NATIONAL WATER-QUALITY ASSESSMENT PROGRAM

Relation of Arsenic, Iron, and Manganese in Ground Water to Aquifer Type, Bedrock Lithogeochemistry, and Land Use in the New England Coastal Basins

Water-Resources Investigations Report 99-4162

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By Joseph D. Ayotte, Martha G. Nielsen, Gilpin R. Robinson, Jr., and Richard B. Moore

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1999

U.S. DEPARTMENT OF THE INTERIOR
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FOREWORD

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

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

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

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

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

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

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

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

Robert M. Hirsch

Robert M. Hirsch
Chief Hydrologist

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CONVERSION FACTORS

Multiply	By	To obtain
foot (ft)	0.3048	meter
square mile (mi^2)	2.590	square kilometer
million gallons per day (Mgal/d)	0.04381	cubic meter per second
feet per day (ft)	0.3048	meters per day
pounds per acre (lbs/acre)	1.12	kilograms per hectare
pounds per acre per year (lbs/acre/yr)	1.12	kilograms per hectare per year
gallons per day per person (gal/d/person)	0.06309	liters per second per person
gallons per minute (gal/min)	3.785	liters per minute

OTHER ABBREVIATIONS USED IN THIS REPORT

milligrams per liter	(mg/L)
parts per million	(ppm)

Relation of Arsenic, Iron, and Manganese in Ground Water to Aquifer Type, Bedrock Lithogeochemistry, and Land Use in the New England Coastal Basins

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Abstract

In a study of arsenic concentrations in public-supply wells in the New England Coastal Basins, concentrations at or above 0.005 mg/L (milligrams per liter) were detected in more samples of water from wells completed in bedrock (25 percent of all samples) than in water from wells completed in stratified drift (7.5 percent of all samples). Iron and manganese were detected (at concentrations of 0.05 and 0.03 mg/L, respectively) at approximately the same frequency in water from wells in both types of aquifers.

Concentrations of arsenic in public-supply wells drilled in bedrock (in the National Water-Quality Assessment Program New England Coastal Basins study unit) vary with the bedrock lithology. Broad groups of lithogeochemical units generalized from bedrock lithologic units shown on state geologic maps were used in the statistical analyses. Concentrations of arsenic in water from public-supply wells in metasedimentary bedrock units that contain slightly to moderately calcareous and calc-silicate rocks (lithogeochemical group M_c) were significantly higher than the concentrations in five other groups of bedrock units in the study unit. Arsenic was detected, at or above 0.005 mg/L, in water from 44 percent of the wells in the lithogeochemical group M_c and in water from less than 28 percent of wells in the five other groups. Additionally, arsenic concentrations in ground water were the lowest in the metasedimentary rocks that are characterized as variably sulfidic (group M_s). Generally, concentrations of arsenic were low in water from bedrock wells in the felsic igneous rocks (group I_f) though locally some bedrock wells in granitic rocks are known to have ground water with high arsenic concentrations, especially in New Hampshire.

The concentrations of arsenic in ground water also correlate with land-use data; significantly higher concentrations are found in areas identified as agricultural land use than in undeveloped areas. There is, however, more agricultural land in areas overlying the metasedimentary rocks of lithogeochemical groups M_c and the minimally-deformed clastic sediments of group M_{md} than in areas overlying other lithogeochemical groups. This correlation complicates the interpretation of sources of arsenic to ground water in bedrock. A test of this association revealed that relations between arsenic concentrations and the metasedimentary rocks of group M_c are not weakened when data associated with agricultural land use is removed; the reverse is true, however, if the data associated with the group M_c are removed from the analysis.

The occurrence and variability of arsenic in water from bedrock supply wells could be related to several factors. These include (1) the distribution and chemical form of arsenic in soils and rocks that are part of the ground-water-flow system, (2) the characteristics that influence the solubility and transport of arsenic in ground water, (3) the differing degrees of vulnerability of ground-water supplies to surface contamination, and (4) the spatial associations between land use, geology, and ground-water-flow patterns. Strong relations between agricultural land use and the

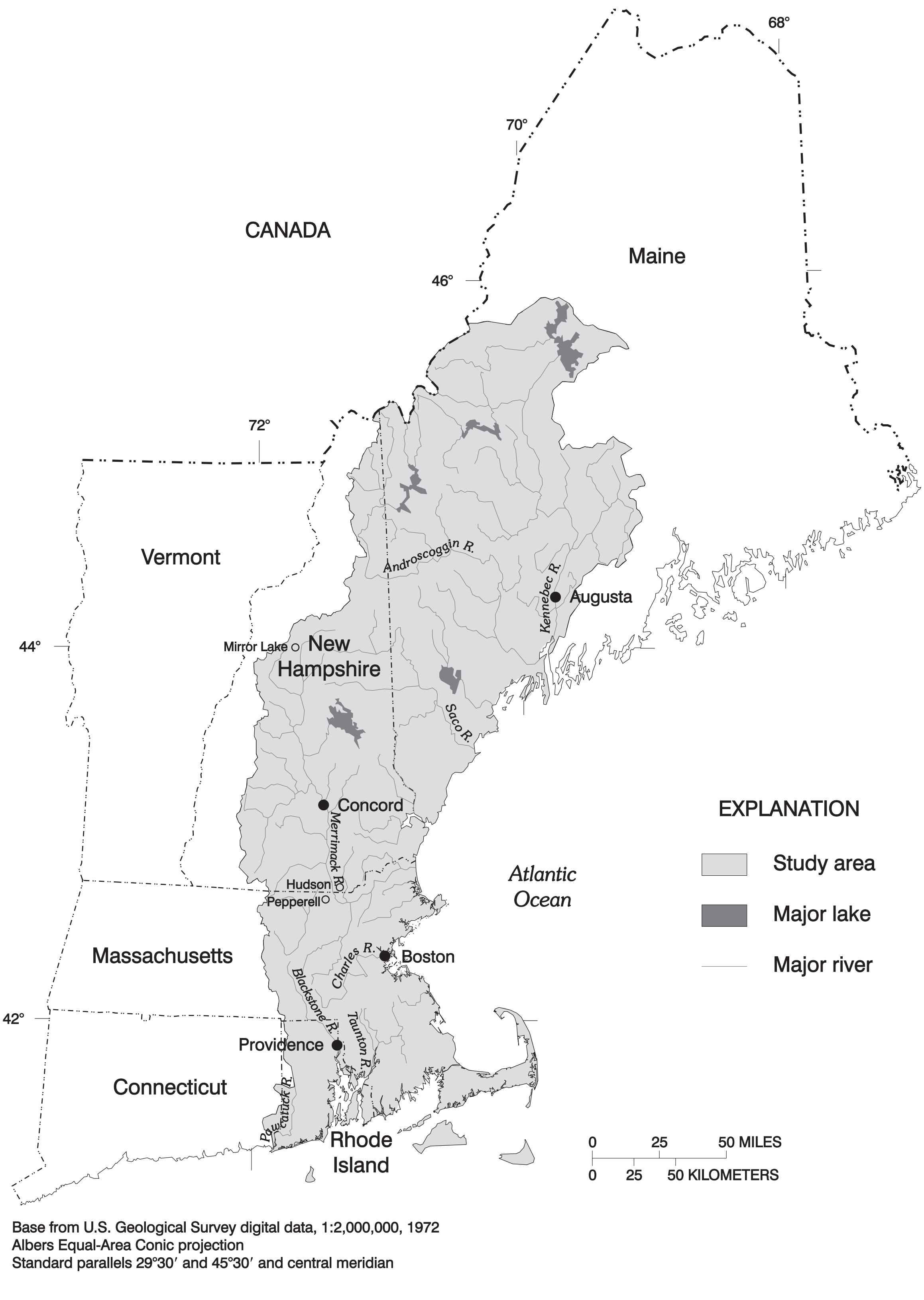


Figure 1. Location of the New England Coastal Basins study unit.

metasedimentary rocks of group M_c complicate the interpretation of arsenic source to water in these bedrock aquifers. This is due in part to the past use of arsenical pesticides; additionally, few whole-rock geochemical data are available for the rock types in the lithogeochemical groups of aquifers that contain ground water with elevated concentrations of arsenic. Without such data, identifying specific bedrock types as arsenic sources is not possible. In southern Maine and south-central New Hampshire, and in northern Massachusetts, the few available whole-rock analyses suggest, at least for these local areas, a connection between known bedrock chemistry and ground-water arsenic levels.

Although the lithogeochemical group and land-use category variables individually describe much of the variance in the concentrations of arsenic in ground water, the lithogeochemical relation is statistically stronger than the land-use relation. Low concentrations of arsenic in water from bedrock public-supply wells are associated with the metasedimentary rocks of group M_s (characterized as variably sulfidic). This association could reflect a variety of factors and suggests that simple dissolution of arsenic-bearing iron phases, such as sulfides, may not explain concentrations of arsenic in water in this bedrock aquifer group. Whole-rock geochemical data and more complete water-chemistry data, as well as studies of historical variation of arsenic concentrations (time-line studies), and site-specific studies, will be critical in addressing the arsenic source issue.

INTRODUCTION

The New England Coastal Basins study unit is one of 59 study units in the U.S. Geological Survey (USGS) National Water-Quality Assessment (NAWQA) Program (fig. 1). The NAWQA program began full implementation in 1991 to (1) describe water-quality conditions for the nation’s major freshwater rivers and aquifers, (2) describe how water quality is changing over time, and (3) to improve our understanding of the primary natural and human factors that affect water-quality conditions (Leahy and others, 1990). Information obtained from these study units can be used to help manage, regulate, or make decisions about water resources in the United States. The New England Coastal Basins study unit is one of several NAWQA studies that began in 1997 (Ayotte and Robinson, 1997).

NAWQA ground-water studies focus on water-quality conditions in major aquifers, primarily by using aquifer-wide surveys (termed subunit surveys) and land-use studies designed to assess the effect of specific land uses on aquifer water quality. Subunit surveys are designed to assess the water quality of the major aquifer systems of each study unit. Land-use studies focus on recently recharged shallow aquifer systems so that the influences of land-use practices and natural conditions can be assessed for selected subunit aquifers.

During the planning period of NAWQA studies, locally important water-quality issues are identified through meetings with Federal, State, and local agencies, as well as universities and the private sector. Existing data, and results from previous studies, are simultaneously reviewed to understand the primary physical, chemical, and biological factors that affect water quality in the study unit and to identify gaps in the current data. In the New England Coastal Basins study unit, a major concern related to ground-water quality is the concentration of trace elements, particularly arsenic, in ground water from the major aquifers. Many trace elements pose potential health risks if they are present in drinking water and, as such, are regulated by Federal and State safe-drinking water programs. Other trace elements are not a health risk but can result in additional maintenance or repair to water-using systems in homes.

Purpose and Scope

This report describes the occurrence and distribution of arsenic, iron, and manganese in the bedrock and stratified-drift aquifers in the New England Coastal Basins NAWQA study unit. Results from this work will be used to help design regional-scale studies of ground-water quality in the study unit. Included in this analysis is a classification of geologic data according to geochemical considerations (Robinson, 1997).

This report includes a description of the sources of the data used; the approach used for screening the data; a description of the methods used to group geologic data by general geochemical characteristics (lithogeochemical maps); and statistical and graphical presentations of the data by aquifer type, major lithogeochemical group, and major land use.

Health and Regulatory Concerns Related to Arsenic, Iron, and Manganese in Ground Water

Arsenic in public drinking water is regulated by the U.S. Environmental Protection Agency (USEPA) because health risks are associated with exposure to arsenic. On the basis of an increased risk of cancer due to low-level arsenic exposure, the National Academy of Sciences (1999) has recommended that the arsenic standard for drinking water be lowered. Although evidence that arsenic causes cancer in animals and humans is limited (International Agency of Research on Cancer, 1987), the National Institute of Environmental Health Sciences (NIEHS), an institute of the National Institutes of Health (NIH), Superfund Basic Research Program is currently (1999) supporting cancer-risk research from long-term, low-level exposure to arsenic through drinking water in New Hampshire. Recent studies indicate that levels of arsenic in drinking water, which are lower than the current drinking-water standard, could be related to an increased risk of cancer (National Institutes of Health, 1998).

The USEPA has identified arsenic as a "known" human carcinogen based on occupational and drinking-water exposures: "arsenic is the only known carcinogen for which exposure through drinking water has been demonstrated to cause human cancer" (U.S. Environmental Protection Agency, 1998a). The USEPA has set enforceable exceedence levels or maximum contaminant levels (MCLs) that must be met to ensure public health and safety. For arsenic, the current MCL is 0.05 mg/L. The USEPA, as specified in the Safe Drinking-Water Act amendments of 1996, is currently reviewing options for revising the MCL for arsenic to a lower concentration (U.S. Environmental Protection Agency, 1998b).

The occurrence of arsenic in public water supplies is a concern with respect to the proposed regulation of arsenic in drinking water (U.S. Environmental Protection Agency, 1998c). An assessment of the distribution of arsenic levels in public water systems will provide a basis for estimating the number of systems exceeding various MCL options and, therefore, the populations exposed to different levels of arsenic. This will likely mean that a percentage of the public-supply wells in the New England Coastal Basins will either require treatment to reduce concentrations of arsenic in the water or an alternative source of supply will be needed.

Historically, arsenic has been detected in bedrock ground waters in local areas of this study unit. Studies of arsenic in water from domestic bedrock wells in Maine (Marvinney and others, 1994), parts of New Hampshire (Boudette and others, 1985; Peters and others, 1999), and in Pepperell, Massachusetts (Zuena and Keane, 1985) have shown arsenic detection rates, at concentrations above 0.005 mg/L, of more than 50 percent. A sample population of domestic well data in New Hampshire (Peters and others, 1999), as well as data from previous studies in Maine, New Hampshire, and Massachusetts, indicates that arsenic concentrations above 0.05 mg/L in domestic well water occur in about 10-15 percent of the samples analyzed (Marvinney and others, 1994; Boudette and others, 1985; Zuena and Keane, 1985).

Iron and manganese in drinking water do not pose a health risk. The USEPA, however, has established non-enforceable exceedence levels or secondary maximum contaminant levels, (SMCLs) that are designed to limit 'nuisance' levels of these constituents. The SMCL for iron is 0.3 mg/L and for manganese is 0.05 mg/L. People who obtain their water from private and public stratified-drift or bedrock wells, however, are affected economically by the presence of iron and manganese in ground water. The most notable effects of these metals in water are the staining of clothes and household fixtures such as clothes washers, dishwashers, and bathtubs. Iron and manganese can also impart a metallic taste to the water. A less obvious effect of iron and manganese in well water is the accelerated deterioration of pipes, water heaters, and home heating systems. In addition, many homes require installation of water treatment systems to remove iron and manganese as it enters the home. Iron and manganese in water also support the growth of iron and manganese bacteria. These bacteria are not considered a health risk, but can cause clogging or restriction of pipes, pumps, valves, and other water-system parts by precipitation of metal hydroxides.

Previous Investigations

Since the late 1970's, there has been an awareness that the concentrations of arsenic in ground water in some areas of eastern New England are above the MCL. Boudette and others (1985) indicated that the presence of elevated concentrations of arsenic (above the USEPA MCL of 0.05 mg/L) in southeastern New Hampshire's ground water had been known since 1977. In Pepperell, Mass., 12 percent of 301 private wells tested for arsenic yielded water with concentrations of arsenic greater than the MCL (Zeuna and Keane, 1985), and 32 percent yielded water with concentrations greater than 0.005 mg/L. Marvinney and others (1994) found that approximately 10 percent of all wells in Maine tested for arsenic yielded water with concentrations greater than the 0.05 mg/L MCL, and 46 percent of the wells tested yielded water with concentrations exceeding 0.005 mg/L. Causes for the elevated arsenic levels in New England ground water have been investigated, but, to date, a definitive regional source has not been identified. The USEPA concluded that the spatial pattern of elevated arsenic concentrations in New Hampshire was random and could not be attributed to land use, and, therefore, was assumed to be attributed to natural sources, such as the dissolution of arsenic-bearing sulfide minerals (U.S. Environmental Protection Agency, 1981). The study by Boudette and others (1985), however, concluded that arsenopyrite and arsenical pyrite were probably not the source of the elevated arsenic concentrations and that anthropogenic sources, specifically arsenical pesticide use and domestic septic leachate, were more probably the cause. After elevated levels of arsenic were found in wells in Pepperell, Mass., Zeuna and Keane (1985) found evidence of arsenical pesticide usage in the area and high levels (49-227 ppm) of arsenic in the soil. They also found high levels (21-710 ppm) of arsenic in bedrock cores collected during domestic-well installation in the same area. Although Zeuna and Keane (1985) did not specifically demonstrate a pathway for the high concentrations of arsenic in soils of the many orchards in the area to reach the ground water, they did demonstrate that arsenic could leach from samples of the local bedrock and produce concentrations exceeding the MCL in the leachate solution.

