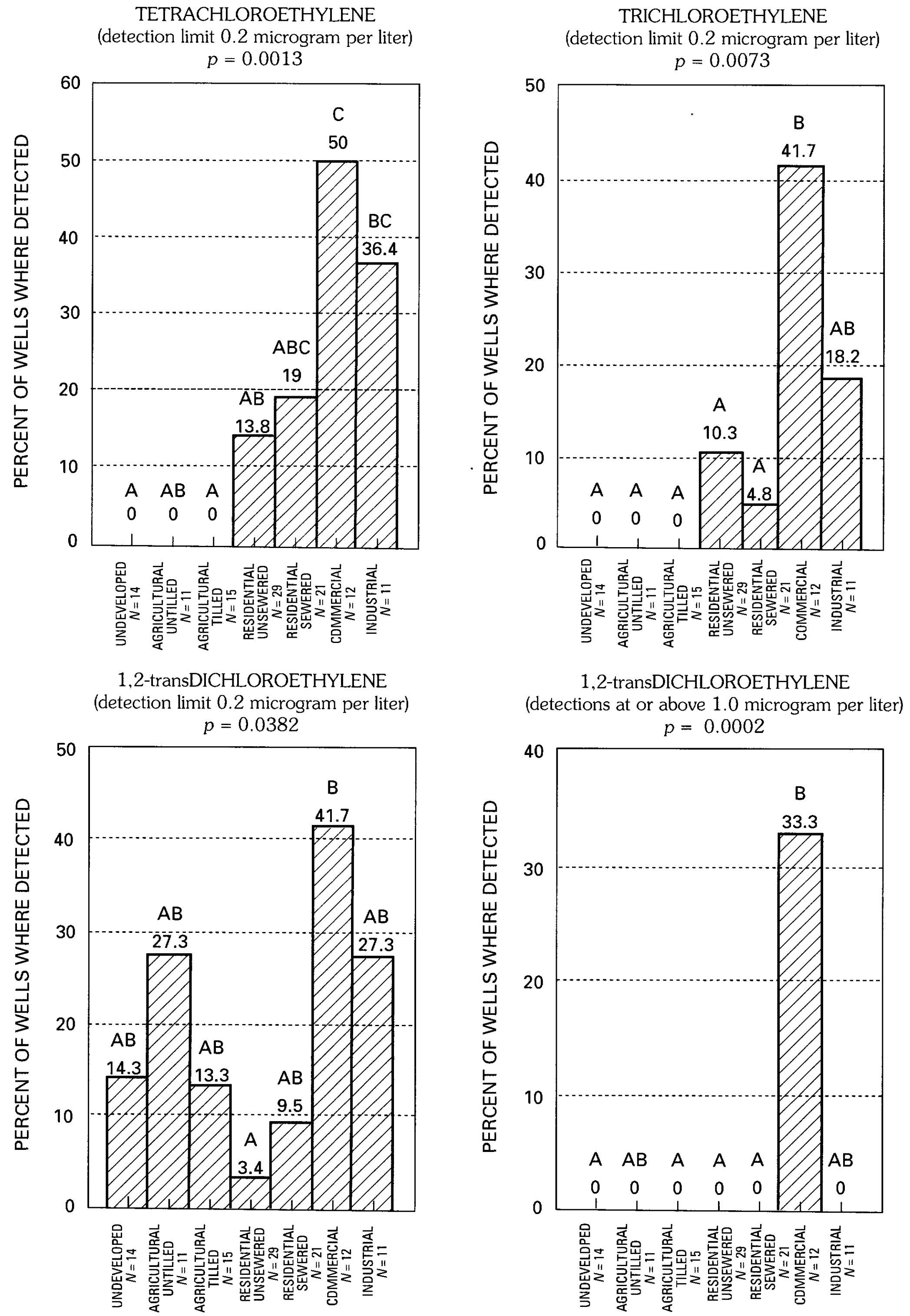


Figure 12. Statistical comparisons by land use of the frequency of tetrachloroethylene, trichloroethylene, and 1,2-transdichloroethylene detections in ground-water samples from four stratified-drift aquifers in Connecticut. The *p* value is the attained significance level for that statistical comparison; *N* is the number of wells sampled per land use category; sample populations are designated by letter symbols A, B, and C; sample populations that share the same letter are not significantly different at the 0.05 level of significance.

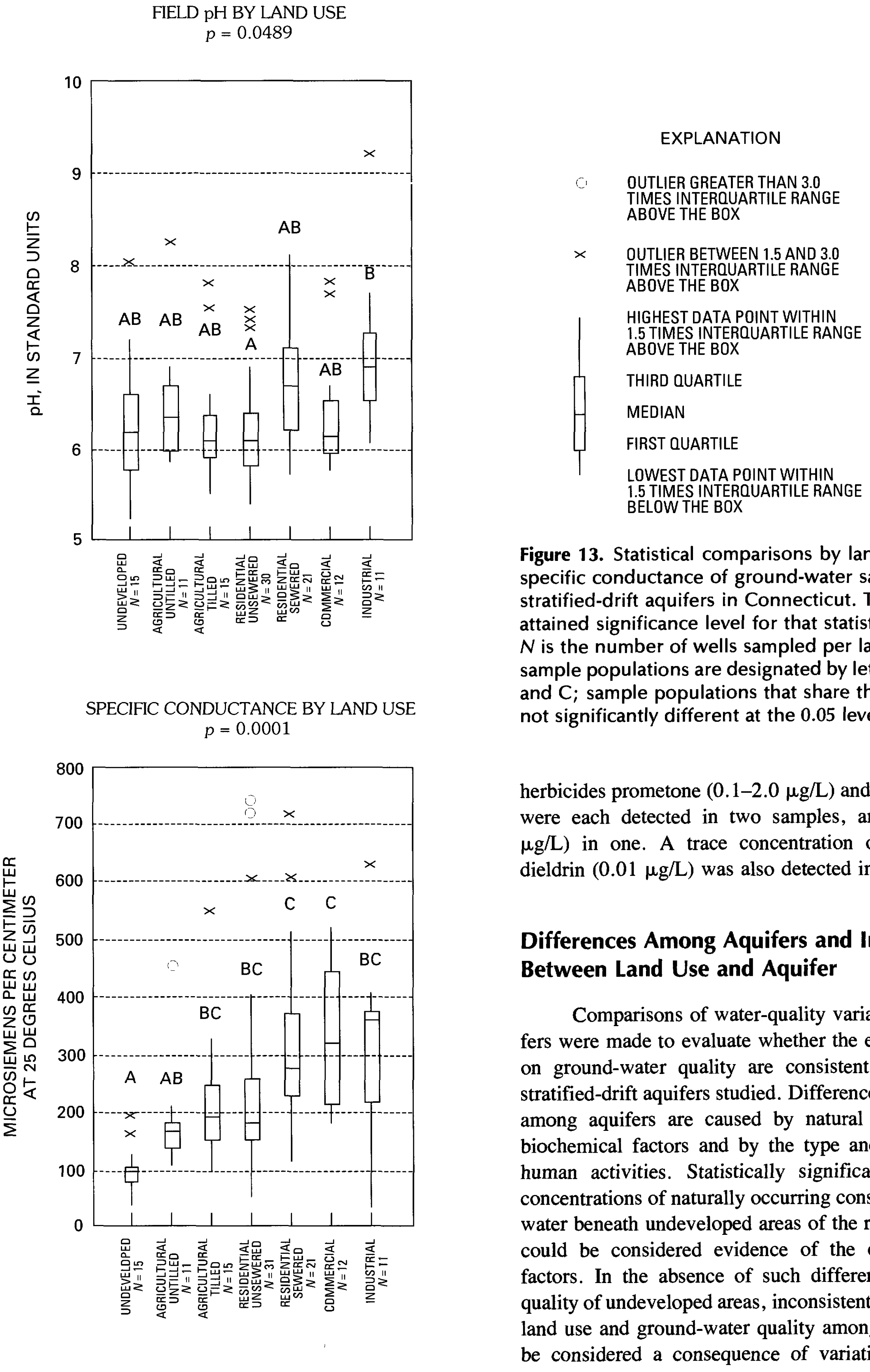


Figure 13. Statistical comparisons by land use of pH and specific conductance of ground-water samples from four stratified-drift aquifers in Connecticut. The *p* value is the attained significance level for that statistical comparison; *N* is the number of wells sampled per land use category; sample populations are designated by letter symbols A, B, and C; sample populations that share the same letter are not significantly different at the 0.05 level of significance.

herbicides prometone (0.1–2.0 μg/L) and 2,4-D (0.2 μg/L) were each detected in two samples, and atrazine (0.01 μg/L) in one. A trace concentration of the insecticide dieldrin (0.01 μg/L) was also detected in one sample.