In Maine, Marvinney and others (1994) studied ground-water arsenic concentrations statewide with a focus on southwestern Maine. Through analysis of more than 5,000 ground water samples, elevated arsenic concentrations were found in many geologic settings. In the Maine study, bedrock wells yielded water with statistically higher concentrations of arsenic than did wells completed in the surficial aquifer. Marvinney and others concluded that if bedrock was the source for the elevated arsenic levels found in ground water, "multiple models for its origin are required to explain its occurrence across such diverse geology;" furthermore, anthropogenic sources could not be ruled out. Chormann (1985) concluded, in a study of arsenic occurrence in stream sediments and soils in Hudson, N.H., that, for some orchard sites, anomalously high soil arsenic concentrations were likely the result of the use of arsenical pesticides. Chormann also concluded that combined arsenic/phosphate anomalies in stream sediments were associated with agricultural land uses but not with residential uses. A more recent study in New Hampshire (Peters and others, 1999) found that arsenic concentrations greater than 0.002 mg/L were measured in water from domestic bedrock wells (35 percent of the 218 bedrock wells sampled) more often than in water from surficial aquifer wells (1 percent of the 54 surficial wells sampled). In addition, they found that arsenic was readily leached by weak acid from some pegmatite rocks in the region. Concentrations of arsenic in whole-rock samples of the pegmatites were as high as 60 ppm and were much less in surrounding rocks. They concluded that arsenic in ground water in this region came from the weathering of bedrock and not from the use of arsenical pesticides or other anthropogenic sources.

In southern Maine, analyses of whole-rock and ground-water samples from an area near a landfill indicates a local connection between known bedrock chemistry and background ground-water arsenic levels. Concentrations of arsenic in rocks near Saco were as high as 120 ppm (J.A. Colman, U.S. Geological Survey, oral commun., 1998). Ground-water arsenic levels of 0.3 mg/L from an uncontaminated bedrock well, up-gradient of the landfill site, were also measured.

As noted in previous studies (Zeuna and Keane, 1985; Boudette and others, 1985; Marvinney and others, 1994), the historical application of arsenical pesticides on orchard and potato crops in New England could be contributing to arsenic concentrations in ground water. Few data exist on the amounts of lead arsenate and calcium arsenate and other inorganic pesticides that were applied to New England crops between the early 1900's and the 1960's, before they were phased out of use. The amounts are believed to be large but are difficult to quantify (D'Angelo and others, 1996). In Maine, arsenic pesticide use on apple orchards was greatest between 1928 and 1943. Up to "15 lead arsenate cover sprays of 100 gallons per tree per year" could have been applied during this period (D'Angelo and others, 1996). By 1958, the recommended usage had been revised downward considerably. Estimates for the total amounts of lead arsenate applied in an orchard sprayed for 40 years was 200 lbs/acre (D'Angelo and others, 1996). Applications of calcium arsenate on potato crops, which are less common than are orchard crops in the New England Coastal Basins study area, are estimated to have been up to 20 lbs/acre/yr (D'Angelo and others, 1996). Contamination of ground water by arsenic in Pepperell, Mass. (Zeuna and Keane, 1985), was found near old apple orchards where elevated concentrations of arsenic were measured in the soils. The use of inorganic arsenic compounds in pesticides was largely discontinued in the study unit by the late 1960's, however, and subsequently has been banned since the 1980's and 1990's (A.H. Welch, U.S. Geological Survey, written commun., April 1999).

Elsewhere, studies have been published about the occurrence of elevated concentrations of arsenic in ground water in Arizona (Robertson, 1989), Ohio (Masitoff and others, 1982), the western United States (A.H. Welch, written commun., April 1999); Maest and Wing, 1986), the Midwestern United States (Korte, 1991), and Montana (Nimick, 1998). Most of these studies indicated that local bedrock or alluvium was the ultimate source of the elevated arsenic levels. Nimick (1998) concluded that multiple causes were responsible for elevated arsenic concentrations in the study area in Montana. He found that a combination of percolation of river water high in arsenic, leaching from bedrock, and the release of sorbed arsenic under reducing conditions in the aquifer, all contributed to high dissolved arsenic concentrations in the aquifer water. He also concluded that agricultural practices in the area (irrigation with river water high in arsenic) were of much less importance than earlier investigators had concluded.

In many parts of the country, arsenic in ground water has been attributed to geologic sources, anthropogenic sources, and combinations of geologic sources and a particular land use. In New England, many studies (Zeuna and Keane, 1985; Boudette and others, 1985; Marvinney and others, 1994) have attempted to associate arsenic concentrations in ground water with either geologic or anthropogenic sources but have not definitively linked ground water arsenic to either source. Other studies have shown a relation to geology. Peters and others (1998, 1999) have shown that concentrations of arsenic in ground water from bedrock wells can be attributed to bedrock associated with the Concord Granite; this bedrock unit, however, is of limited extent and does not explain other significant areas with high concentrations of arsenic in ground water. No previous work has described the occurrence of arsenic in ground water on a regional scale and the sources of, and controls on, ground water arsenic in this region are still poorly understood.

Acknowledgments

The authors would like to acknowledge the following people for their invaluable help in providing the chemistry data used for this study: Paul Hunt and Donald Hoxie, Maine Department of Health; Patricia Bickford, Laurie Cullerot, and Scott Gentley, New Hampshire Department of Environmental Services; Steven Hallem and Mette Schwartz, Massachusetts Department of Environmental Protection; and June Swallow, Rhode Island Department of Health. The authors also wish to thank the State Geologists and (or) State Geological Surveys for providing digital coverages of state geologic maps. Dr. Rudolph Hon, Boston College, provided the digital data for the bedrock geologic map of Massachusetts. Leslie DeSimone, U.S. Geological Survey, oversaw the compilation and digitization of bedrock geologic data into the lithogeochemical coverage, and John Rader, formerly of the U.S. Geological Survey, assisted in the Geographic Information System compilation of the geologic data. John Peper, U.S. Geological Survey, did the lithogeochemical coding for the New Hampshire part of the study unit. Members of the New England Coastal Basins study Liaison Committee were also helpful in providing feedback and suggestions. The authors also acknowledge and thank Julia L. Barringer and Alan H. Welch, U.S. Geological Survey, and Robert G. Marvinney, State Geologist and Director of the Maine Natural Resources Information and Mapping Center, for their insightful reviews of this report.

DESCRIPTION OF THE STUDY AREA

The New England Coastal Basins study unit encompasses 23,000 mi^2 in western and central Maine, eastern and central New Hampshire, eastern Massachusetts, and most of Rhode Island. The study unit includes the drainage basins of the Kennebec, Androscoggin, Saco, Merrimack, Charles, Blackstone, Taunton, and Pawcatuck Rivers, as well as small coastal drainage basins between these major river basins (fig. 1). Almost two-thirds of New Hampshire is in the study area, as well as a third of Maine, half of Massachusetts, and 85 percent of Rhode Island (Flanagan and others, 1999).

Two principal aquifer types underlie the study area—(1) the surficial stratified-drift aquifers, which are discontinuous, and (2) fractured-bedrock aquifers, which are continuous and underlie stratified drift and (or) glacial till (Flanagan and others, 1999). The highly permeable, relatively shallow, discontinuous stratified-drift aquifers that occupy most river valleys in New England are the principal source of drinking water for many communities that obtain all or part of their public-water supply from ground water. Conversely, fractured-bedrock aquifers are the primary source of drinking water for rural households, for many small communities and trailer parks, and for non-community water suppliers such as restaurants and businesses.

Stratified-Drift Aquifers

Stratified-drift aquifers consist primarily of sand and gravel deposits that were deposited in layers by meltwater streams flowing from the retreating glacial ice. This aquifer type was formed primarily in valleys in the northern parts of the study area, and is of limited extent (fig. 2). In the southern third of the study area, the stratified-drift aquifers formed on broad plains as glaciers retreated and cover a wide geographic area (fig. 2). Stratified-drift aquifers contain significant amounts of coarse-grained, ice-contact, and outwash deposits and where saturated, are characterized by hydraulic conductivities that range from 35 to 1,000 ft/d. Ground-water residence time in stratified-drift aquifers is relatively short, where the flow is restricted to narrow glacial valleys. Recharge to these aquifers is generally from the surface and at the edges of the valleys from upland runoff. Discharge generally is to valley streams and rivers, though water can leave these surficial aquifers by recharging an underlying bedrock aquifer. As these aquifers often yield large amounts of water to wells, they are used wherever possible as public water supplies.

Bedrock Aquifers

Fractured-bedrock aquifers underlie the entire study area (Flanagan and others, 1999). These bedrock aquifers are dense, relatively impermeable, and have low porosity. Bedrock, in the study unit, ranges in age from Precambrian to Cretaceous and includes primarily fractured crystalline igneous and metamorphic rocks. Fractured-bedrock aquifers store and transmit water primarily through intersecting fractures. These fractures were formed by stresses caused by the erosion of overlying rock, the melting of glacial ice sheets that once covered New England, tectonic activity, and cooling stresses associated with igneous intrusion (Hansen and Simcox, 1994).

Single-hole hydraulic testing by Hsieh and others (1993) indicated that the hydraulic conductivity in New England fractured crystalline bedrock varies over four orders of magnitude, ranging from 2.8×10^{-4} to 2.8 ft/d. Other sources (Randall and others, 1988; Harte, 1992; Paillet and Kapucu, 1989) reported ranges in hydraulic conductivity for fractured crystalline bedrock in New England to be between 3.5×10^{-3} to 26 ft/d. Bedrock aquifers are recharged by infiltration through overlying unconsolidated materials (low to moderate permeability glacial till and low to high permeability stratified drift). Water discharges from bedrock aquifers into hillside streams, springs, rivers and lakebeds, overlying stratified-drift aquifers, and, at the coast, to the ocean. Flows modeled in New England bedrock terrain suggest that flow paths are limited to the upper 700-1,000 ft below the land surface (Harte, 1992), largely because fracture density decreases with depth. Residence times vary widely depending on the local or regional nature of a particular flowpath, and the degree of interconnections of fractures in an aquifer. Water in some wells in the bedrock aquifers at Mirror Lake, N.H., has been shown to be older than 50 years (Busenberg and Plummer, 1993) and potentially could be much older.

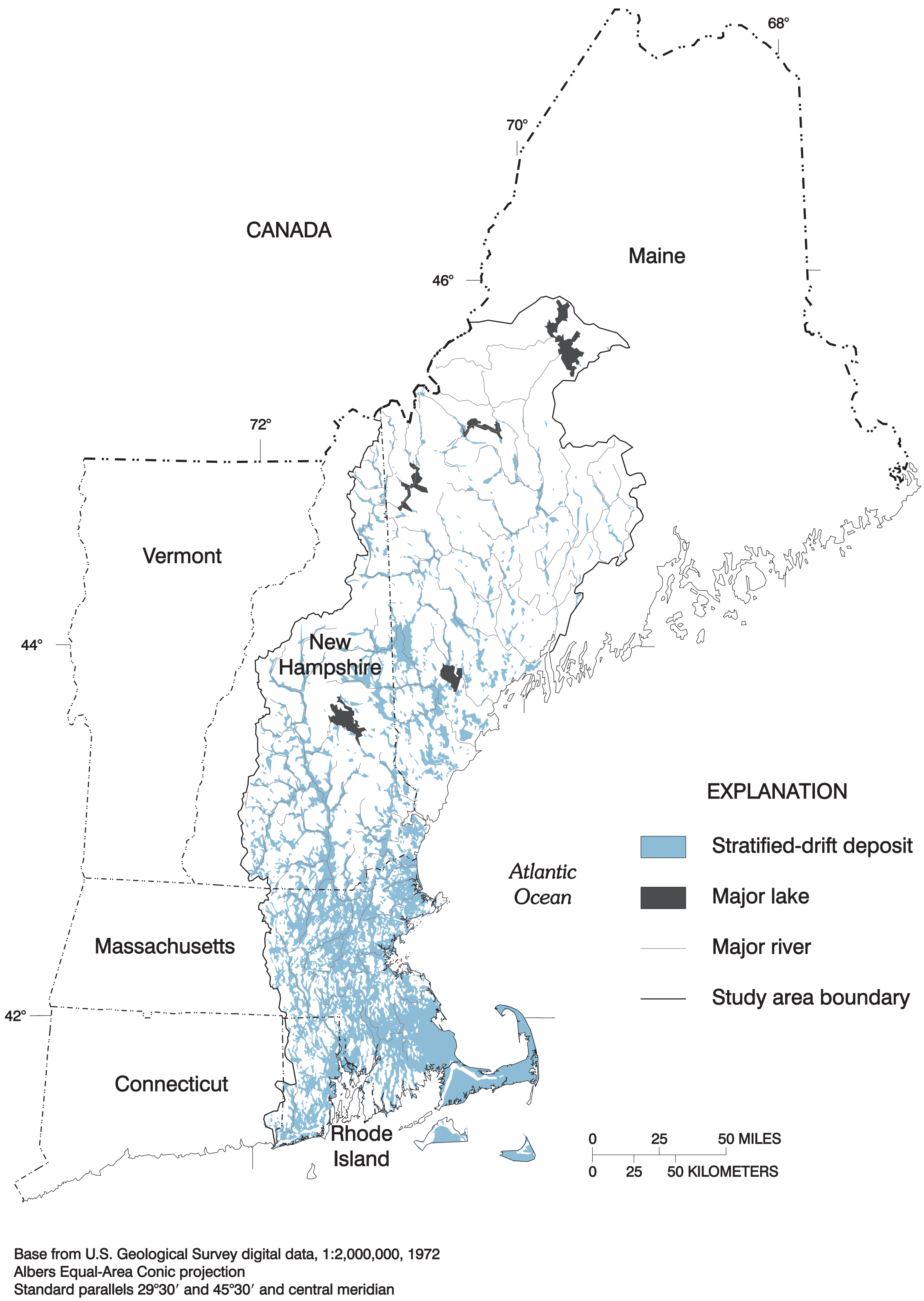


Figure 2. Location of stratified-drift deposits in the New England Coastal Basins study unit. (From Flanagan and others, 1999)

Water Use

In the New England Coastal Basins study unit, drinking water is supplied from public and private sources. People living in large metropolitan areas and large cities and towns generally are connected to public supplies that come from surface-water reservoirs, stratified-drift aquifers, or bedrock aquifers. People living in rural communities and on the outskirts of metropolitan areas generally obtain their water from private wells drilled into the bedrock aquifers, with some private wells in stratified-drift aquifers. In the Cape Cod area of southeastern Massachusetts, however, almost all wells are in stratified-drift aquifers, or till aquifers—unsorted, unconsolidated material overlying bedrock.

In 1995, approximately 47 percent of all drinking water in the New England Coastal Basins, or about 247 Mgal/d, came from ground water (USGS Aggregate Water-Use Data System (AWUDS) data bases in Maine, New Hampshire, Massachusetts, and Rhode Island, accessed October 1997; data are available from individual District USGS offices in each state). More than 30 percent of that ground water, or about 74 Mgal/d, is self-supplied, coming predominantly from private domestic wells drilled in bedrock aquifers. The remaining 70 percent, or about 173 Mgal/d, is publicly-supplied ground water which comes primarily from stratified-drift aquifers with a lesser amount coming from the bedrock aquifers.

The amount of water withdrawn from the bedrock aquifers for public supply is difficult to assess. Many community public-supply systems use bedrock ground water to supplement stratified-drift aquifer or surface-water sources. Most non-community public-supply systems (including restaurants and businesses) withdraw water from the bedrock aquifers but at low rates compared to the rates for community suppliers—probably less than 10 gal/min (F. Chormann, New Hampshire Department of Environmental Services, oral commun., 1998). In relatively few cases, high-yielding bedrock wells are the sole source or major component of a community supply.

To better define water use by aquifer type from public-supply wells in the study unit, a data base of community public-supply wells was generated from a subset of the USEPA Safe Drinking-Water Information System (SDWIS) data base, retrieved in August 1997. This data set contains USEPA identification numbers (ID's), population-served data, and individual/source descriptions (discrete wells) among other fields. Aquifer type was assigned to each well, where possible, for any given system (M.A. Horn, U.S. Geological Survey, written commun., December 1998). In the New England Coastal Basins study unit, approximately 1,145 systems, (including entire counties that are only partially in the study unit) use only ground water and do not purchase additional water. Aquifer-type data were available for wells in 734 of these systems. Data from these 734 systems were used to compute the percent of ground water withdrawn from stratified-drift and bedrock aquifers; using a factor of 70 gal/d/person, an estimated 71.0 Mgal/d are withdrawn by these systems. About 92 percent of this ground water is derived from stratified drift and about 8 percent comes from bedrock aquifers (table 1). This relation holds when the data

Table 1. Summary of estimated water use for community water supplies by aquifer type in the New England Coastal Basins study unit

[Mgal/d, million gallons per day]

State	Total systems (excluding purchased water and surface water)	Number of systems in dataset (percent of total)	Total withdrawals for systems (Mgal/d)	Stratified-drift aquifer	Bedrock aquifer
				Percent of water from above aquifer	
Maine	237	62 (26)	4.34	98.0	2.0
New Hampshire	611	527(86)	15.6	71.4	28.6
Massachusetts	242	137 (57)	49.7	97.8	2.2
Rhode Island	55	8 (15)	1.42	98.6	1.4
Entire New England Coastal Basins study unit	1,145	734 (64)	71.0	92.0	8.0

are arranged by state except for the New Hampshire part of the study unit where an estimated 71 percent comes from stratified-drift aquifers and 29 percent from bedrock aquifers. Whereas these data indicate about 8 percent of public ground water is supplied from the bedrock aquifer, the number is probably somewhat larger because this data set does not include any non-community supplies.

Assuming that about 8 percent of all public ground water for drinking water in the study unit comes from the bedrock aquifer, about 14 Mgal/d (8 percent) comes from bedrock aquifers. This rate, in addition to the 74 Mgal/d from bedrock that is self-supplied, brings the estimated total from bedrock aquifers to approximately 88 Mgal/d (about 36 percent) for all ground water used for drinking water. In addition, the population growth trends indicate that the population of communities in the northern part of the study unit, in particular in southern New Hampshire and coastal Maine, is increasing rapidly (Flanagan and others, 1999) and that the bedrock aquifers are an important water resource for this continued growth.

STUDY DESIGN AND METHODS

The study approach involved three general components: (1) collection of existing public and some private drinking-water chemistry data for ground water in stratified drift and bedrock aquifers from State agencies responsible for monitoring Safe Drinking-Water Act regulations; (2) compilation and reclassification of State geologic-map data into 'lithogeochemical' units for the four states in the study unit; and (3) statistical analyses of variance of arsenic, iron, and manganese data by various groupings and combinations of lithogeochemical and land-use data.

Several considerations are worth noting with respect to relating water-quality data to regional data layers such as generalized lithogeochemical and land-use maps. First, land use and geology are heterogeneous even at the local scale (Alley, 1993). For example, in the study unit, water quality in private bedrock-supply wells can vary markedly from house-to-house over short distances (horizontal heterogeneity due to factors including differences in ground-water flow paths or lithologic changes). Additionally, for the bedrock aquifers, lithology can vary with depth for any well (vertical heterogeneity). This variation, however, is not expected to have a significant effect for this regional-scale evaluation because well depths, for wells used in this study, are less than the thickness of the geologic units in which they are completed and are less than the spatial uncertainty of most unit boundaries. Small-scale horizontal and vertical heterogeneity are not represented in the lithogeochemical data set; regional variation could outweigh these small-scale heterogeneous effects, especially when a large number of wells are available across the study unit. Another factor to consider, when evaluating land use, is the relevance of the time period of the land-use data (Alley, 1993). For example, in bedrock-aquifer systems where flow paths of ground water are complex and travel times of ground water can be long, it is difficult to determine which time period of land-use data could be responsible for the observed water quality in a well.

Lithogeochemical Reclassification of Bedrock Units and Regional-Scale Approach

The geologic data were compiled from statewide geologic maps of Maine (Osberg and others, 1985, 1:500,000 scale), New Hampshire (Lyons and others, 1997, 1:250,000 scale), Massachusetts (Zen and others, 1983, 1:250,000 scale), and Rhode Island (Hermes and others, 1994, 1:100,000 scale). Digital versions of the state geologic maps were obtained for Maine, New Hampshire, and Rhode Island.
For Massachusetts, a digitized data layer based on Zen and others (1983), and created under the direction of Dr. Rudolph Hon, Department of Geology, Boston College, was obtained and verified. Lithogeochemical codes were added in ARC/INFO to each statewide geologic map. For Maine, metamorphic grade and protolith (pre-metamorphism source rock) rock type were used to classify polygons into lithogeochemical categories using a digital data layer of generalized regional metamorphic zones obtained from the Maine Geological Survey (Osberg and others, 1985). For example, rocks with protoliths of "limestone and (or) dolostone" were classified as "limestone, dolomite, and carbonate-rich clastic sediments" in areas with or without weak regional metamorphism and as "marble, which include some calc-silicate rock," in areas of greenschist-facies- or higher-grade metamorphism. Coded statewide data were joined to create one data layer for the New England Coastal Basins study unit.

Because the state geologic maps were produced at somewhat different scales, the level of detail of adjacent maps is variable; there are also discrepancies between bedrock units at state borders. The more than 700 bedrock geologic units on the four state maps were combined into a study-unit-wide digital map and were reclassified into 29 general 'lithogeochemical' units. These 29 units were then combined into 7 groups of similar geochemical nature, which were used in the analysis of arsenic, iron, and manganese concentration trends (fig. 3). These seven groups are described in figure 3; however, group I_u, which consists of primarily ultramafic igneous rocks, occupied less than 1 percent of the study unit and was omitted from the analysis. The thick unconsolidated sediments of Cape Cod (2 percent of the study unit) also were omitted from this study.

The lithogeochemical classification scheme was originally developed as part of an adjacent NAWQA study that included the Connecticut, Housatonic, and Thames River Basins (Robinson and others, 1999); a detailed description of the classification scheme and associated expected water-quality and ecosystem characteristics is presented in Robinson (1997).

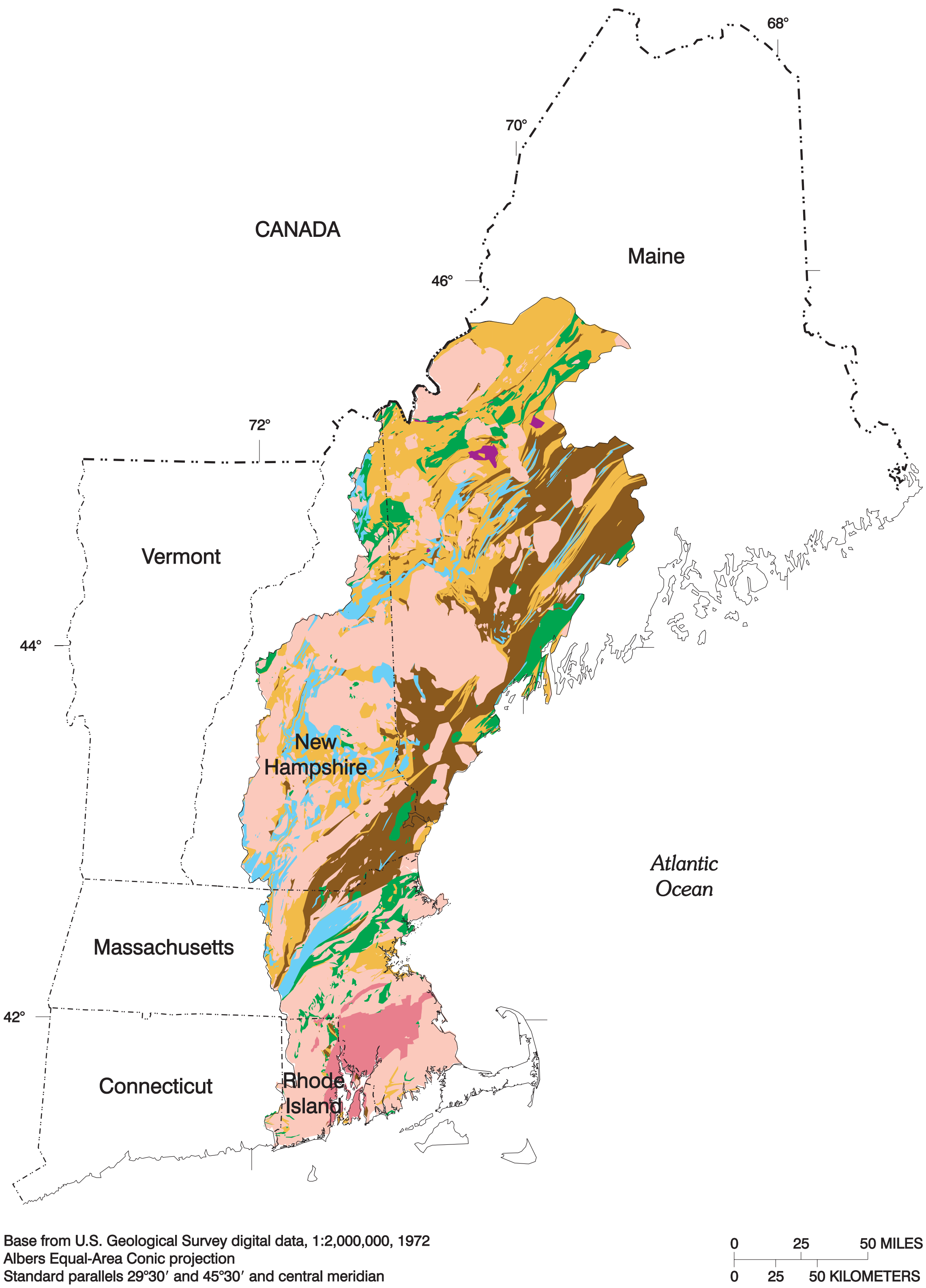


Figure 3. Areal distribution and description of major lithogeochemical groups of bedrock geologic units.

EXPLANATION

MAJOR LITHOGEOCHEMICAL GROUPS

M_c Clastic metasedimentary rocks derived predominantly from moderately calcareous sedimentary protoliths. Generally deformed and at or above greenschist facies of regional metamorphism; at lower metamorphic grades, bulk units typically contain 5-45 percent of carbonate minerals distributed either throughout the rock unit or in discrete carbonate-rich layers or laminae. At higher metamorphic grades, the percentage of carbonate minerals typically decreases and the percentage of calc-silicate minerals increases. May include locally noncalcareous rocks, sulfidic rocks, and metavolcanic rocks

M_s Clastic metasedimentary rocks derived predominantly from variably sulfidic sedimentary protoliths. Generally deformed and at or above greenschist facies of regional metamorphism. Bulk units are characterized by rusty-weathering intervals that typically contain a small percentage of pyrite and (or) pyrrhotite distributed either throughout the rock unit or in discrete sulfide-rich layers or laminae. May include locally nonsulfidic rocks, calcareous and calc-silicate rocks, and metavolcanic rocks

M_u Undifferentiated clastic metasedimentary rocks derived predominantly from noncalcareous and nonsulfidic sedimentary protoliths. Generally deformed and at or above greenschist facies of regional metamorphism. May include locally sulfidic rocks, calcareous and calc-silicate rocks, and metavolcanic rocks

M_{md} Undifferentiated clastic metasedimentary rocks derived predominantly from noncalcareous and nonsulfidic sedimentary protoliths occurring in fault-bounded depositional basins at or below greenschist facies of regional metamorphism. May contain volcanic rocks

I_m Mafic igneous rocks and their metamorphic equivalents. May contain local areas of felsic and intermediate volcanic and intrusive rocks and metasedimentary rocks

I_f Felsic igneous rocks and their metamorphic equivalents. May contain areas of mafic and intermediate volcanic and intrusive rocks and metasedimentary rocks

I_u Ultramafic igneous rocks and their metamorphic equivalents

STUDY AREA BOUNDARY

The geologic-unit descriptions and structural and metamorphic data from the four state geologic maps were reviewed for information on the chemical character of the bedrock (Robinson and others, 1999; Robinson, 1997). The geologic units were assigned to 'lithogeochemical' units on the basis of these data (fig. 3). The lithogeochemical classification scheme is based on the relative stability or "weatherability" of the constituent minerals and on the presence of carbonate and sulfide minerals in the bedrock or in the bedrock protolith. Carbonate and sulfide minerals are distinguished because these highly reactive minerals can have a disproportionately large effect on water chemistry compared to other minerals commonly found in the rocks of this region. For metamorphosed bedrock units in Maine, information about metamorphic grade also was used.

The lithogeochemical map, which was produced with the aid of a Geographic Information System (GIS), was designed to be flexible enough to regroup units based on relevance to the particular constituent being studied. For example, the number of groups and the composition of those groups relative to the occurrence of arsenic could differ from those chosen to assess the occurrence of radon.

Sources of Ground-Water Data and Well Selection

The most readily available source of ground-water chemical data in all states across the study area is data collected by states and public-water suppliers for monitoring compliance with the Federal Safe Drinking Water Act. These data are collected to ensure the safe delivery of public drinking-water supplies to communities, schools, and businesses. Each state operates its safe drinking-water program in accordance with Federal standards, and each uses the same sample-collection and laboratory-analysis methods. This standardization means that the data from each state are comparable, and thus usable for a regional analysis.

One disadvantage of using data collected for compliance with the Safe Drinking Water Act is that the testing is done on water being delivered to customers, not necessarily on the source water. Thus, any of the drinking-water suppliers can blend water from many wells or from wells and reservoirs before testing, and can also treat the water before testing. In order to eliminate wells that treat the water or that blend samples, data were selected from public water suppliers who (a) had only one supply source (a single well), and (b) were not required to do any treatment, because the raw water met current Federal drinking-water standards, and (c) had sampled for arsenic, iron, or manganese (table 2, appendixes 1 and 2). By meeting these criteria, the data represent conditions as close to natural conditions as possible, from this source of data, in the aquifers used for supplying drinking water to the public.

Data that met these criteria were collected from the Maine Department of Health; the New Hampshire Department of Environmental Services, Water Division, Water Supply Engineering Bureau; the Massachusetts Department of Environmental Protection, Bureau of Resource Protection, Drinking Water Program; and the Rhode Island Department of Health. The resulting data base of 804 bedrock wells and 145 surficial wells represents mostly small, non-community suppliers (such as restaurants) (table 2). Because of our requirement that the selected wells have no treatment, the data base is skewed away from systems that obtain water from sources that have naturally high concentrations of arsenic. The total number of systems requiring treatment, however, is not large. In Maine, for example, only 26 of 800 single-source ground-water systems in the study area (not all of which had arsenic analyses) required any sort of treatment, and only 4 of those required treatment for removing arsenic.

In addition, because the lowest common detection limit for the analytical results in this data set is 0.005 mg/L, there are a high number of non-detections for the accompanying arsenic analyses. The data set also is limited because the supplier is required to meet the USEPA MCL of 0.05 mg/L; a few samples from this data set, however, exceeded 0.05 mg/L. Thus, this data set represents a limited range of concentrations and represents a range of concentrations that are associated with public-supply drinking-water wells.

Data on well depth were analyzed only for public-supply wells in Rhode Island, New Hampshire, and Maine. From these, well depths ranged from 25 to 1,180 ft. Ninety-five percent of the wells are less than 620 ft deep. A survey of bedrock wells drilled in New Hampshire from 1984 to 1990 indicated that the median well depth in these New Hampshire bedrock

Table 2. Summary of public water supplies compiled by State and aquifer type in the New England Coastal Basins study unit

[mg/L, milligrams per liter]

State	Number of wells with chemistry data								
	Arsenic			Iron			Manganese		
	Surficial	Bed-rock	Detec-tion limit (mg/L)	Surficial	Bed-rock	Detec-tion limit (mg/L)	Surficial	Bed-rock	Detec-tion limit (mg/L)
Maine	20	168	0.001	20	167	0.01	20	167	0.01
New Hampshire	40	296	.005	0	296	.05	0	296	.01
Massachusetts	0	197	.005	0	18	.05	0	18	.03
Rhode Island	85	143	.005	81	99	.02	81	99	.02
Entire New England Coastal Basins study unit	145	804	.005	101	580	.05	101	580	.03

wells was 295 ft. (F.H. Chormann, written commun., 1990); it is likely that the median depth of bedrock wells in Massachusetts is similar.