Differences Among Aquifers and Interactions Between Land Use and Aquifer

Comparisons of water-quality variables among aquifers were made to evaluate whether the effects of land use on ground-water quality are consistent for each of the stratified-drift aquifers studied. Differences in water quality among aquifers are caused by natural geochemical and biochemical factors and by the type and the intensity of human activities. Statistically significant differences in concentrations of naturally occurring constituents in ground water beneath undeveloped areas of the respective aquifers could be considered evidence of the effects of natural factors. In the absence of such differences in the water quality of undeveloped areas, inconsistent relations between land use and ground-water quality among the aquifers can be considered a consequence of variations in effects of human activities.

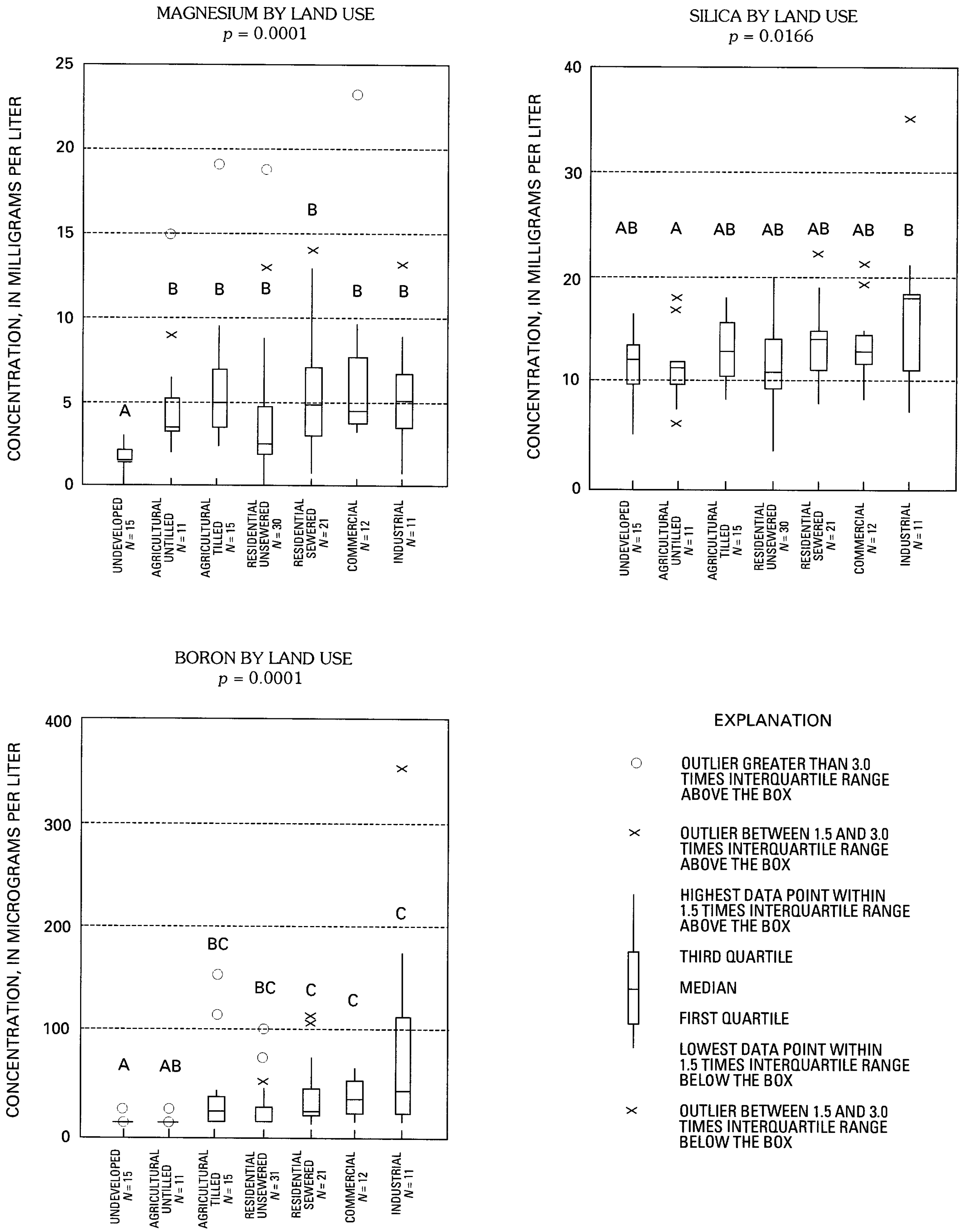


Figure 14. Statistical comparisons by land use of magnesium, silica, and boron concentrations in ground-water samples from four stratified-drift aquifers in Connecticut. The *p* value is the attained significance level for that statistical comparison; *N* is the number of wells sampled per land use category; sample populations are designated by letter symbols A, B, and C; sample populations that share the same letter are not significantly different at the 0.05 level of significance.

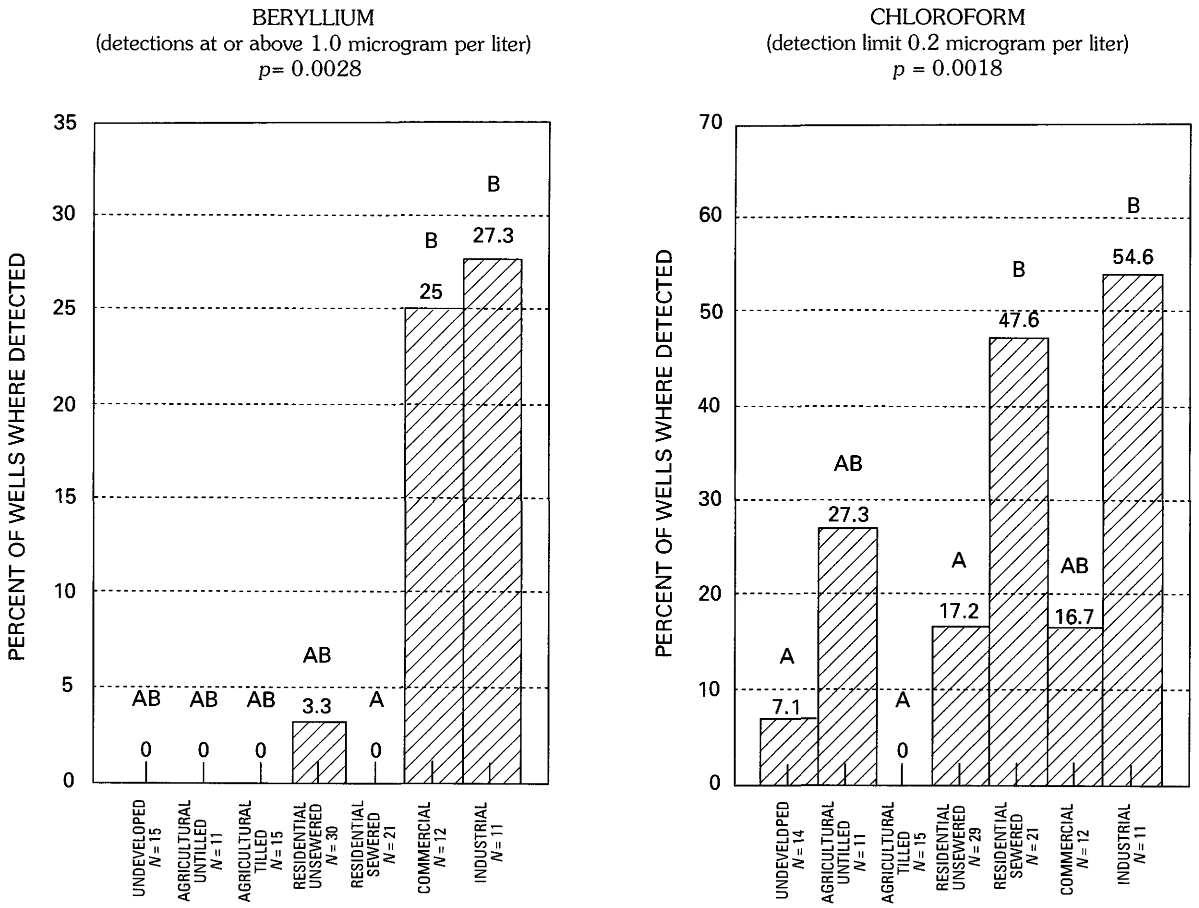
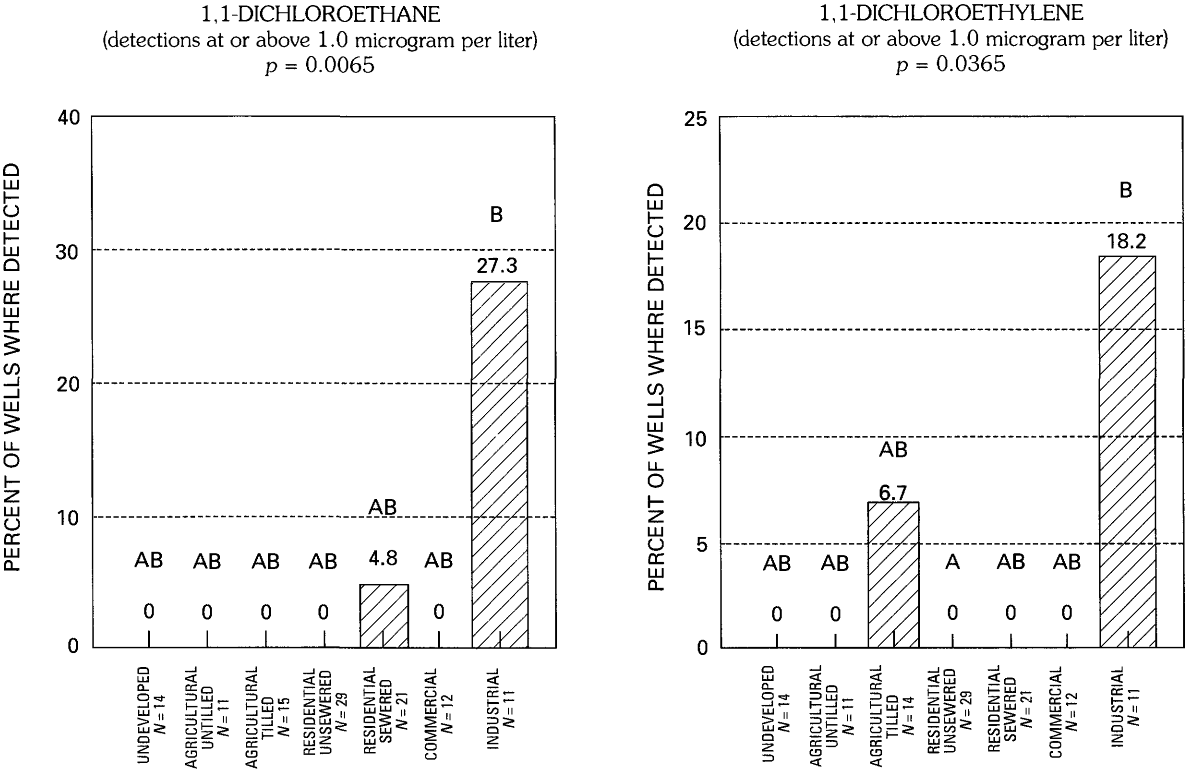


Figure 15. Statistical comparisons by land use of the frequency of detection of beryllium at concentrations equal to or exceeding 1.0 microgram per liter and chloroform in ground-water samples from four stratified-drift aquifers in Connecticut. The *p* value is the attained significance level for that statistical comparison; *N* is the number of wells sampled per land use category; sample populations are designated by letter symbols A and B; sample populations that share the same letter are not significantly different at the 0.05 level of significance.

Statistical comparison of water quality between aquifers was impeded in this study by the uneven distribution of land use categories among the four aquifers. As a result, the number of wells per land use category in each of the aquifers ranges from zero to 21 (see table 1). Consequently, interaquifer comparisons were done only for the 21 uncensored or slightly censored water-quality variables that were analyzed by ANOVA. Table 3 gives *p* values for the two-way ANOVA on the rank-transformed data for the effects of land use and aquifer on ground-water quality. The type III (partial sum of the squares) factorial model used by the ANOVA for these comparisons tests the significance of each factor in the model (including the "main effects" of land use and aquifer, and the interaction between these effects) in the presence of all other factors. Interaction refers to the dependence of the effect of one factor on the level of another factor and can contribute a positive (synergism) or negative (interference) increment to the level of the variable (Sokal and Rohlf, 1969, p. 306). By evaluating all factors simultaneously, the effect of each can be measured while compensating for the presence of the others.

Although 17 water-quality variables appear to be significantly related to land use, only 9 (specific conductance, calcium, magnesium, hardness, sodium, chloride, sulfate, dissolved solids, and barium) appear to be significantly related to aquifers. An interaction between land use and aquifer appears to have a significant effect on the concentrations of four variables—magnesium, silica, nickel, and MBAS.

Based on the two-way ANOVA results identified in table 3, land use appears to be the only significant factor affecting the sample populations for five variables (pH, nitrate plus nitrite-nitrogen, boron, iron, and strontium). For nitrogen, boron, and strontium the magnitude and variation of concentrations under natural conditions are so small that any elevated levels are clearly the result of human contributions. The conclusion that land use is the sole influencing factor is misleading, however, for pH and iron,



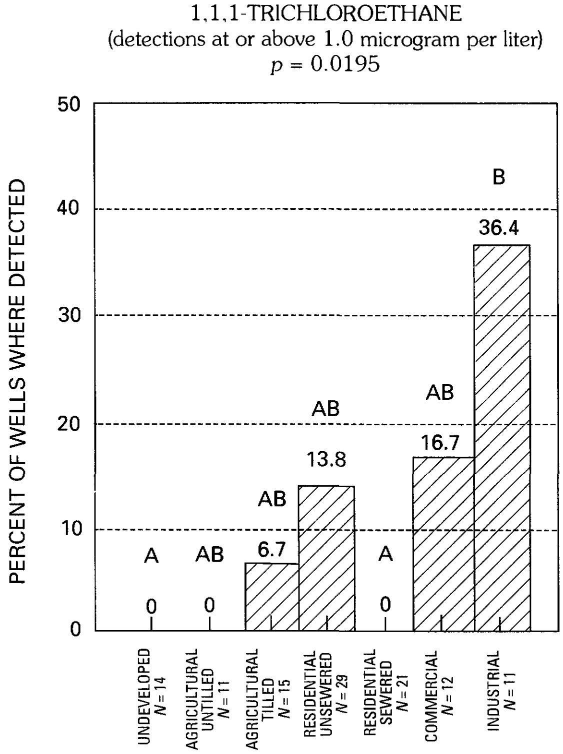


Figure 16. Statistical comparisons by land use of the frequency of detection of 1,1-dichloroethane, 1,1-dichloroethylene, and 1,1,1-trichloroethane at concentrations equal to or exceeding 1.0 microgram per liter in ground-water samples from four stratified-drift aquifers in Connecticut. The *p* value is the attained significance level for that statistical comparison; *N* is the number of wells sampled per land use category; sample populations are designated by letter symbols A and B; sample populations that share the same letter are not significantly different at the 0.05 level of significance.

whose concentrations are naturally highly varied. Iron concentrations, for example, which differ by more than four orders of magnitude in the study areas, clearly reflect natural geochemical and biochemical conditions that control the solubility of iron in ground water (Hem, 1985, p. 75–84) but also are apparently influenced by land use (fig. 17).