The geographic distribution of the final set of wells used in this study is shown in figures 4a and 4b. Bedrock wells in Massachusetts are more clustered because there is an absence of wells in the large service areas of the Massachusetts Water Resources Authority, which serves the Boston Metropolitan area and other area communities with surface water. Cape Cod is served primarily by water withdrawn from a large stratified-drift aquifer and was not included in this study.

The greatest limitation of the data set used is its reliance on data from public-supply wells, which, by the nature of their use, are skewed towards supplies of cleaner, less contaminated water. Another limitation is that different states used different reporting limits for arsenic; these range from 0.001 to 0.005 mg/L. All sample results were converted to the single, highest reporting limit for each constituent. The resulting adjusted detection limits for each constituent were 0.005 mg/L for arsenic, 0.05 mg/L for iron, and 0.03 mg/L for manganese. A few samples were reported with higher reporting limits than the adjusted reporting limit used in this study (less than 0.30 or less than 0.010 mg/L for arsenic), and thus were deleted from the data set.

Statistical Analyses

Helsel and Hirsch (1992) note that water-quality data cannot be normally distributed because the data are bounded at zero or censored at one or more lower reporting levels. These data commonly are skewed and often have unknown distributions. For these reasons, robust statistical methods must be used to avoid potentially large errors associated with using parametric tests on non-normally distributed data (Helsel and Hirsch, 1992). Normality tests were performed on the arsenic, iron, and manganese data, and on the logs of these data. The constituents analyzed for this report were neither normally nor lognormally distributed. Therefore, nonparametric methods, which do not require assumptions about the distribution of the data, were used in this study.

Tests for differences in chemical distributions by aquifer type, major lithogeochemical group, and land use were performed using contingency-table analysis, Kruskal-Wallis and multiple-stage Kruskal-Wallis tests. To compare the rates of arsenic, iron, and manganese detection in the bedrock and surficial aquifers, the data were transformed into categorical values of “above” or “below” the detection level (data for this test were available from Maine, New Hampshire, and Rhode Island only). Contingency-table analysis was used to determine whether any of the constituents occurred at different frequencies in either of the aquifers at the $\alpha = 0.05$ level. Contingency-table analysis was also used to test for independence between the two explanatory variables, lithogeochemical group, and major land-use category, which were used to analyze the bedrock-well water-quality data. The null hypothesis for this test is that the distribution of the data in the categories of one variable is not affected by the classification of another

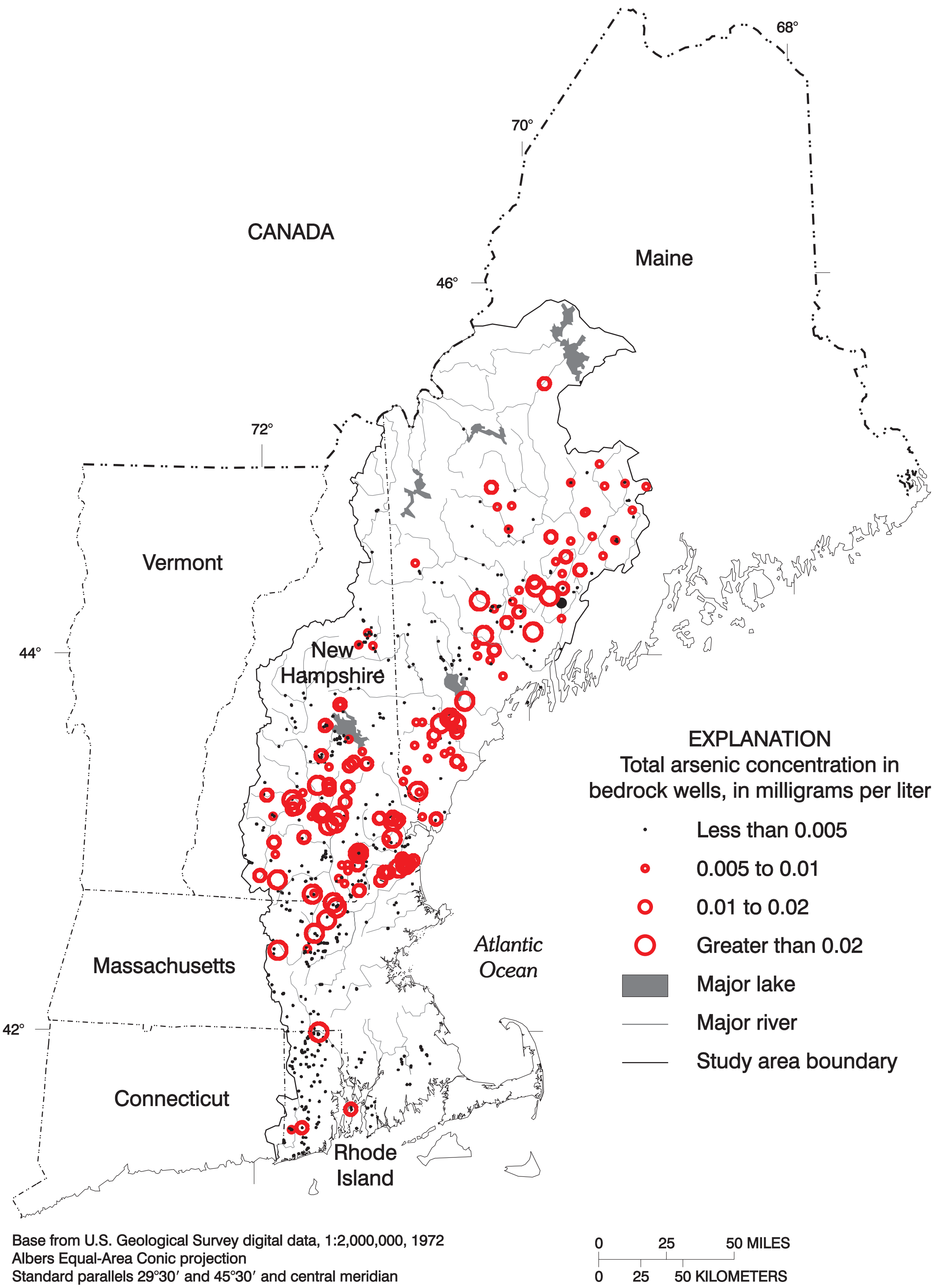


Figure 4a. Areal distribution of arsenic concentrations in water from selected bedrock wells.

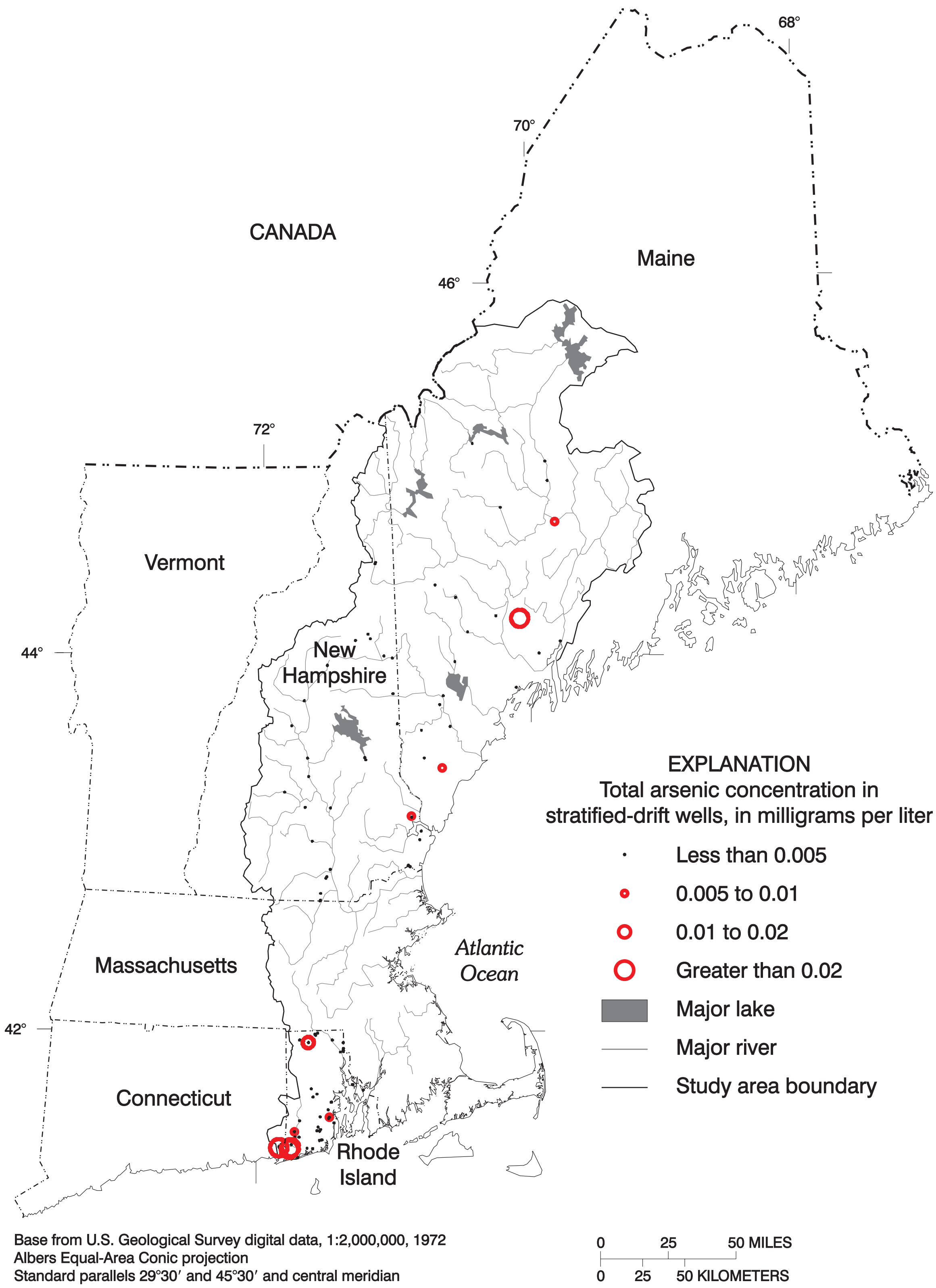


Figure 4b. Areal distribution of arsenic concentrations in water from selected stratified-drift wells.

variable (Helsel and Hirsch, 1992). Rejection of the null hypothesis indicates that the variables are dependent.

Kruskal-Wallis tests on the ranks of the data were run to test the null hypothesis that the water-quality data from all the lithogeochemical groups or land-use categories are from the same population. The null hypothesis is that there is no significant difference between the means of the ranks of the concentrations of a chemical constituent among the major lithogeochemical or land-use groups. This test does not indicate, however, which groups have higher or lower values of a constituent than others. To detect specific significant differences between populations in pairs of lithogeochemical groups, a subsequent multiple-stage Kruskal-Wallis test was used. This multiple-stage test is valid only if the null hypothesis was rejected by the initial Kruskal-Wallis test.

The general linear model (GLM) procedure (SAS Institute Inc., 1990) provides a method of testing each mean from each group against all other means in a non-parametric test, the Tukey test. This test is equivalent to a multiple-stage Kruskal-Wallis test when performed on the ranks of the data and is valid for unequal sample sizes in each group (Helsel and Hirsch, 1992). This test controls for experiment-wise errors rather than comparison-wise (pair-wise) errors; the comparison-wise error rate is dependent on the number of means (number of independent variables) being compared, and will be much less than the overall error rate. The ability to detect significant differences in the means of the ranks of data for three or more groups of explanatory variables is maintained at the desired alpha level by controlling the experiment-wise error rate; if comparison-wise errors were controlled, the overall experiment-wise error rate would increase and could lead to a false sense of confidence in the results. Methods for computing the comparison-wise error rates are given by Helsel and Hirsch (1992). For all possible pair-wise comparisons, the Tukey test uses the within-group variance to calculate the minimum difference in mean rank that is necessary to consider groups significantly different (SAS Institute Inc., 1990). For all hypothesis tests in this study, rejection of the null hypothesis requires that the attained significance level (p) is less than 0.05. Lastly, rank-order correlation (Spearmans rho) was used to determine if the concentrations of arsenic, iron, and manganese were associated.

RELATION OF ARSENIC, IRON, AND MANGANESE IN GROUND WATER TO AQUIFER TYPE, LITHOGEOCHEMISTRY, AND LAND USE

Ground-water quality in natural systems is a result of many environmental factors. Climate, geology, biochemistry, composition of atmospheric precipitation, and the nature of the hydrology are among the more important factors (Hem, 1985). Hem (1985) also notes that the source of most dissolved ions in natural waters is the mineral assemblages in the rocks near the land surface. Rock composition is only one of many related geologic factors; other geologic factors, such as nature of minerals, texture, porosity, and regional structure, can affect the composition of waters (Hem, 1985, Robinson, 1997). Ground-water quality in the stratified-drift and bedrock aquifers of New England evolves according to similar reaction types but differs primarily in the degree of chemical evolution (Rogers, 1989). Rogers (1989) further notes that the bedrock-aquifer waters are more chemically evolved probably because of longer contact time between the water and the aquifer matrix in the bedrock aquifer than in the stratified-drift aquifer. In the New England Coastal Basins study unit, aquifer type, bedrock lithology, and land use are expected to play an important role in the chemical character of ground water. This section focuses on how existing water-quality data relate to geologic and land-use factors on a regional scale.

Occurrence of Arsenic, Iron, and Manganese by Aquifer Type

The frequency of detection of arsenic, iron, and manganese was compared between stratified-drift and the bedrock aquifers in the study unit. Water-quality data were available for 145 public-supply wells in stratified-drift aquifers in Maine, New Hampshire, and Rhode Island. These were compared to data from 607 bedrock public-supply wells in those same states (table 3). Arsenic, at concentrations of 0.005 mg/L or greater, was detected in 7.6 percent of the 145 public-supply wells in the stratified-drift aquifers and in 25.5 percent of the public-supply wells in the bedrock aquifers (fig. 5, table 3). Results of contingency-table analysis indicate that the detection rate of arsenic in the two aquifer types is significantly different ($p = 0.0001$). This is consistent with previous studies (Marvinney and others, 1994; Peters and others, 1999). The detection rates for iron and manganese, however, are virtually identical and the contingency-table test indicates no difference by aquifer type for either constituent.

The difference in detection rate by aquifer type could be related to the type of aquifer materials, differences in ground-water residence times, and geochemical factors related to contact time and redox conditions. Shallow, surficial wells are more likely to

Table 3. Percent of wells in stratified-drift and bedrock aquifers in the New England Coastal Basins study unit yielding water with detectable concentrations of arsenic, iron, and manganese, and Chi-square statistics

[mg/L, milligrams per liter]

Chemical (detection limit)	Percent detected		Chi-square statistic	p-value
	Surficial aquifer (145 wells)	Bedrock aquifer (607 wells)		
Arsenic (As) (0.005 mg/L)	7.6	25.5	21.65	0.0001
Iron (Fe) (.05 mg/L)	59.8	56.7	.300	.584
Manganese (Mn) (.03 mg/L)	45.8	44.4	.064	.801

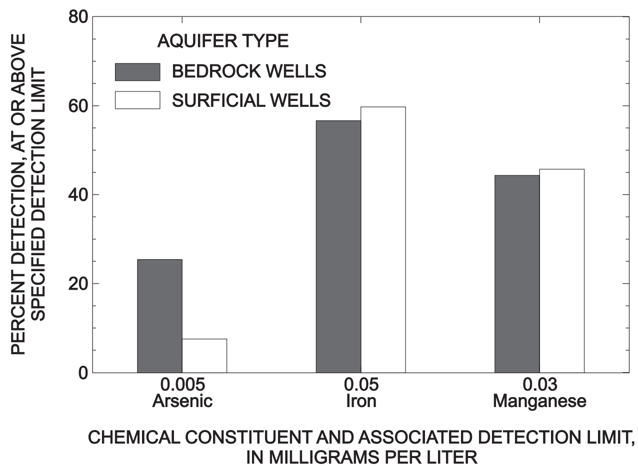


Figure 5. Percent detection of arsenic, iron, and manganese concentrations in ground water by aquifer type.

contain measurable dissolved oxygen, have lower pH, and the reaction-path length is short. In deep bedrock wells, the water is more likely to be in contact with the aquifer materials for a long time, have higher pH, and redox conditions tend to be reducing.

Occurrence of Arsenic, Iron, and Manganese by Lithogeochemical Group

Arsenic, at concentrations of 0.005 mg/L or greater, was detected in 20.4 percent of the 804 public-supply wells in the bedrock aquifer; however, the frequency of arsenic detection is significantly different among the six major lithogeochemical groups defined in this study (fig. 6, table 4). Analysis of arsenic concentrations in water from wells associated with the 6 lithogeochemical groups shows that 44 percent of the water samples from wells in the metasedimentary lithogeochemical group M_c (primarily calcareous or calc-silicate rocks) had arsenic detections at or above the 0.005 mg/L level, whereas water samples from wells in the other 5 lithogeochemical categories had arsenic detections of 28 percent or less. Thus, in group M_c, which extends from northern Massachusetts through southeastern New Hampshire and northeastward into Maine, arsenic is detected in water from public-supply wells about 2 to 10 times the rate of detection in water from public-supply wells in the other major lithogeochemical groups (fig. 6). In the northern half of the study unit, rock units in group M_c underlie some of the most populated parts of those states, including southeastern and coastal New Hampshire and south-coastal Maine (Flanagan and others, 1999, fig. 16a). Water from the igneous lithogeochemical group I_f, (mostly felsic igneous rocks; primarily granites) had an overall arsenic detection rate of 11.9 percent (table 4).

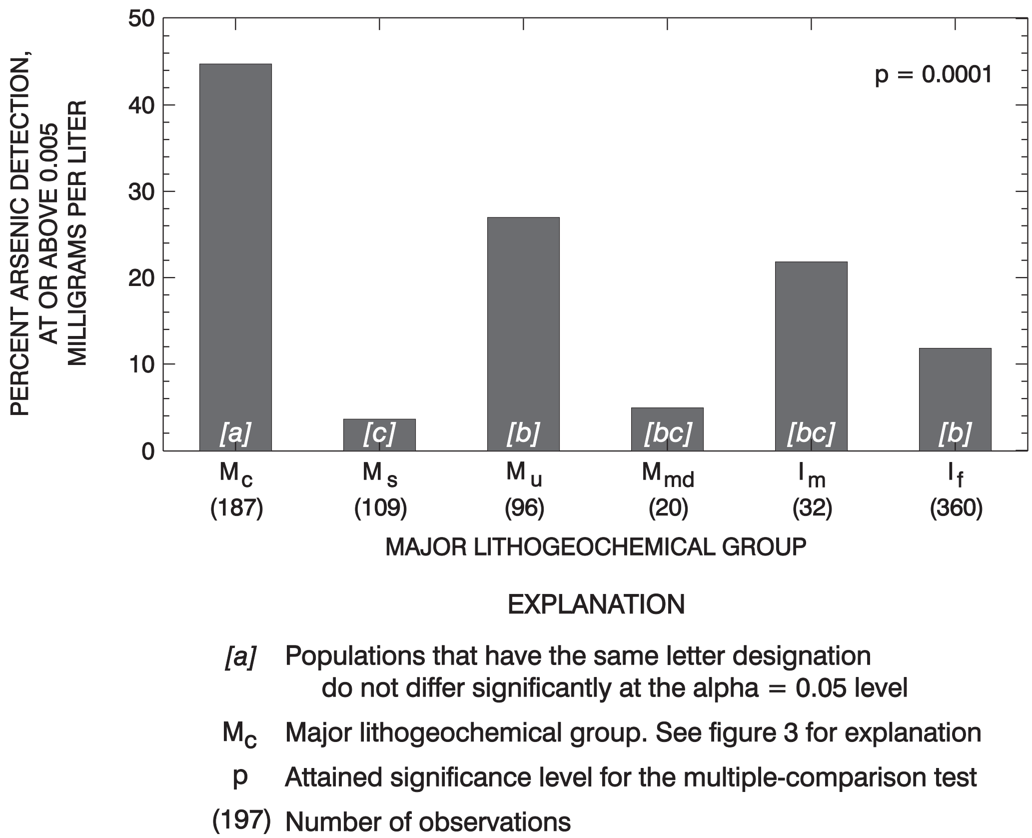


Figure 6. Percent detection of arsenic concentrations in ground water, at or above 0.005 milligrams per liter, in selected bedrock geologic units in lithogeochemical group M_c.

Table 4. Summary statistics for concentrations of arsenic, iron, and manganese in ground water by major lithogeochemical group in the New England Coastal Basins study unit

[mg/L, milligrams per liter; <, less than]

Major litho-geochemical group	Number of wells	Percent at or above detection limit			Percentiles								
					Arsenic (mg/L)			Iron (mg/L)			Manganese (mg/L)		
		Arsenic (0.005 mg/L)	Iron (0.05 mg/L)	Manga-nese (0.03 mg/L)	50th	75th	Maxi-mum	50th	75th	Maxi-mum	50th	75th	Maxi-mum
M_c	187	44.4	51.6	49.7	< 0.005	0.008	0.058	0.05	0.13	7.42	< 0.03	0.07	3.53
M_s	109	3.7	73.2	75.6	< .005	< .005	.018	.14	.47	4.69	.06	.1	2.2
M_u	96	27.1	52.6	52.6	< .005	.005	.176	.05	.13	6.16	.03	.09	.4
M_{md}	20	5.0	80.0	70	< .005	< .005	.016	.335	1.09	38.9	.12	.29	.62
I_m	32	22.0	61.9	42.9	< .005	< .005	.046	.07	.24	1.5	< .03	.08	5.88
I_f	360	11.9	52	36.8	< .005	< .005	1.1	.05	.17	21.6	< .03	.06	3.29

Many of the arsenic concentrations above the detection limit in water from wells in group I_f were associated with specific intrusive igneous rocks with anomalously high arsenic levels (Peters and others, 1998; Peters and others, 1999).

Arsenic detections in water from wells in the metasedimentary group M_s was the lowest, at 4 percent. Many sulfide minerals commonly contain arsenic, and when oxidized, could contribute arsenic to ground water (A.H. Welch, written commun., April 1999). The low frequency of detection suggests that sorption of arsenic on iron-oxide precipitates, or other solubility controls, may limit the concentration of arsenic in drinking water derived from aquifers in group M_s. Because of the limitations of using public-supply drinking water data for this analysis, certain biases could be responsible for the low detection of arsenic in these variably sulfidic bedrock aquifers. One such bias could be that drinking-water wells are not drilled as commonly in the aquifers of the metasedimentary group M_s. Another could be that wells are placed in order to avoid certain parts of these rock types.

Seven of the 804 wells yielded water with maximum reported arsenic concentrations that ranged from greater than the USEPA MCL of 0.05 mg/L to 1.1 mg/L. Four of these wells were in group M_c and three were in group I_f.

Kruskal-Wallis tests indicate a significant difference in concentrations of arsenic in ground water between different lithogeochemical groups (table 5, p = 0.0001). Results of subsequent multiple comparisons of means tests (Tukey) of arsenic concentrations by lithogeochemical group indicate, by pair-wise comparison, which groups are different from the others. Results are shown in figure 6 and indicate that arsenic concentrations in water from wells in the group M_c (fig. 6, [*a*]) were significantly higher than concentrations in the other five groups ([*b*] and [*c*]) and that there was no significant difference in the concentrations among the other five groups with one exception: the concentrations of arsenic in water from wells in group M_s [*c*] were significantly lower than in water in wells in group M_u [*b*].

Within the metasedimentary group M_c, most of the geologic units (rock formations and formation members) have a high percentage of wells with water containing detectable arsenic (fig. 7). These units, although commonly quite variable in composition within any given unit, are grouped as calcareous or calc-silicate rocks according to descriptive information on the state bedrock geologic maps of Maine (Osberg and others, 1985), New Hampshire (Lyons and others, 1997), Massachusetts (Zen and others, 1983), and Rhode Island (Hermes and others, 1994). The Madrid Formation in Maine, and an unnamed member of the Berwick Formation in New Hampshire, have detectable arsenic in ground water from 75 percent or more of the wells in their respective units (fig. 7).

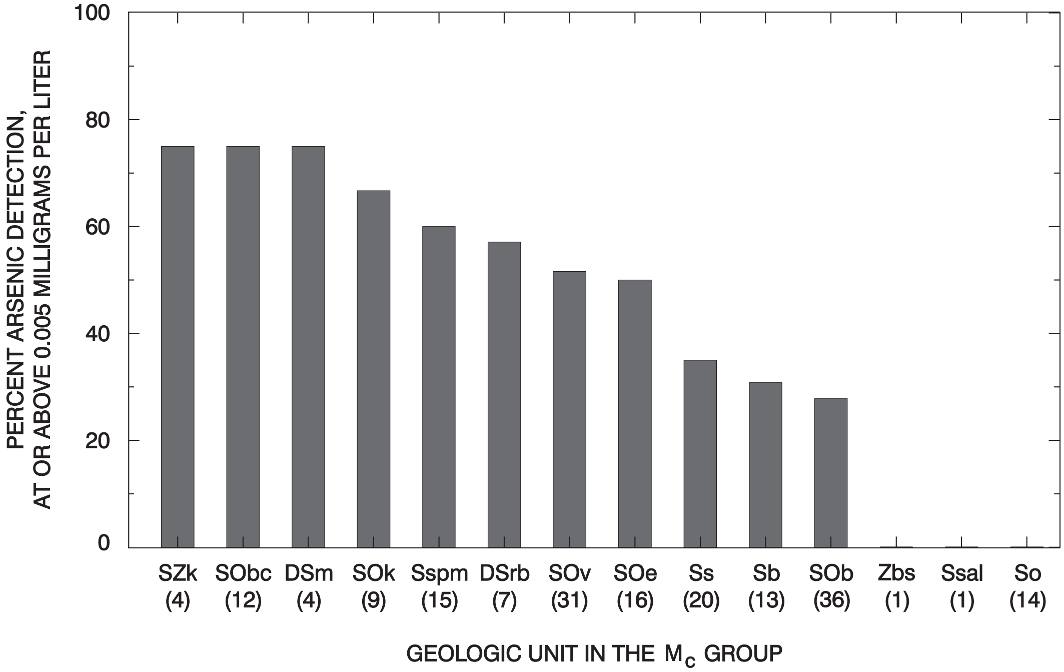
Table 5. Summary of attained significance levels (p-values) for Kruskal-Wallis tests of the concentrations of water-quality variables compared by lithogeochemical and land use variables in the New England Coastal Basins study unit

[p-values, the probability that the observed differences are due to chance rather than the factor tested, are for SAS General Linear Models Type III sum of squares (SAS Institute Inc., 1990); p-values significant at a = 0.05 are shown in bold; --, none computed]

Water-quality variable	Factor	
	Lithogeochemistry	Land use
Arsenic	**0.0001**	**0.0128**
Iron	**0.0023**	--
Manganese	**0.0002**	--

Variation in the occurrence of iron and manganese was analyzed by lithogeochemical group. Kruskal-Wallis analysis showed significant differences in iron concentration by lithogeochemical group (table 5), and a subsequent multiple comparison test (Tukey) showed that water from wells in group M_s [*a*] had significantly greater concentrations than water from wells in group M_c [*b*] and group I_f [*b*] (fig. 8). Concentrations of iron in water from wells in groups M_u, M_{md}, and I_m [*ab*] were not significantly different from those in water from any other lithogeochemical group. The highest median concentration of iron was in water from wells in group M_{md}; however, only 10 samples were collected from wells in this lithogeochemical group (fig. 8).

A Kruskal-Wallis test on the manganese data also indicates differences in concentration by lithogeochemical group (table 6). For manganese, the multiple comparison test (Tukey) showed that water from wells in the group M_s [*a*] had significantly higher concentrations of manganese than did water from wells in the group I_f [*b*], but that manganese in water from the other four groups [*ab*] was not significantly different from water from groups M_s and I_f (fig. 8).



EXPLANATION

(10) Number of samples

Bedrock geologic units in decreasing order of arsenic detection

SZk	Kittery Formation, Maine
SObc	Berwick Formation, unnamed member, New Hampshire
DSm	Madrid Formation, Maine
SOk	Kittery Formation, New Hampshire
Sspm	Sangerville Formation, Patch Mountain Member, Maine
DSrb	Rindgemere Formation, lower member, Maine
SOv	Vassalboro Formation, Maine
SOe	Eliot Formation, New Hampshire
Ss	Sangerville Formation, Maine
Sb	Berwick Formation, Massachusetts
SOb	Berwick Formation, New Hampshire
Zbs	Blackstone Group, Rhode Island
Ssal	Sangerville Formation, Anasagunticook Member, Maine
So	Oakdale Formation, Massachusetts

Figure 7. Percent detection of arsenic concentrations in ground water, at or above 0.005 milligrams per liter, in selected bedrock geologic units in lithogeochemical group M_c. [Bedrock geologic unit names from Lyons and others, 1997; Hermes and others, 1994; Osberg and others, 1985; and Zen and others, 1983; Lithogeochemical group described in figure 3.]

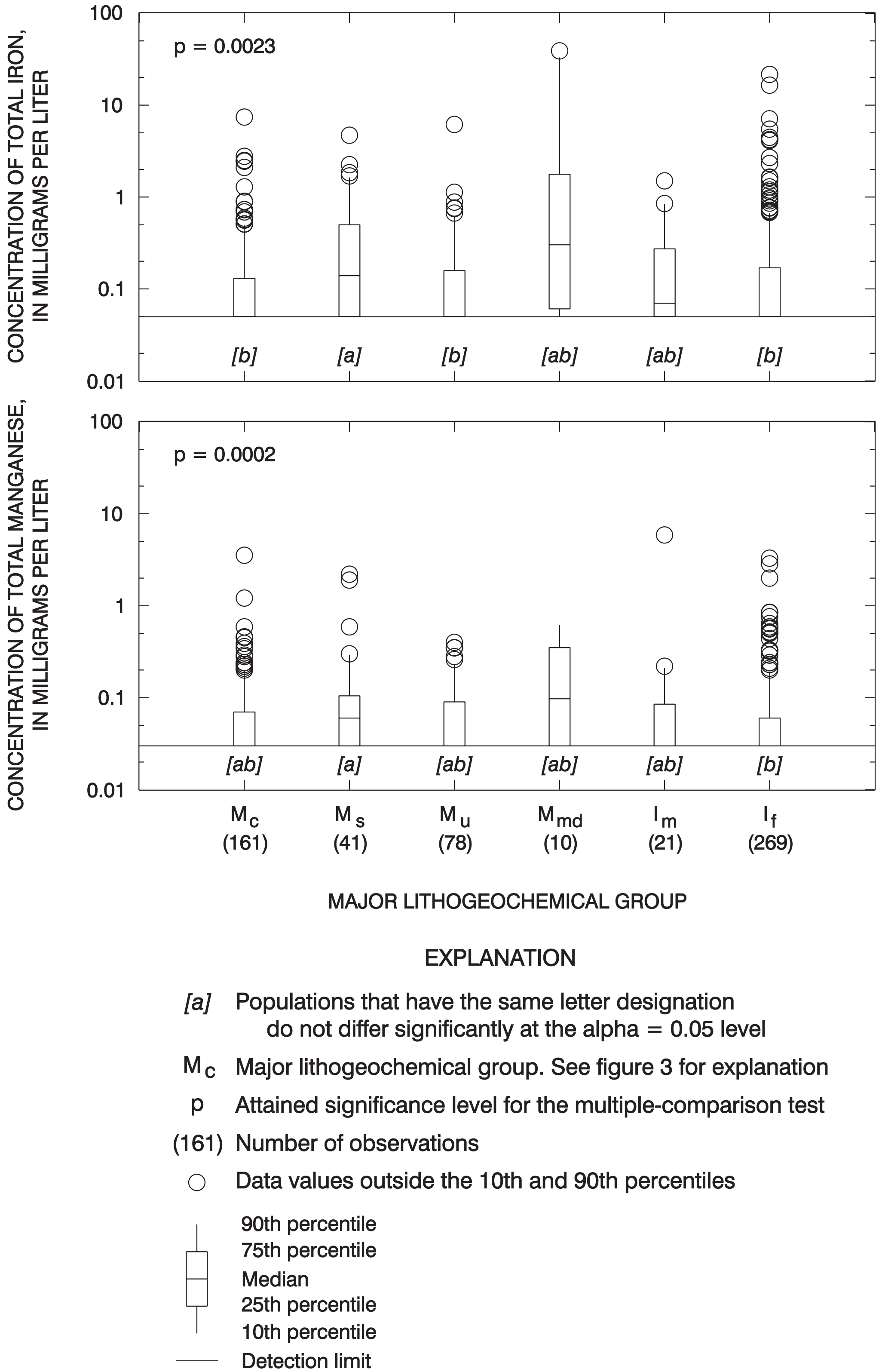


Figure 8. Iron and manganese concentrations in ground water by major lithogeochemical group.