It is likely that the statistically significant differences observed between the "elevated" iron concentrations associated with the sewered residential and commercial land, and the low concentrations measured in the tilled agricultural areas (see fig. 17) are the result of natural and human factors. First, neither the low iron concentrations in ground-water samples from the tilled agricultural areas nor the elevated iron concentrations in samples from the sewered residential and commercial areas are significantly different from iron concentrations in ground water from the undeveloped area. Thus, natural variation in iron concentrations

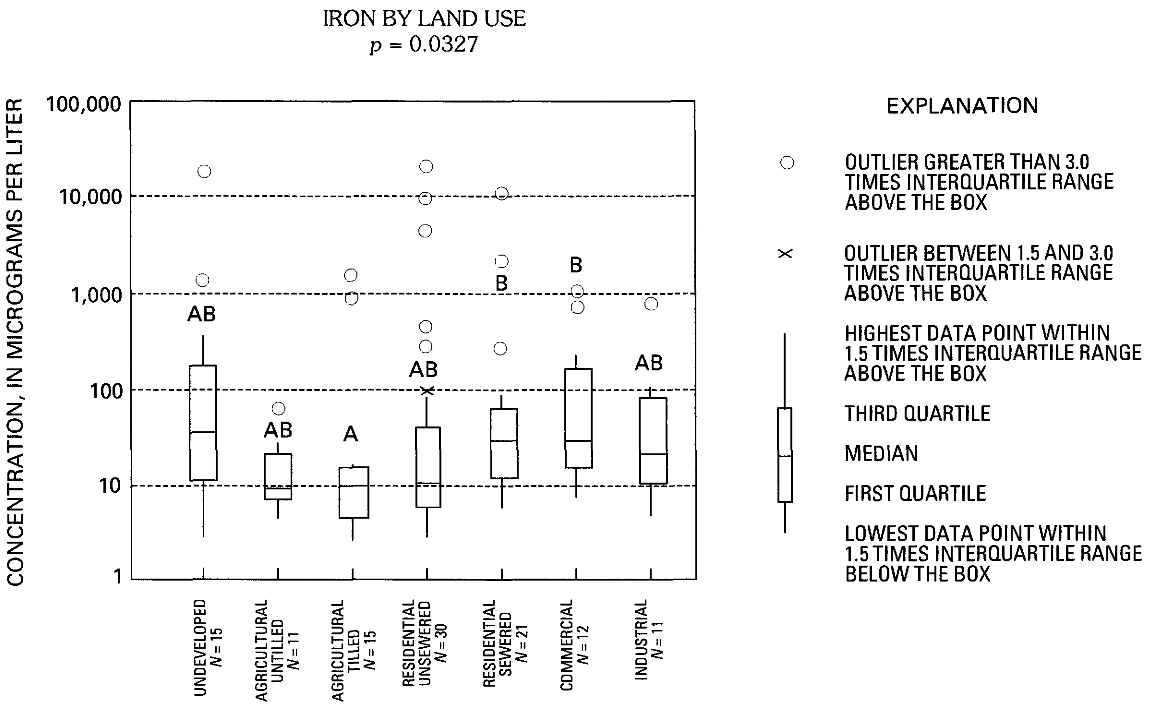


Figure 17. Statistical comparison by land use of iron concentrations in ground-water samples from four stratified-drift aquifers in Connecticut. The *p* value is the attained significance level for that statistical comparison; *N* is the number of wells sampled per land use category; sample populations are designated by letter symbols A and B; sample populations that share the same letter are not significantly different at the 0.05 level of significance.

could explain the observed differences among these land use areas if the conditions controlling iron solubility differed. It is possible that ground water in the tilled agricultural areas has higher dissolved oxygen concentrations unfavorable to iron solubility because the depth to the water table is generally shallower and less varied than it is in other land use areas (see fig. 6, bottom). Iron, however, is also a nonpoint-source contaminant associated with wastewater, solid wastes, and stormwater runoff.

The results of interaquifer comparisons for the one water-quality variable, magnesium, that demonstrates significant differences for all three effects—land use ($p = 0.0001$), aquifer ($p = 0.0001$), and interaction between land use and aquifer ($p = 0.0386$), are summarized in table 6. The interaquifer comparisons described in table 6 were obtained by segregating the data by a classification scheme that reflected both the land use and aquifer categories, and by conducting a one-way ANOVA on the ranks of the magnesium concentrations in each composite land use/aquifer category. Table 6 shows the median and interquartile range for each of the 17 land use/aquifer categories for which at least three wells were sampled. Populations were compared by Tukey's honest significant-difference test; sample populations are designated by letter symbols (A, B, and C), and sample populations that share the same letter are not significantly different at a 0.05 level of significance.

The Tukey test results indicate that the significant land use effect is manifest in the difference between magnesium concentrations in the undeveloped land use areas and in one or more of the developed land use areas in the Farmington and Hockanum aquifers. Specifically, magnesium concentrations are significantly higher in the tilled agricultural areas of the Farmington aquifer than in the undeveloped areas of that aquifer. In the Hockanum aquifer, magnesium concentrations are significantly higher in the untilled agricultural, sewered residential, and commer-

Table 6. Statistical summary of magnesium concentrations by land use and aquifer

[Concentrations in milligrams per liter; N, number of wells per land use/aquifer category; dashes indicate insufficient number of samples to calculate statistic; IQR, interquartile range; Tukey, results of Tukey's honest significant-difference test; sample populations are designated by letter symbols (A, B, and C); sample populations that share the same letter are not different at the 0.05 level of significance]

Aquifer	Land use category						
	Undevel-oped	Agricultural		Residential		Commercial	Industrial
		Untilled	Tilled	Unsewered	Sewered		
Pootatuck							
N	0	1	0	2	0	0	3
Median	—	—	—	—	—	—	8.8
IQR	—	—	—	—	—	—	5.2
Tukey	—	—	—	—	—	—	C
Pomperaug							
N	3	1	7	7	0	4	1
Median	2.5	—	4.4	5.4	—	4.85	—
IQR	.5	—	4.0	4.85	—	15.3	—
Tukey	ABC	—	BC	C	—	BC	—
Farmington							
N	7	5	6	20	7	3	4
Median	1.4	3.2	4.8	2.05	2.5	4.4	2.7
IQR	.5	1.3	2.18	2.02	4.9	1.3	3.58
Tukey	A	ABC	BC	AB	ABC	ABC	ABC
Hockanum							
N	5	4	2	1	14	5	3
Median	.9	7.7	—	—	5.5	6.6	4.7
IQR	1.4	9.35	—	—	3.62	5.25	1.8
Tukey	A	C	—	—	C	C	ABC

cial areas than in the undeveloped areas. No land use difference was observed for the Pomperaug aquifer, and no comparison can be made for the Pootatuck aquifer.

The results of the Tukey multiple comparison test for the same land uses in different aquifers show that the only significant difference is between unsewered residential areas in the Pomperaug and Farmington aquifer. Magnesium concentrations are significantly higher in the Pomperaug than in the Farmington aquifer, but the source of the higher concentrations in the Pomperaug aquifer is unclear. Interaquifer comparisons for the other three land use areas that were sampled in both aquifers show no other significant or even consistent differences in magnesium concentrations. It is possible that the apparent significant relation of magnesium concentration to aquifer for the unsewered residential categories is the result of some characteristic inherent to that land use in the Pomperaug aquifer. For example, the density of housing with on-site septic systems may be somewhat higher in the Pomperaug than in the Farmington aquifer. It is also possible, however, given the small sample size, that the difference is an artifact of the limited data. It is unlikely that the apparent significant relation of the concentrations of magnesium and the other eight variables to the aquifer is the result of natural geochemical differences between these aquifers, inasmuch as no differences have been described for comparisons of ground-water quality in undeveloped lands.

The effect of the interaction between land use and aquifer is demonstrated in table 6 by the inconsistency of the relation of land use to magnesium concentrations for different aquifers. For example, although magnesium concentrations are significantly higher in the tilled agricultural areas of the Farmington aquifer than in the undeveloped areas of that aquifer, there is no difference in magnesium concentrations in ground-water samples from these land uses in the Pomperaug aquifer. Therefore, the effect of tilled agricultural land use on the magnesium concentration of ground water depends on the aquifer sampled, and the results may not be extrapolated to other aquifers. Similarly, the relation between concentrations of magnesium and land use is not consistent among the aquifers for other land use categories, namely, for the untilled agricultural and sewered residential land use areas with respect to undeveloped land use areas in the Farmington and Hockanum aquifers, and for the commercial areas with respect to undeveloped areas of all three aquifers sampled. However, the apparent interaction between land use and aquifer may be attributable to the small sample size and the inherent large variation of the magnesium concentrations demonstrated by the wide interquartile ranges for the very limited data available for many of the land use/aquifer categories.

Because only four variables appear to be significantly related to the interaction of land use and aquifer, and three of these did not show significant differences attributable to the aquifer alone, it is the author's conclusion that the effects of land use on ground-water quality are largely independent of aquifer. However, the small number of wells sampled in most land use/aquifer categories and the limited number of variables compared constrain the extrapolation of these results to other stratified-drift aquifers. Additional data are needed in order to establish whether the relations between land use and water quality demonstrated by this study of four stratified-drift aquifers in Connecticut can be extrapolated to similar aquifers throughout the Northeastern United States.

The data needed to establish the validity of relations between land use and ground-water quality on a regional scale could best be obtained in two ways. First, augmenting the number of wells per land use in each aquifer to approximately 20–30 wells per land use category per aquifer would improve confidence in the statistical inference. Second, inclusion of several additional stratified-drift aquifers in areas of differing geologic terrane, hydrologic setting, and population density would ensure that the statistical comparisons accounted for conditions representative of the entire region.

Although stratified-drift aquifers are the most productive aquifers in the region and supply some of the most populated areas, they have limited distribution. In most of the glaciated Northeast, where stratified-drift aquifers are absent, shallow-till and bedrock aquifers are the only source of domestic and commercial self-supplied water. A complete appraisal of the effects of land use on ground-water quality in the region needs to include information on the effect of nonpoint-source contaminants on water quality in these aquifers as well.

SUMMARY AND CONCLUSIONS

The quality of water in four stratified-drift aquifers in Connecticut has been affected by nonpoint-source, inorganic and organic contaminants that can be related to human activities within specific land use areas. Differences observed in the concentration, the frequency of detection, or the frequency of observations equal to or exceeding 1 µg/L of 27 water-quality variables for sample populations from seven land use categories are statistically significant at the 0.05 level. Water-quality variables that differ significantly for one or more land use areas are the physical properties pH and specific conductance; the major inorganic constituents calcium, magnesium, hardness, sodium, chloride, sulfate, silica, and dissolved solids; the nutrients nitrate plus nitrite-nitrogen and ammonia-nitrogen; the trace elements barium, beryllium, boron, iron, nickel, and strontium; methylene-blue-active substances; the volatile organic compounds chloroform, 1,1-dichloroethane, 1,1-dichloroethylene, 1,2-transdichloroethylene, tetrachloroethylene, 1,1,1-trichloroethane, and trichloroethylene; and the pesticide atrazine. Other organic contaminants were detected in water samples from one or more wells in this study, but their frequencies of detection within any land use area were not statistically different. These variables consist of 14 volatile organic compounds, 13 pesticides, and 9 base-neutral and acid-extractable compounds.

The following relations between ground-water quality and land use were observed.

1. The quality of ground water in stratified-drift aquifers in undeveloped areas is assumed to be unaffected by human activities and is considered to represent background conditions. Median concentrations and detection frequencies of 19 physical properties or inorganic constituents in ground water are lowest for samples from the undeveloped areas. The mean rank of the concentrations or the frequency of detection of 13 of these properties or constituents is significantly lower for ground-water samples from the undeveloped areas than it is for those from one or more of the other six land use areas. Fewer organic compounds were detected in ground water from the undeveloped areas than in ground water from all other land use areas.
2. The quality of ground water in agricultural areas reflects tillage practices, the greater effect occurring beneath tilled areas than untilled areas because the former endure more intense agricultural activities, such as heavier fertilizer and pesticide applications, than do untilled areas. Although median concentrations of most inorganic constituents are elevated in the untilled areas with respect to the undeveloped areas, only concentrations of magnesium and hardness are significantly higher. Organic compounds were detected in few ground-water samples from the untilled agricultural areas, and the source of those compounds is ambiguous. No organic compound was detected significantly more often in samples from the untilled agricultural areas than in samples from the undeveloped areas. Only one pesticide was detected in ground-water samples from the untilled agricultural areas (0.1 µg/L of cyanazine in one well), probably reflecting the minimal use of such agricultural chemicals in these areas.

   Conversely, the mean rank of the specific conductance measurements; the mean rank of the concentrations of calcium, magnesium, hardness, sulfate, dissolved solids, nitrate plus nitrite-nitrogen, boron, and strontium; and the frequency of detection of ammonia-nitrogen are significantly higher in ground water beneath tilled agricultural areas than beneath undeveloped areas. Median nitrate plus nitrite-nitrogen concentration is highest for the tilled agricultural areas, where 20 percent of the wells yielded water with nitrate plus nitrite-nitrogen concentrations higher than 10 mg/L. The frequency of detecting the herbicide atrazine—at low concentrations (0.1–0.2 µg/L) in 33 percent of the wells in the tilled agricultural areas—was significantly higher than in the undeveloped areas, where it was undetected. The insecticides dieldrin and 1,2-dichloropropane have also been detected infrequently in ground-water samples from the tilled agricultural areas.

3. The quality of ground water beneath residential areas is widely affected by inorganic and organic nonpoint-source contaminants. Sewered residential areas have a greater effect on water quality than unsewered areas. The greater housing density, more heterogeneity of land use, and higher number of potential nonpoint sources of contaminants in the sewered residential areas compared with the unsewered residential areas may obscure any improvements in water quality attributable to removal of wastewater by municipal sewer systems. The mean rank of the specific conductance measurements and the mean rank of the concentrations of calcium, magnesium, hardness, sodium, chloride, dissolved solids, nitrate plus nitrite-nitrogen, boron, and strontium are significantly higher for samples from the unsewered and sewered residential areas than from the undeveloped areas. Median concentrations or detection frequencies for most of the physical properties and inorganic constituents of ground water are higher in the sewered than the unsewered areas. The similarity of nitrate plus nitrite-nitrogen concentrations for sewered and unsewered residential areas may indicate exfiltration from sanitary sewers. Alternatively, some additional source of nitrogen, possibly increased lawn and garden fertilizer use in the more densely populated sewered areas, is replacing the release of nitrogen from on-site domestic septic systems as the principal source of this constituent in ground water. The similarity of sodium and chloride concentrations for sewered and unsewered areas suggests that use of deicing chemicals may be a more important source than septic tank effluents for these constituents.

   Although 62 percent of the wells in the unsewered residential areas yielded ground-water samples containing one or more volatile organic compounds, the frequency of detections was not statistically significant for any specific compounds. Chloroform detections in 47 percent of the wells in the sewered residential areas, however, were significantly more common than in the undeveloped, tilled agricultural, and unsewered residential areas.

4. The quality of ground water is most adversely affected by human activities in commercial areas. Although most commercial areas are served by sanitary sewers that remove wastes and wastewater from the immediate area, exfiltration of wastewater from leaky sewer lines may be contributing inorganic and organic contaminants to the ground water. Numerous other nonpoint sources may also contribute contaminants to the soil and, ultimately, to the aquifer beneath commercial land use areas. The mean rank of specific conductance measurements; the mean rank of the concentrations of calcium, magnesium, hardness, sodium, chloride, sulfate, dissolved solids, nitrate plus nitrite-nitrogen, boron, and strontium; and the frequency of detection of ammonia-nitrogen are significantly higher in ground-water samples from the commercial areas than in samples from the undeveloped areas. Measurements and concentrations of five of the above water-quality variables—specific conductance, sodium, chloride, boron, and dissolved solids—were significantly higher in ground-water samples from the commercial areas than in samples from the untilled agricultural areas. The mean rank of the concentrations of sodium, chloride, and iron is significantly higher in water samples from the commercial-area wells than from the tilled agricultural areas. Median concentrations of sodium (22.5 mg/L), chloride (36 mg/L), and dissolved solids (286 mg/L) were highest in ground water from the commercial areas. Beryllium detections at concentrations equal to or exceeding 1.0 μg/L were significantly more frequent in the commercial areas than in the sewered residential areas.

   The mean rank of MBAS concentrations is significantly higher for ground-water samples from the commercial areas than from the undeveloped areas. Detections of tetrachloroethylene were significantly more frequent in samples from 50 percent of the commercial-area wells than in wells of the undeveloped, untilled and tilled agricultural, and unsewered residential areas. Trichloroethylene detections were significantly more frequent in ground water beneath the commercial areas than they were in the undeveloped, untilled and tilled agricultural, and unsewered and sewered residential areas. A third volatile organic compound, 1,2-transdichloroethylene, was widely detected at concentrations lower than 1.0 μg/L in ground-water samples from all land use areas, so that the frequency of detection in the commercial areas was different only with respect to the unsewered residential areas. Comparing detections of 1,2-transdichloroethylene at concentrations equal to or exceeding 1.0 μg/L, however, shows that elevated concentrations of this compound were present only in samples from the commercial areas. A significant difference was evident between the high frequency of elevated 1,2-transdichloroethylene detections in samples from wells in the commercial areas (33 percent) and those from the undeveloped, tilled agricultural, and unsewered and sewered residential areas.