Table 6. Summary of Spearman's rho rank-correlation coefficients for concentrations of arsenic and iron, arsenic and manganese, and iron and manganese in the New England Coastal Basins study unit

[Significant correlations, the probability that the observed correlations are due to the relation tested rather than to chance, at alpa =0.05, are shown in bold; see figure 3 for lithogeochemical group explanation]

Lithogeochemical group	Spearman's correlation coefficients for correlation of well water concentrations of		
	Arsenic and iron	Arsenic and manganese	Iron and manganese
M_c	0.03362	0.16096	**0.60472**
M_s	.05433	.10787	**.77128**
M_u	-.10321	.02278	.31353
M_{md}	-.05838	-.41248	**.86072**
I_m	-.01091	-.06781	.26320
I_f	-.01490	.02278	**.47104**

The variability of iron and manganese concentrations in ground water by lithogeochemical groups could be related to differences in iron and manganese concentrations in rock groups and the relative abundance of iron and manganese minerals that react with water. Sulfide-mineral oxidation and dissolution is identified as being a potential source for sulfate and metals concentrations in bedrock ground waters (Hem, 1985; Drever, 1988; Robinson, 1997). The Tukey analyses indicated that concentrations of iron and manganese were higher in water from the metasedimentary group M_s than in the other metasedimentary groups.

To test if arsenic concentrations are related to iron or manganese concentrations in the data set, Spearman's rank-correlation coefficients were calculated for the arsenic concentrations with iron and manganese concentrations, as well as between iron and manganese. The arsenic concentrations are weakly correlated with iron concentrations in every lithogeochemical group; however, the correlation is positive for two of the groups of metasedimentary rocks and is negative for groups M_u, M_{md}, I_m, and I_f (table 6, fig. 9). Arsenic concentrations are also weakly correlated to manganese concentrations and the correlation is positive for three of the four metasedimentary groups. Iron and manganese concentrations are almost always strongly correlated, except for samples in the igneous group I_m, and these correlation were all significant (p = 0.0001). Iron and manganese are strongly correlated in three of the four metasedimentary groups. The fact that the correlation coefficients in these metasedimentary categories are similar (table 6) and that arsenic concentrations differ

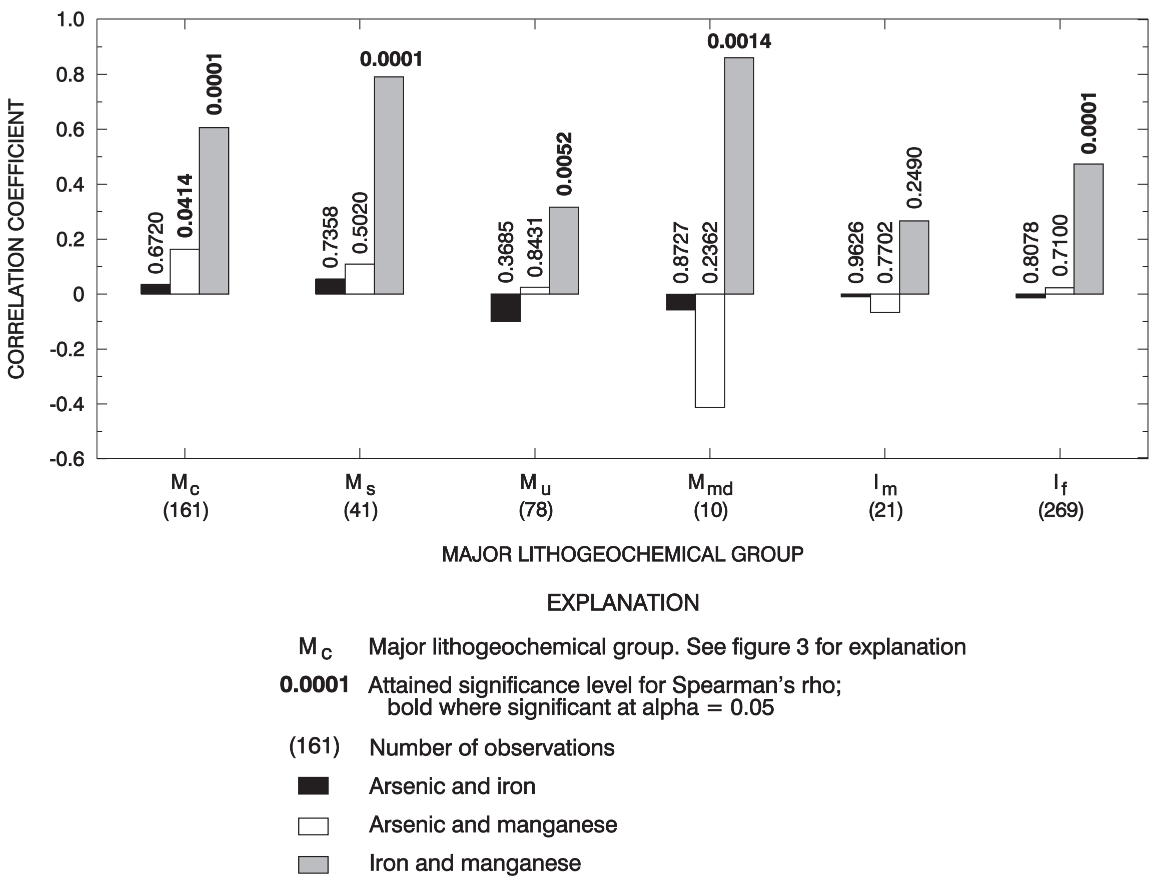


Figure 9. Correlation of arsenic and iron, arsenic and manganese, and iron and manganese concentrations in ground water by major lithogeochemical group in the New England Coastal Basins study unit.

widely among water samples from these same categories indicates that high iron and manganese concentrations are not good indicators of high arsenic concentrations in ground water from these public-supply wells. These relations suggest that simple dissolution of arsenic-bearing iron sulfides and hydroxides probably does not account for arsenic concentrations in ground water from bedrock.

Anomalous Concentrations of Arsenic By Bedrock Geologic Unit

The lithogeochemical associations discussed above show strong correlations of arsenic to the metasedimentary lithogeochemical group M_c; however, some variation at the geologic formation scale from State geologic maps is present. The six lithogeochemical groups used in this report to analyze arsenic occurrence and distribution were defined on the basis of existing rock unit data on State bedrock geologic maps of Maine (Osberg and others, 1985), New Hampshire (Lyons and others, 1997), Massachusetts (Zen and others, 1983), and Rhode Island (Hermes and others, 1994) in the study unit. In two lithogeochemical groups that show statistically low concentrations of arsenic in water, wells in five rock units, as shown on the State bedrock geologic maps, yield water with high arsenic concentrations. Three of these rock units are in the igneous group I_f (fig. 3) and include the Concord Granite, Spaulding Tonalite, and the Winnipesaukee Tonalite (Lyons and others, 1997); and two, the Waterville Formation, in Maine (Osberg and others, 1985), and the Rangeley Formation, lower part, in New Hampshire (Lyons and others, 1997), are part of the metasedimentary group M_u (fig. 3). This section describes those geologic units where greater than 25 percent of wells in the unit yield water with detectable arsenic concentrations at or above 0.005 mg/L.

Wells in three rock units in the igneous group I_f yield water with anomalous (greater than 25 percent detection at 0.005 mg/L) arsenic detections; arsenic was detected in water from 47 percent of the wells in the Concord Granite, from 31 percent of wells in the Spaulding Tonalite, and from 29 percent in the Winnipesaukee Tonalite; wells in these bedrock units yield water with arsenic detections at more than twice the overall detection rate of 12 percent for igneous group I_f (fig. 10). Wells in the Concord Granite yield water with a detection rate for arsenic (47 percent) similar to the overall rate for wells completed in the metasedimentary group M_c (44 percent detection rate) (fig. 6). Thus, the detection rate for arsenic in water from the Concord Granite is approximately three times the detection rate for water from the entire I_f group. Peters and others (1998) also found anomalously high arsenic concentrations in domestic bedrock wells completed in the Concord Granite. These concentrations are attributed to natural sources of arsenic in the bedrock based on geochemical analysis of whole-rock samples and geochemical leach tests of several rock types (Peters and others, 1999).

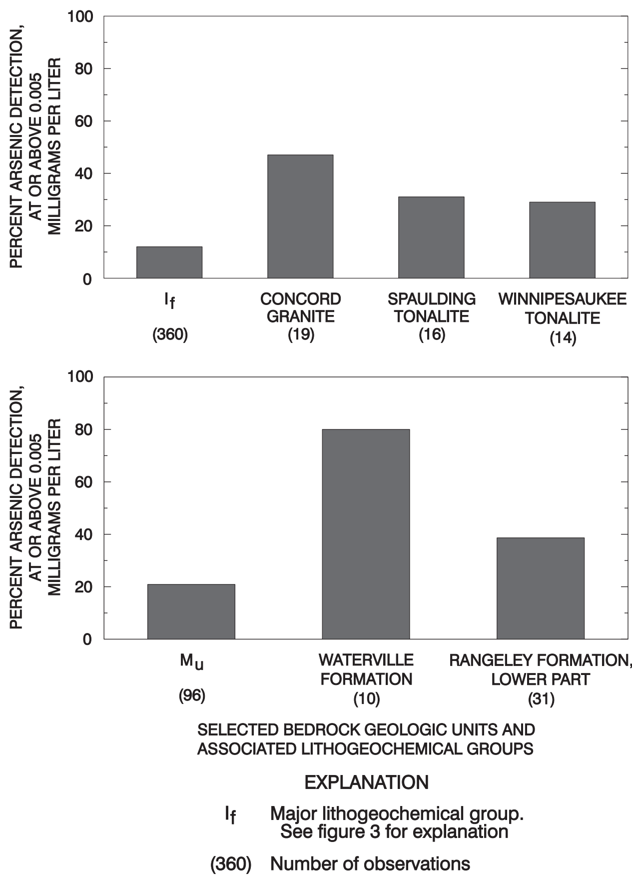


Figure 10. Percent detection of arsenic concentrations, at or above 0.005 milligrams per liter, in ground water, by selected bedrock geologic units and their associated lithogeochemical groups.

Within the M_u group, 80 percent of the wells in the Waterville Formation and 39 percent of the wells in the lower part of the Rangeley Formation, yielded water with detectable arsenic concentrations; the Waterville Formation had a rate of more than twice the overall detection rate (28 percent) from well water from the M_u group (fig. 10). The Waterville Formation, with 8 of the 10 wells in this lithology having water with detectable arsenic, has the highest rate of detection of all bedrock geologic units in the study unit. This rate (80 percent) is more representative of detection rates of arsenic in water from geologic units in the M_c group (fig. 7) than rates of detection in the M_u group.

The two bedrock units with the highest concentrations of arsenic in well water (the Concord Granite and the lower part of Rangeley Formation are located primarily in central New Hampshire) and are adjacent to each other (fig. 11).

Relation of Arsenic in Ground Water to Land Use and Lithology

Previous studies (Boudette and others, 1985; Marvinney and others, 1994; Zeuna and Keane, 1985) have suggested a possible link between land use, specifically the historical application of large amounts of arsenical pesticides in agricultural areas, and arsenic detections in ground water. The present study used a land-use coverage (scale 1:250,000) compiled from high-altitude aerial photographs from the late 1960's and early 1970's (fig. 12), when the use of arsenical pesticides was being phased out, to try to determine whether there is a relation between that pesticide use and the water-quality data compiled for this report. The land-use data are classified into Level I and II land-use categories (Anderson and others, 1976). These data were obtained in digital form in a Geographic Information Retrieval and Analysis System (GIRAS) described in Hitt (1994). Level I data include broad categories such as Urban, Agriculture, and Undeveloped. Level II further classifies land use; for example, agriculture is classified into categories such as cropland and orchards. The bedrock-well arsenic data were compared by major categories of land use (Anderson Level I) including urban, agriculture, and undeveloped land uses (fig. 13). A Kruskal-Wallis test of arsenic concentrations by land use alone is significant ($p = 0.0128$), although this was not as strong as the lithogeochemical relation. Results of a subsequent multiple comparison of means test of ground-water-arsenic concentrations by land-use category indicated that concentrations of arsenic in the agricultural land-use category [*a*] are significantly higher than concentrations in the undeveloped category [*b*], but are not significantly different from the urban category [*ab*] (fig. 13). Land use was determined by identifying the particular land-use polygon in which the well was located.

The GIRAS data was used because no earlier land-use coverage was available, but that data base may not accurately represent agricultural land use between 1920 and 1950 when arsenical pesticides were used on orchards and potatoes in the study area. Agricultural lands could have been urbanized or reverted back to forests by the time of the GIRAS photography and thus would not be represented by this data set.

Another point to consider when comparing historical land-use data with ground-water-quality data representing current conditions is that the ground water may have travelled significant distances from the land use that affected the water quality. Ground water with high arsenic concentrations derived from a specific land-use activity could now be located under a different land-use type. This could also account for a weaker relation between ground-water arsenic concentrations and land use than between ground-water arsenic concentrations and lithogeochemical data.

A qualitative test was done to assess the significance of the land-use arsenic relation: the detection-rate bar graph by lithogeochemical category was recomputed with and without the water-quality data from the agricultural land-use category (fig. 14a). The percentages of detection of arsenic at the 0.005 mg/L level by lithogeochemical group for all of the data is virtually identical to the percentages without the data in the agricultural category. This indicates that if the effect of land use is removed, the geologic (lithogeochemical) relation still holds. Similarly, the land-use category comparison was also redone without the data from the wells in the metasedimentary group M_c and these bars were plotted with the original data (fig. 14b). This plot shows that the frequency of detection of arsenic is significantly less in all three categories; however, it is still higher in the agricultural category than in the urban and forested category. This relation indicates that a significant amount of the variance in arsenic concentrations is probably the effect of the lithogeochemical group M_c rather than agricultural land use; however, some amount of the variance can be attributed to land use.