5. Industrial land occupies less of the study areas than do the other land use areas, but it has a disproportionately large effect on ground-water quality. The mean rank of the specific conductance measurements; the mean rank of the concentrations of calcium, magnesium, hardness, dissolved solids, boron, strontium; and the frequency of detection of ammonia-nitrogen are significantly higher

in ground-water samples from the industrial areas than from the undeveloped areas. The mean rank of boron and silica concentrations is significantly higher for ground-water samples from wells in the industrial areas than in the untilled agricultural areas, and the mean rank of pH is significantly higher for ground water in the industrial areas than in the unsewered residential areas. Beryllium detections at concentrations equal to or exceeding 1.0 μg/L are significantly more frequent in the industrial areas than in the sewered residential areas.

In the industrial areas, water samples from 91 percent of the wells contained one or more of 12 volatile organic compounds. Chloroform detections in samples from more than half of the industrial-area wells were significantly more frequent than in samples from the undeveloped, tilled agricultural, and unsewered residential areas. The frequency of tetrachloroethylene detections, found in 36 percent of the industrial-area wells, was significantly higher than in samples from wells in the undeveloped and tilled agricultural areas. The frequency of 1,1,1-trichloroethane detections at concentrations equal to or greater than 1.0 μg/L was significantly higher in industrial areas than in undeveloped and sewered residential areas, and 1,1-dichloroethane and 1,1-dichloroethylene were found significantly more often at similarly elevated concentrations in ground water beneath the industrial areas than beneath the unsewered residential areas.

Interaquifer comparisons for those water-quality variables using two-way ANOVA indicate that effects of aquifer on ground-water quality were significant for specific conductance, calcium, magnesium, hardness, sodium, chloride, sulfate, dissolved solids, and barium. Only magnesium, however, appears to be significantly related to the interaction between land use and aquifer. Three additional variables, silica, nickel, and MBAS, appear to be significantly related to the interaction between land use and aquifer, but not for the aquifer alone. The significant differences among stratified-drift aquifers for some variables may mean that the effect of human activities associated with specified land uses is not the same in each aquifer. Consequently, relations among land use and some water-quality variables may not be extrapolated beyond aquifers in the study areas. However, the general lack of significant interaction between land use and aquifer, and the uncertainty generated by the small sample size for data on interaquifer differences, indicate that effects of land use on ground-water quality are largely independent of aquifer. Where differences in ground-water quality do exist among aquifers, they may reflect the intensity of human activities or may be artifacts of the limited data. Additional study is needed to establish the transfer value of relations between land use and water quality that were demonstrated for four stratified-drift aquifers in Connecticut to similar aquifers in the Northeastern United States.

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Appendix. Summary of site information, sample date and time, and water level for wells sampled during this study

[Chemical analyses of water samples from wells listed below are published in a series of U.S. Geological Survey reports containing water-resources data for Connecticut. U.S. Geological Survey Water-Data Reports CT–85–1 to CT–89–1 (published annually) are maintained in the U.S. Geological Survey's Water Data Storage and Retrieval System (WATSTORE) or are on file in the U.S. Geological Survey's Hartford, Conn., office. Depth of well is the distance below land surface to the bottom of the well screen. Land uses are AT, tilled agricultural; AU, untilled agricultural; C, commercial; I, industrial; RS, sewered residential; RU, unsewered residential; and U, undeveloped. Depth to water is the distance below land surface to the static water level measured just prior to sampling the well. Dash indicates no data available]

Local well number	Site identification number	Depth of well (feet)	Land use	Date	Time	Depth to water (feet)
			POOTATUCK AQUIFER			
NT98	412312073160501	15.6	RU	April 8, 1985	1145	2.60
				August 26, 1986	1320	2.78
				August 19, 1987	1412	3.00
NT99	412320073165201	26.5	I	April 10, 1985	1400	17.40
				August 5, 1985	1245	8.10
				August 27, 1986	1512	17.54
				August 19, 1987	1108	18.50
				November 9, 1988	1108	16.18
NT100	412438073165601	11.4	AU	April 8, 1985	1425	6.30
				August 26, 1986	1122	5.13
				June 24, 1987	1155	6.90
				July 27, 1987	1410	7.60
				August 25, 1987	1000	7.80
				September 23, 1987	1005	5.90
				October 20, 1987	0854	6.70
				November 18, 1987	1017	6.60
				February 16, 1988	1045	5.40
				March 17, 1988	1000	4.95
				April 26, 1988	1000	6.40
				May 23, 1988	1040	6.79
				June 23, 1988	1130	7.58
NT101	412453073170201	16.4	I	April 9, 1985	1115	8.10
				August 26, 1986	1324	7.97
				August 18, 1987	1407	9.40
				November 14, 1988	1304	7.87
				December 1, 1988	1420	7.55
NT102	412526073161802	16.3	RU	April 11, 1985	1145	7.50
				May 8, 1985	1112	7.60
NT103	412308073164301	21.0	I	April 10, 1985	1114	5.80
				August 5, 1985	1040	6.20
				August 28, 1986	1145	6.42
				August 19, 1987	1215	7.50
				November 9, 1988	1243	5.72
			POMPERAUG AQUIFER			
SB34	412939073131901	16.8	AT	April 5, 1985	1440	7.00
				September 2, 1986	1440	8.20
				August 3, 1987	1330	7.80
SB35	412918073132501	26.1	C	April 11, 1985	1410	9.60
				August 5, 1985	1435	9.90
				September 2, 1986	1325	10.50
				August 18, 1987	1027	10.80
				August 10, 1988	1100	10.80
				June 28, 1989	1252	8.75
SB36	412819073133101	11.6	RU	April 12, 1985	0955	3.10
				August 6, 1985	1110	3.50
				September 2, 1986	1130	3.62
				August 18, 1987	1202	3.50

Appendix. Summary of site information, sample date and time, and water level for wells sampled during this study—Continued

Local well number	Site identification number	Depth of well (feet)	Land use	Date	Time	Depth to water (feet)
POMPERAUG AQUIFER—Continued						
SB37	412947073131801	21.5	AT	August 22, 1986	1335	9.50
				June 24, 1987	1335	8.30
				August 3, 1987	1205	9.30
				August 25, 1987	1114	9.70
				September 23, 1987	1120	8.20
				October 20, 1987	1105	8.50
				November 18, 1987	1128	8.50
				February 16, 1988	1235	7.60
				March 17, 1988	1128	6.92
				April 26, 1988	1105	7.89
				May 23, 1988	1153	7.97
				June 28, 1988	0843	9.12
SB38	412916073130001	25.3	I	August 25, 1987	1312	12.60
				June 28, 1988	0948	12.35
				November 15, 1988	1115	12.15
				December 1, 1988	1512	11.29
WY44	413128073121901	16.4	C	April 12, 1985	1330	11.90
				August 20, 1986	1155	12.30
				August 13, 1987	1325	12.70
				November 14, 1988	1433	12.63
WY45	413317073120001	15.3	AT	April 4, 1985	1250	6.50
				September 3, 1986	1326	—
				August 7, 1987	1326	7.60
WY46	413413073133101	11.6	U	April 1, 1985	1400	5.30
				April 12, 1985	1150	—
				August 22, 1986	0940	6.69
				August 11, 1987	1530	6.70
				August 22, 1988	1205	7.00
WY47	413322073124501	15.6	RU	April 5, 1985	1240	5.10
				August 21, 1986	1210	5.79
				August 12, 1987	1316	5.70
WY48	413311073125601	15.9	AT	April 2, 1985	1310	7.60
				August 21, 1986	1310	5.23
				August 4, 1987	1450	8.10
WY49	413223073133701	15.1	AU	April 5, 1985	1015	7.00
				August 20, 1986	1335	6.90
				August 3, 1987	1440	6.90
WY50	413326073114201	16.4	AT	April 4, 1985	1030	5.30
				August 11, 1987	1148	5.70
WY51	413309073122901	45.6	RU	April 2, 1985	1450	33.80
				May 8, 1985	1405	33.90
				September 4, 1986	1215	34.10
				August 12, 1987	1438	32.30
WY52	413347073112601	11.6	U	April 3, 1985	1230	7.70
WY53	413130073122201	20.5	C	April 12, 1985	1500	7.10
				August 26, 1987	1310	8.00
				November 14, 1988	1530	7.74
WY54	413326073123501	30.5	RU	April 1, 1985	1600	12.10
				August 21, 1986	1105	12.58
				August 12, 1987	1145	12.30
WY55	413322073122301	11.5	RU	April 2, 1985	1130	4.40
WY56	413300073125901	16.0	AT	September 3, 1986	1125	7.30
				August 4, 1987	1330	7.20
				November 21, 1988	1322	4.63
WY57	413228073125201	16.2	AT	August 19, 1986	1030	4.20
				August 4, 1987	1130	4.20
				August 22, 1988	1400	4.40