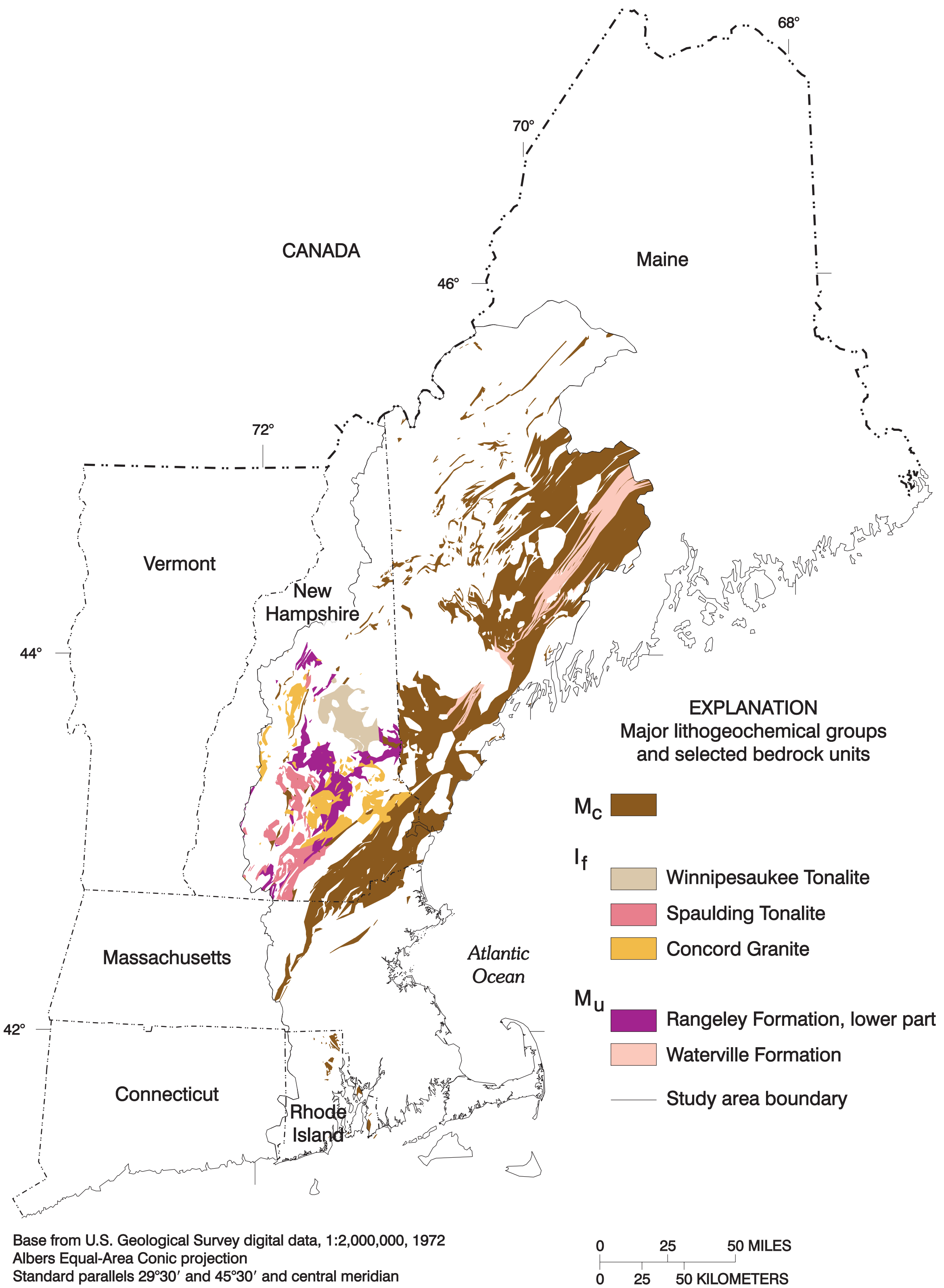


Figure 11. Areal distribution of selected bedrock geologic units, and their associated lithogeochemical groups that have anaomalous arsenic concentrations in ground water. [Lithogeochemical groups are explained in figure 3. Bedrock units are from Lyons and others, 1997; Hermes and others, 1994, Osberg and others, 1985; and Zen and others, 1983.]

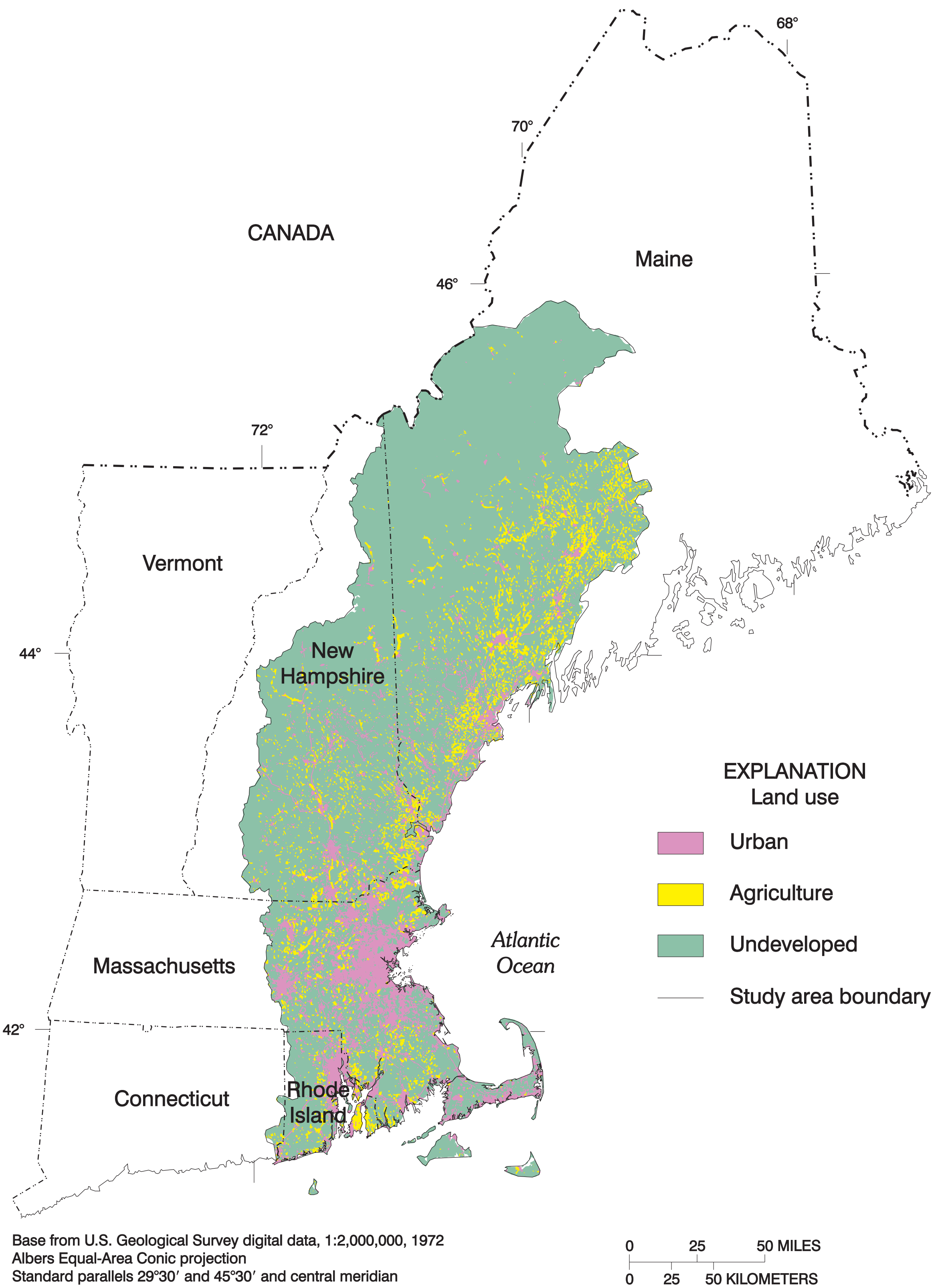


Figure 12. Areal distribution of major land-use categories. (From Flanagan and others, 1999)

To test for independence between geology and land use, a contingency table test was computed as a measure of association between the two variables. The results show that the variables (three land-use and six lithogeochemical variables) are not independent ($p = 0.001$). The analysis showed significantly more agricultural land use in the metasedimentary groups M_c and M_{md} than in the other groups. Agricultural land use was significantly lower in group M_s than in the other lithogeochemical groups. These associations indicate that geology and land use are related and, therefore, should not be treated as if they were independent variables.

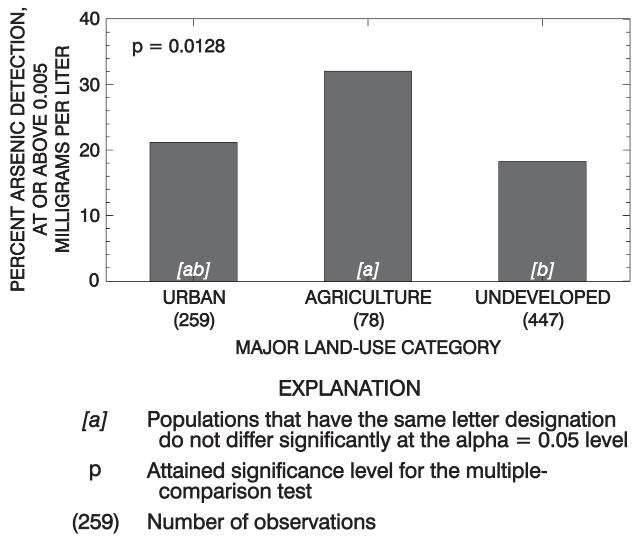


Figure 13. Percent detection of arsenic concentrations in ground water, at or above 0.005 milligrams per liter, by major land-use category.

Possible Sources of, and Controls on, Arsenic in Ground Water

Two categories of sources for arsenic in ground water in New England are (1) natural geologic sources, including arsenic-containing sulfide minerals, or arsenic contained in trace amounts in other minerals present in rocks, and (2) anthropogenic sources, primarily considered to be from past (early 1900's to the 1960's) arsenical-pesticide use.

Some investigators in this region have suggested relations between likely geologic sources of arsenic and ground-water-arsenic concentrations; none, however, have found a relation between arsenic concentrations in ground water and the presence of calcareous and calc-silicate rocks. Stream sediment chemistry data (Grossman, 1998) from the National Uranium Evaluation Program (NURE), for the Massachusetts portion of the NECB study unit, show higher concentrations of arsenic in stream sediments in small drainage basins underlain by the metasedimentary group M_c compared to other lithogeochemical groups. Whole-rock arsenic concentrations are commonly higher in sulfidic rocks than in other rock types, and high arsenic concentrations are commonly associated with sulfidic rocks in New England (U.S. Environmental Protection Agency, 1981). Hitchcock (1878) noted many localities in New Hampshire where occurrences of arsenic minerals (arsenopyrite) have been reported. Arsenopyrite is reported as occurring throughout Rockingham County, which is largely underlain by rocks of the M_c group. Hitchcock also noted several other towns that are reported to have occurrences of arsenopyrite, but many of these towns do not have known arsenic problems in ground water. Some studies have suggested possible relations between rusty-weathering schists (associated with sulfidic rocks) (Boudette and others, 1985) and natural sulfides in rocks (Zeuna and Keane, 1985) and high ground-water arsenic concentrations in New England. More recently, data show that arsenic-bearing minerals are found in granite pematites within the Concord-type granite in central New Hampshire in areas of elevated arsenic in bedrock ground water (Peters and others, 1999; Peters and others, 1998).

The presence of arsenic in water from wells in bedrock aquifers, and the variation of these arsenic concentrations among major lithogeochemical groups of bedrock units, indicates bedrock could be a source for at least some of the arsenic; anthropogenic sources of arsenic are also possible in some instances, but the relative importance and the interrelation of the two sources are not clear. Few whole-rock geochemical data exist for the rock types in the lithogeochemical groups where elevated arsenic concentrations are present in ground water. Without such data, the effect of the specific bedrock types on arsenic concentrations in ground water cannot be determined. In northern Massachusetts, central New Hampshire, and in Maine, a few whole-rock geochemistry analyses detected concentrations of arsenic ranging from 30-700 ppm. These analyses indicate that the rocks could provide a natural source of arsenic to ground water, and some of the rocks with elevated arsenic concentrations occur near areas with elevated concentrations of arsenic in ground water.

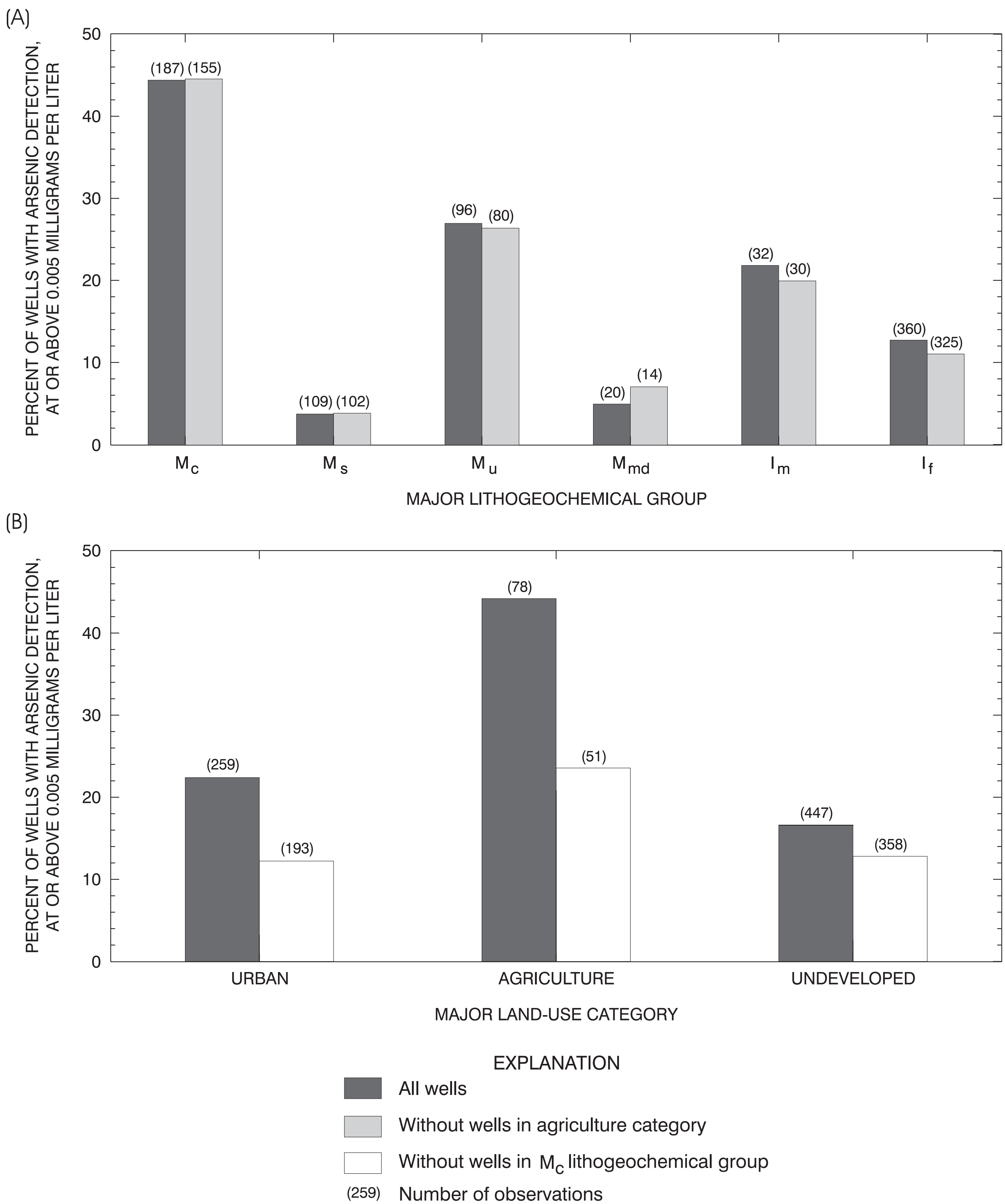


Figure 14. Percent detection of arsenic concentrations in ground water by lithogeochemical group and major land-use category; (a) major lithogeochemical group with and without wells in the agricultural category, and (b) major land-use category with and without wells in the M_c lithogeochemical group. (Major lithogeochemical groups are described in figure 3.)

The statistical analysis developed in this report measures the degree of spatial association between arsenic in ground waters used for public drinking-water supply and landscape features such as bedrock geology and land use. The causes and processes responsible for controlling arsenic concentrations in ground water are not well defined for the region. In addition, all the factors underlying the statistical associations presented are unclear, but probably include the following four elements: (1) the distribution and chemical form of arsenic in soils and rocks that are part of the ground-water-flow system, (2) the characteristics that influence the solubility and transport of arsenic in ground water, (3) the differing degrees of vulnerability of ground-water supplies to surface contamination, and (4) the spatial associations between land use, geology, and ground-water-flow patterns. In addition, the use of data from public water-supply wells eliminates analytical data from non-potable ground waters (with higher dissolved solid loads or with water that does not meet regulatory standards) that may differ with respect to spatial and chemical association patterns from the potable ground waters in the region.

The application of the observed spatial-association patterns toward a predictive model for the occurrence and distribution of arsenic in drinking water from bedrock aquifers will benefit from an understanding of the chemical, physical, and land-use factors and processes that control and significantly influence the solubility of arsenic in ground water.