Appendix. Summary of site information, sample date and time, and water level for wells sampled during this study—Continued

Local well number	Site identification number	Depth of well (feet)	Land use	Date	Time	Depth to water (feet)
POMPERAUG AQUIFER—Continued						
WY58	413301073122101	20.8	RU	July 2, 1987	1220	9.60
				June 28, 1988	1058	11.36
				November 21, 1988	0904	12.72
WY59	413258073123001	44.7	RU	August 19, 1986	1330	29.00
				July 10, 1987	1430	26.30
				August 10, 1988	1410	28.69
				November 21, 1988	1032	29.67
				June 28, 1989	0952	25.89
WY60	413232073124001	25.8	C	August 19, 1986	1200	10.90
				August 26, 1987	1052	9.00
				July 26, 1988	0943	9.70
				November 15, 1988	1417	10.91
				November 21, 1988	1147	9.58
WY61	413053073141801	11.2	U	August 25, 1986	1200	4.51
				August 26, 1987	1417	4.80
				November 15, 1988	1230	4.11
FARMINGTON AQUIFER						
PV82	414126072512101	20.9	RS	August 29, 1986	1225	8.14
				August 21, 1987	1400	8.50
				July 1, 1988	1300	8.26
				November 8, 1988	1220	7.66
PV83	414055072522301	20.9	RU	July 22, 1988	1000	14.60
PV84	413921072513401	11.4	RS	July 15, 1988	1207	6.80
PV85	413944072512901	16.3	RS	July 15, 1988	0925	11.70
F322	414412072500701	20.6	AU	July 21, 1986	1430	6.80
				July 24, 1987	1250	6.40
				July 5, 1988	1441	6.40
F323	414323072502501	21.1	AT	July 31, 1986	1330	5.60
				July 24, 1987	1114	6.30
				July 19, 1988	—	6.50
F324	414312072504301	21.1	AT	July 25, 1986	1320	7.90
				June 24, 1987	0930	7.70
				July 24, 1987	0905	8.30
				August 27, 1987	1016	8.20
				September 23, 1987	1320	7.50
				October 20, 1987	1255	7.50
				November 18, 1987	1307	7.20
				February 16, 1988	1418	7.20
				March 17, 1988	1320	7.33
				April 26, 1988	1247	7.80
				May 23, 1988	1323	6.76
				June 24, 1988	0930	7.92
				July 19, 1988	1050	8.00
F325	414454072504801	25.5	U	July 30, 1986	1215	17.30
				August 14, 1987	1250	17.20
				July 29, 1988	1220	17.80
F326	414521072510801	15.5	U	July 31, 1986	1020	3.00
				August 17, 1987	1045	3.10
				July 29, 1988	—	2.80
F327	414207072514801	16.4	I	July 24, 1986	1545	7.73
				August 20, 1987	1036	8.40
				October 25, 1988	1428	6.78
F328	414439072515401	25.7	RS	July 22, 1986	1530	18.70
				August 10, 1987	1330	19.50
				July 1, 1988	1625	19.79

Appendix. Summary of site information, sample date and time, and water level for wells sampled during this study—Continued

Local well number	Site identification number	Depth of well (feet)	Land use	Date	Time	Depth to water (feet)
FARMINGTON AQUIFER—Continued						
F329	414324072495601	38.5	RS	August 1, 1986	0950	32.00
				July 28, 1987	1645	32.10
				August 15, 1988	1345	32.20
				June 23, 1989	0955	29.74
				August 25, 1989	1000	31.33
F330	414338072512601	16.1	U	July 24, 1986	1335	6.80
				July 28, 1987	1340	6.90
				July 29, 1988	0925	4.80
F331	414436072514401	25.9	RS	August 1, 1986	1145	19.20
				July 14, 1987	1030	19.30
				August 14, 1987	1030	19.30
				July 1, 1988	1515	19.40
				October 25, 1988	1300	20.28
F332	414157072520801	46.2	I	March 30, 1988	1000	40.00
				November 23, 1988	1500	37.61
F333	414208072510601	55.6	I	August 1, 1986	1335	44.00
				August 20, 1987	1155	44.20
				November 8, 1988	1353	43.55
A304	414905072491301	16.2	AT	August 7, 1986	1530	8.90
				August 6, 1987	1315	8.80
				July 25, 1988	1134	8.90
				November 18, 1988	1020	8.90
A305	414601072493901	20.6	AT	July 29, 1986	0945	8.90
				August 5, 1987	1145	8.70
				July 27, 1988	1000	8.83
A306	414637072493501	21.0	AU	July 23, 1986	1340	7.90
				August 5, 1987	1305	7.90
				August 18, 1988	1110	8.20
				June 23, 1989	1235	7.13
				August 25, 1989	1130	7.64
A307	414714072494701	16.0	AU	July 29, 1986	1205	10.30
				August 6, 1987	1525	9.80
A308	414541072495101	25.3	U	July 28, 1986	1032	21.90
				August 17, 1987	1300	21.50
				July 27, 1988	1135	22.90
				August 19, 1988	1345	22.20
A309	414828072492701	35.8	C	September 5, 1986	1400	24.10
				September 1, 1987	1355	24.40
				August 18, 1988	1430	24.60
A310	414626072495601	20.6	U	July 23, 1986	1115	15.00
				August 31, 1987	1427	15.30
				July 27, 1988	1300	15.20
				August 18, 1988	1250	15.40
A311	414839072505101	16.1	C	September 5, 1986	1030	8.50
				August 27, 1987	1215	8.40
				August 19, 1988	1200	8.70
A312	414747072500801	25.6	I	August 4, 1986	1515	17.50
				September 1, 1987	1139	17.00
				July 25, 1988	1410	17.30
SI445	415246072512001	16.0	AT	August 14, 1986	1010	3.82
				August 6, 1987	1124	3.90
				August 26, 1988	1055	3.80
SI446	414922072490401	21.1	AT	August 7, 1986	1400	8.00
				August 5, 1987	1440	8.00
				July 25, 1988	0942	8.00

Appendix. Summary of site information, sample date and time, and water level for wells sampled during this study—Continued

FARMINGTON AQUIFER—Continued

Local well number	Site identification number	Depth of well (feet)	Land use	Date	Time	Depth to water (feet)
SI447	415251072483001	15.8	RU	August 12, 1986	1525	8.30
				July 9, 1987	0945	6.60
				August 17, 1988	1100	8.70
				October 31, 1988	1147	8.82
				June 26, 1989	0935	5.04
SI448	415351072500501	25.8	U	August 13, 1986	1500	17.40
				July 9, 1987	1240	14.20
				October 31, 1988	1019	21.60
SI449	415118072512301	25.9	U	August 13, 1986	1107	18.80
				July 9, 1987	1405	19.50
				August 1, 1988	1053	18.90
SI450	415234072480301	21.1	C	August 12, 1986	0945	14.80
				August 28, 1987	1112	13.70
				October 31, 1988	1310	15.30
SI451	415300072480301	45.7	RU	August 12, 1986	1400	34.30
				July 8, 1987	1515	32.30
				August 17, 1988	0930	34.50
				June 26, 1989	1100	32.75
				August 25, 1989	1425	32.53
				September 6, 1989	1345	—
SI452	415340072472501	31.2	RU	August 11, 1986	1125	18.10
				July 7, 1987	1330	18.20
				August 16, 1988	1400	22.05
				June 20, 1989	0940	16.12
SI453	415441072472601	20.3	RU	August 11, 1986	1430	15.90
				July 7, 1987	1107	14.50
				August 16, 1988	1130	16.40
				November 7, 1988	1524	16.70
				June 22, 1989	1310	13.07
				August 25, 1989	1305	14.88
SI461	415037072485501	6.4	RU	July 18, 1988	1300	5.70
SI462	415045072512301	16.0	RU	July 14, 1988	1035	6.00
SI463	415011072513401	10.7	RU	July 14, 1988	1400	7.90
SI464	415035072512201	21.1	RU	July 14, 1988	1220	12.70
SI465	415308072480101	25.5	RU	July 7, 1988	1020	22.20
SI466	415328072490901	11.1	RU	July 7, 1988	1130	2.30
SI467	415316072483601	15.6	RS	July 13, 1988	1420	7.90
SI468	415425072505801	14.4	RU	July 12, 1988	1405	6.40
SI469	415441072505201	15.3	RU	July 12, 1988	1200	6.20
SI470	415450072510401	16.3	RU	July 13, 1988	1220	6.90
SI471	415500072481801	19.5	RU	July 6, 1988	0845	11.90
GR334	415642072474601	15.9	AU	June 30, 1988	1120	5.60
GR335	415706072475601	16.0	RU	July 1, 1988	1217	6.60
GR336	415747072475901	21.0	RU	July 1, 1988	1005	14.60
				December 2, 1988	0932	13.82
GR337	415722072475701	26.2	RU	July 11, 1988	1045	22.50
				November 7, 1988	1400	22.19
GR338	415643072501901	11.2	AU	June 28, 1988	1055	4.70
				July 18, 1988	1025	4.80
GR339	415534072473201	26.0	RU	June 30, 1988	1330	13.60
GR340	415516072473301	30.9	RU	July 11, 1988	1330	24.70
GR341	415858072481001	34.9	RU	June 28, 1988	1340	23.20

HOCKANUM AQUIFER

Local well number	Site identification number	Depth of well (feet)	Land use	Date	Time	Depth to water (feet)
M157	414853072303601	15.2	C	July 14, 1987	1135	3.80
				August 23, 1988	1430	4.10
M158	414547072304801	11.5	RS	July 16, 1987	1400	7.30
				June 29, 1988	1110	7.69

Appendix. Summary of site information, sample date and time, and water level for wells sampled during this study—Continued

Local well number	Site identification number	Depth of well (feet)	Land use	Date	Time	Depth to water (feet)
HOCKANUM AQUIFER—Continued						
M159	414629072290601	15.2	U	June 25, 1987	1230	6.10
				July 28, 1988	1152	7.60
M160	414624072283301	31.0	U	June 25, 1987	1555	14.80
				July 15, 1987	1410	15.00
				July 28, 1988	1017	20.20
M161	414857072302701	19.9	C	July 14, 1987	1535	3.60
				August 23, 1988	1211	3.80
M162	414741072284501	16.0	U	June 26, 1987	1200	3.20
				June 29, 1988	1252	2.81
				August 23, 1988	0930	6.30
M163	414740072301801	15.0	RS	March 18, 1988	1035	13.41
				March 29, 1988	1330	12.90
				December 2, 1988	1315	12.68
M164	414814072301901	15.0	I	July 17, 1987	0935	2.10
				June 29, 1988	1404	2.85
				October 26, 1988	1248	3.36
M165	414637072314401	35.2	RS	June 29, 1987	1315	22.60
				August 11, 1988	—	23.30
				October 27, 1988	1037	23.52
				June 27, 1989	1200	22.67
M166	414709072330601	15.3	I	July 17, 1987	1145	3.00
				June 29, 1988	1017	3.08
				October 26, 1988	1109	3.13
M167	414709072332601	15.8	I	July 15, 1987	1630	4.20
				August 26, 1988	0830	4.30
M168	414631072332301	16.3	RS	July 20, 1988	1425	6.11
				July 21, 1988	1200	6.11
M169	414548072330501	16.2	RU	July 20, 1988	1330	11.50
				July 21, 1988	1230	11.50
M170	414618072331101	21.6	RS	July 21, 1988	1200	17.50
				July 21, 1988	1500	17.50
				July 22, 1988	1209	17.50
				July 27, 1988	0815	8.60
M171	414528072305101	36.0	RS	June 29, 1988	1510	18.40
				December 1, 1988	0847	21.94
M172	414509072304301	26.0	RS	June 24, 1988	1200	8.10
				July 20, 1988	1300	8.40
M173	414901072305001	29.9	RS	June 23, 1988	1220	18.20
M175	414454072311401	9.8	AU	August 15, 1988	1415	2.70
				August 18, 1989	1303	1.19
SW134	414914072310101	20.6	RS	June 23, 1988	1432	7.50
SW135	414913072304701	35.8	RS	June 29, 1988	1145	12.70
V89	415134072292601	20.6	RS	June 23, 1987	1000	4.80
				July 22, 1987	1443	5.23
				August 24, 1987	1512	5.50
				September 22, 1987	1425	5.00
				October 19, 1987	1505	5.20
				November 19, 1987	1014	5.20
				February 17, 1988	1256	3.70
				March 18, 1988	1245	3.91
				April 26, 1988	1718	4.13
				May 24, 1988	1103	4.36
				June 24, 1988	1351	5.02
				December 2, 1988	1133	4.33
V90	415123072292601	14.0	RS	June 30, 1987	1015	11.90
				June 30, 1988	1058	12.18
V91	415102072291801	9.5	RS	June 30, 1987	1240	5.40
				June 30, 1988	1152	5.59
				October 27, 1988	1414	5.74

Appendix. Summary of site information, sample date and time, and water level for wells sampled during this study—Continued

Local well number	Site identification number	Depth of well (feet)	Land use	Date	Time	Depth to water (feet)
HOCKANUM AQUIFER—Continued						
V92	415155072284601	25.6	C	June 23, 1987	1445	12.50
				June 30, 1988	1250	12.76
				November 7, 1988	1008	12.57
V93	415201072284601	15.7	RS	June 23, 1987	1230	6.00
				June 30, 1988	1340	6.52
V94	415013072263901	11.1	U	June 26, 1987	0930	3.60
				July 28, 1988	1330	4.20
V95	414936072300201	20.7	C	June 30, 1987	1445	8.70
				June 30, 1988	0958	9.20
				October 27, 1988	1318	9.17
				November 17, 1988	1350	8.50
V96	414926072300801	25.8	C	June 22, 1987	1522	13.00
				July 22, 1987	1220	13.44
				August 24, 1987	1620	13.70
				September 22, 1987	1525	12.90
				October 20, 1987	1430	13.40
				November 19, 1987	1112	12.90
				February 17, 1988	1412	12.00
				March 18, 1988	1140	12.47
				April 26, 1988	1813	12.80
				May 24, 1988	1202	12.60
				June 23, 1988	1402	13.33
				July 28, 1988	1509	12.70
				October 27, 1988	1218	10.44
EL81	415616072303801	27.4	U	June 22, 1987	1150	13.10
				July 31, 1987	1555	26.20
				August 24, 1987	1245	27.40
				February 17, 1988	1000	27.30
				March 18, 1988	1530	22.71
				April 26, 1988	1517	23.43
				May 24, 1988	0845	23.67
				June 24, 1988	1110	25.20
EL82	415458072291901	24.5	AU	July 31, 1987	1445	6.50
				July 1, 1988	0946	6.47
EL83	415450072272801	16.0	AU	July 21, 1987	0930	4.40
				July 5, 1988	1130	5.50
				November 18, 1988	1315	3.35
EL84	415453072273801	16.1	AT	July 21, 1987	1255	4.01
				July 5, 1988	1300	3.80
EL85	415511072284201	21.2	AT	June 22, 1987	1400	9.70
				July 23, 1987	1055	10.52
				August 24, 1987	1402	11.10
				September 22, 1987	1310	11.00
				October 19, 1987	1310	11.00
				November 19, 1987	0914	11.00
				February 17, 1988	1115	8.80
				March 18, 1988	1405	8.84
				April 26, 1988	1613	9.95
				May 24, 1988	1002	10.13
				June 24, 1988	1226	10.70
				November 7, 1988	1116	11.30
EL86	415441072274101	16.4	AU	July 21, 1987	1500	6.20
				August 15, 1988	1045	6.20
				June 29, 1989	1043	5.70

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