Arsenic in Water from Public-Supply Wells and Future Drinking-Water Standards

The National Academy of Sciences recommends that the current standard for arsenic in drinking water be lowered in order to protect public health (National Academy of Sciences, 1999). The 1996 Safe Drinking Water Act requires the USEPA to revise the existing drinking-water standard (0.05 mg/L) for arsenic. Currently (1999), the USEPA is evaluating lowering this level and must have a proposal to revise the MCL by 2000 and a final rule by 2001 (U.S. Environmental Protection Agency, 1998b). Data from the 804 public bedrock supply wells used in this study indicate that 4 percent of all wells have arsenic concentrations above 0.02 mg/L, 9 percent have arsenic concentrations above 0.01 mg/L, and 19 percent have arsenic concentrations above 0.005 mg/L. This indicates that for a subset of public-supply wells used in this study, depending on the limit in the final rule, the drinking-water standard would be excluded.

The percent of wells that will potentially exceed the drinking-water standard, however, is likely to vary significantly depending on the lithogeochemical group of the aquifers in which the well is drilled. For wells drilled in the metasedimentary group M_c, 8 percent of wells yield water with arsenic concentrations above 0.02 mg/L, 20 percent yield water with arsenic concentrations above 0.01 mg/L, and 41 percent yield water with arsenic concentrations above 0.005 mg/L. The percent of wells exceeding 0.005, 0.01, and 0.02 mg/L, respectively, by lithogeochemical groups of bedrock aquifers and for the bedrock aquifers of the entire study unit are shown in table 7.

Table 7. Percent of wells yielding water with arsenic concentrations exceeding 0.005, 0.01, and 0.02 milligrams per liter by lithogeochemical group in the New England Coastal Basins study unit

[mg/L, milligrams per liter]

Major lithogeochemical group	Percent of wells with arsenic exceeding		
	0.005 mg/L	0.01 mg/L	0.02 mg/L
M_c	41	20	8
M_s	4	2	0
M_u	24	10	4
M_{md}	5	5	0
I_m	22	9	9
I_f	11	6	3
Overall (all groups—804 wells)	19	9	4

This study focused primarily on water-quality data for samples from public-supply wells in the bedrock aquifer; however, past studies of arsenic in bedrock ground water in the study area focused primarily on domestic-well data. Arsenic data from privately-supplied ground water from domestic bedrock wells needs to be considered because of the large amount of drinking water that these wells supply (approximately 36 percent of all ground-water use). Additionally, this self-supplied ground-water use is not subject to regulation by USEPA and many of these users do not test for, or treat for, arsenic in their water. Peters and others (1998) show, in graphical form, that about 25 percent of domestic bedrock wells tested for arsenic in New Hampshire yielded water with arsenic concentrations that exceed 0.005 mg/L, 17 percent yielded water with arsenic concentrations that exceed 0.01 mg/L, and 11 percent yielded water with arsenic concentrations that exceed 0.02 mg/L.

Some states recommend testing for arsenic in water from all private domestic bedrock-supply wells. The State of New Hampshire (New Hampshire Department of Environmental Services, 1998) recommends that water from bedrock wells be tested for arsenic and radon. In Massachusetts, local Boards of Health can require testing to determine if water meets drinking-water standards (Massachusetts Department of Environmental Protection, 1998). The Maine Bureau of Land and Water Quality issued a 'Safe Home' fact sheet that similarly recommends that home owners test their wells for contaminants including trace inorganic constituents (Maine Bureau of Land and Water Quality, 1998).

SUMMARY AND CONCLUSIONS

Arsenic concentrations in public-supply wells in the New England Coastal Basins at or above 0.005 mg/L were detected in more samples of water from wells completed in bedrock (25 percent of all samples) than in water from wells completed in stratified drift (7.5 percent of all samples). Iron and manganese were detected (at concentrations of 0.05 mg/L and 0.03 mg/L, respectively) at approximately the same frequency in water from wells in both types of aquifers.

The concentration of arsenic in bedrock public-supply wells has been evaluated relative to lithogeochemical data generalized from state bedrock geologic maps in the New England Coastal Basins study unit. Arsenic concentrations were significantly higher in water from wells in the metasedimentary rock group M_c than in five other groups of rocks in the study unit. Arsenic was detected, at concentrations of 0.005 mg/L or above, in ground water from 44 percent of the wells in group M_c and less than 28 percent in the other 5 groups. Additionally, arsenic concentrations were the lowest in the metasedimentary group M_s.

Arsenic concentrations in bedrock wells also correlate with land use; significantly higher concentrations are found in areas identified as agricultural land use than in undeveloped and urban land uses. The attained significance level for the land-use relation ($p = 0.0123$), however, is lower than for the geologic relation ($p = 0.0001$). Additionally, geologic and land-use data appear to be correlated to one another; specifically, there is more agricultural land use in the metasedimentary groups M_c and M_{md} than in other lithogeochemical groups. Relations between arsenic concentrations and lithogeochemical groups of bedrock units remained the same when arsenic data associated with agricultural land were removed from the analysis. However, the relations between arsenic concentration and agricultural land use were weakened when arsenic data from group M_c were removed.

The correlation of arsenic in bedrock ground water could be the result of various factors including (1) arsenic in soils and rocks that are part of the ground-water-flow system, (2) solubility and transport controls of arsenic in ground water, (3) vulnerability of ground-water supplies to surface contamination, and (4) the spatial associations between land use, geology, and ground-water-flow patterns. Two possible general sources for arsenic in ground water in New England are (1) natural geologic sources, including arsenic-containing sulfide minerals, or arsenic contained in trace amounts in other minerals present in rocks, and (2) anthropogenic sources, primarily considered to be from past (early 1900's to the 1960's) arsenical-pesticide usage.

The presence of arsenic in water from wells in bedrock aquifers, and the variation of these arsenic concentrations in wells in major lithogeochemical groups and in some bedrock units indicates a bedrock source is probable for at least some of the arsenic in the water. Anthropogenic sources could also be contributing to the concentrations of arsenic in ground water; however, the relative importance and interrelation of the anthropogenic and geologic sources is unclear. Few whole-rock geochemical data exist for the rock types in the lithogeochemical groups where elevated arsenic concentrations are present in ground water. The few available whole-rock and ground-water analyses from northern Massachusetts, central New Hampshire, and in southern Maine, indicate that, at least locally, a spatial connection between bedrock chemistry and concentrations of arsenic in ground water. Without additional data, however, the quantitative effect of the specific bedrock types on arsenic concentrations in ground water cannot be determined. The interdependence of lithogeochemical group and land-use indicates that additional data are needed to explain the cause of the arsenic concentrations in ground water. If ground-water flow over time has resulted in the movement of ground water with measurable arsenic from agricultural land use to other land-use types, this could also account for the lack of a strong relation between land use and arsenic. The low levels of arsenic in the metasedimentary group M_s indicate that the arsenic in bedrock ground water cannot be explained by simple dissolution of arsenic-bearing iron sulfides.

The anomalous ground-water arsenic detections in water wells from a few, small, bedrock units highlight some exceptions to the regional-scale generalizations presented in this report. More detailed examination of these anomalies, using additional water-quality data for wells in the current data set, and data from domestic wells, could improve the resolution of the model and the understanding of what controls sources and solubility of arsenic.

The statistical relations determined for arsenic concentration and lithogeochemistry are reasonably strong, but interpretation of the results is limited by the nature of the data set. Current data do not allow the cause of arsenic in ground water to be determined, nor is it possible to predict the occurrence and distribution of arsenic in ground water. By using data from public water-supply wells, non-potable ground waters (with high dissolved solid loads or with water that does not meet regulatory standards) that could differ with respect to spatial and chemical association patterns from the potable ground waters in the region were not included in the analysis. The relation of arsenic concentration to lithogeochemical groups, using this data set, does, however, provide an important beginning to understanding arsenic source and solubility controls. Geochemical data from rocks, more complete water-quality data, time-line studies of arsenic concentrations, and site-specific studies, will be critical in determining the source of, and controls on, arsenic in ground water.

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APPENDIX

Appendix 1. Geologic, land-use, and chemical data for bedrock wells in the New England Coastal Basins study unit

[No., number; ° ′ ″, Latitude and longitude are given in degrees, minutes, seconds; Major lithogeochemical groups are described in figure 3; Bedrock map units are from the following State geologic maps: Osberg and others, 1985; Lyons and others, 1997; Zen and others, 1983; and Hermes and others, 1994; mg/L, milligrams per liter; Major land-use groups use the following abbreviations: Undev, undeveloped; Urb, urban; Ag, agricultural; <, actual value is less than value shown; --, no data available]

Unique well identification No.	Latitude (° ′ ″)	Longitude (° ′ ″)	Geologic data		Land-use data	Chemical data		
			Major litho-geochemical group	Bedrock map unit	Major land use group	Arsenic (mg/L)	Iron (mg/L)	Manganese (mg/L)
RHODE ISLAND								
1000007-1	415235	0713807	I_f	Zha	Undev	<0.005	0.07	<0.03
1000007-2	415236	0713807	I_f	Zha	Undev	<0.005	<0.05	<0.03
MASSACHUSETTS								
2034010-01G	422658	0713758	M_u	St	Urb	0.009	--	--
2125000-02G	422943	0713513	M_u	St	Undev	<0.005	<0.05	<0.03
2147001-01G	423123	0714221	M_u	Sp	Undev	<0.005	--	--
2151000-01G	421836	0715454	M_u	Sp	Ag	<0.005	--	--
2151000-02G	421832	0715454	M_u	Sp	Ag	<0.005	--	--
2151000-03G	421838	0715450	M_u	Sp	Undev	<0.005	--	--
2151004-01G	421530	0715323	M_u	Sp	Undev	<0.005	--	--
2151009-01G	421316	0715224	M_u	Sp	Ag	<0.005	--	--
2151009-02G	421314	0715223	M_u	Sp	Urb	<0.005	--	--
2151009-03G	421313	0715222	M_u	Sp	Urb	<0.005	--	--
3038021-01G	424147	0705923	M_u	OZf	Undev	<0.005	--	--
2147001-02G	423123	0714218	M_u	DSw	Undev	<0.005	--	--
2162002-01G	423549	0714057	M_u	DSw	Undev	<0.005	--	--
2162002-03G	423548	0714103	M_u	DSw	Undev	<0.005	--	--
2162002-04G	423549	0714104	M_u	DSw	Undev	<0.005	--	--
2162003-01G	423538	0714019	M_u	DSw	Undev	<0.005	--	--
2125000-03G	422927	0713456	M_s	SZtb	Urb	<0.005	--	--
2017003-03G	421238	0714833	M_s	SObo	Urb	<0.005	--	--
2017003-04G	421238	0714833	M_s	SObo	Urb	<0.005	1.70	2.20
2002003-01G	423038	0712526	M_s	OZn	Urb	<0.005	--	--
2002003-02G	423039	0712525	M_s	OZn	Urb	<0.005	--	--
2002005-01G	423014	0712510	M_s	OZn	Undev	<0.005	--	--
2002006-01G	423023	0712520	M_s	OZn	Urb	<0.005	--	--
2002006-02G	423020	0712522	M_s	OZn	Urb	<0.005	--	--
2002009-01G	423035	0712524	M_s	OZn	Urb	<0.005	--	--
2002009-02G	423037	0712528	M_s	OZn	Urb	<0.005	--	--
2002010-01G	422919	0712458	M_s	OZn	Urb	<0.005	--	--
2002012-01G	423037	0712514	M_s	OZn	Urb	<0.005	--	--
2002014-01G	422934	0712457	M_s	OZn	Urb	<0.005	--	--
2002014-02G	422935	0712455	M_s	OZn	Urb	<0.005	--	--
2002018-01G	423148	0712411	M_s	OZn	Undev	<0.005	--	--
2017003-01G	421248	0714815	M_s	OZn	Urb	<0.005	<0.05	<0.03
2017003-02G	421248	0714816	M_s	OZn	Urb	<0.005	1.20	1.90
2017005-01G	421241	0714822	M_s	OZn	Urb	<0.005	--	--
2017009-01G	421239	0714827	M_s	OZn	Urb	<0.005	<0.05	0.05

Appendix 1. Geologic, land-use, and chemical data for bedrock wells in the New England Coastal Basins study unit—Continued

Unique well identification No.	Latitude (° ′ ″)	Longitude (° ′ ″)	Geologic data: Major litho-geochemical group	Geologic data: Bedrock map unit	Land-use data: Major land use group	Chemical data: Arsenic (mg/L)	Chemical data: Iron (mg/L)	Chemical data: Manganese (mg/L)
MASSACHUSETTS--*Continued*								
2017009-02G	421238	0714830	M_s	OZn	Urb	<0.005	--	--
2028001-01G	422346	0713611	M_s	OZn	Undev	<0.005	<0.05	<0.03
2028005-01G	422250	0713825	M_s	OZn	Urb	<0.005	--	--
2028005-02G	422250	0713825	M_s	OZn	Urb	<0.005	--	--
2028007-01G	422216	0713801	M_s	OZn	Undev	<0.005	--	--
2028007-02G	422215	0713801	M_s	OZn	Undev	<0.005	--	--
2028007-03G	422215	0713803	M_s	OZn	Undev	<0.005	--	--
2028007-04G	422218	0713806	M_s	OZn	Undev	<0.005	--	--
2028008-01G	422128	0713724	M_s	OZn	Ag	<0.005	<0.05	<0.03
2034009-01G	422553	0713634	M_s	OZn	Undev	<0.005	<0.05	<0.03
2034014-01G	422533	0713452	M_s	OZn	Undev	<0.005	--	--
2034018-01G	422628	0713322	M_s	OZn	Undev	<0.005	--	--
2034021-01G	422559	0713637	M_s	OZn	Undev	<0.005	--	--
2037001-01G	422852	0713309	M_s	OZn	Undev	<0.005	--	--
2037001-02G	422853	0713308	M_s	OZn	Undev	<0.005	--	--
2037002-01G	422932	0713254	M_s	OZn	Undev	<0.005	--	--
2037002-02G	422942	0713239	M_s	OZn	Undev	<0.005	--	--
2037002-03G	422927	0713252	M_s	OZn	Undev	<0.005	--	--
2037002-04G	422938	0713249	M_s	OZn	Undev	<0.005	--	--
2037002-05G	422937	0713250	M_s	OZn	Undev	<0.005	--	--
2037006-01G	422853	0713051	M_s	OZn	Urb	<0.005	--	--
2037007-01G	422934	0713234	M_s	OZn	Undev	<0.005	--	--
2037007-02G	422934	0713234	M_s	OZn	Undev	<0.005	--	--
2037008-01G	422851	0713247	M_s	OZn	Undev	<0.005	--	--
2037008-02G	422853	0713244	M_s	OZn	Undev	<0.005	--	--
2037008-03G	422853	0713243	M_s	OZn	Undev	<0.005	--	--
2037008-04G	422855	0713241	M_s	OZn	Undev	<0.005	--	--
2037009-01G	422857	0713058	M_s	OZn	Undev	<0.005	--	--
2037010-01G	422855	0713022	M_s	OZn	Undev	<0.005	--	--
2037013-01G	422852	0712934	M_s	OZn	Undev	<0.005	--	--
2037013-02G	422848	0712923	M_s	OZn	Undev	<0.005	--	--
2037013-03G	422853	0712917	M_s	OZn	Undev	<0.005	--	--
2037014-01G	422850	0712943	M_s	OZn	Undev	<0.005	--	--
2037017-01G	422907	0713225	M_s	OZn	Undev	<0.005	--	--
2037017-02G	422905	0713224	M_s	OZn	Undev	<0.005	--	--
2037017-03G	422908	0713216	M_s	OZn	Undev	<0.005	--	--
2037020-01G	422902	0713210	M_s	OZn	Undev	<0.005	--	--
2037020-02G	422901	0713210	M_s	OZn	Undev	<0.005	--	--
2037023-01G	422839	0713318	M_s	OZn	Undev	<0.005	--	--
2037025-01G	423047	0713208	M_s	OZn	Undev	<0.005	--	--
2037025-02G	423046	0713208	M_s	OZn	Undev	<0.005	--	--

Appendix 1. Geologic, land-use, and chemical data for bedrock wells in the New England Coastal Basins study unit—Continued

Unique well identification No.	Latitude (° ′ ″)	Longitude (° ′ ″)	Geologic data: Major litho-geochemical group	Geologic data: Bedrock map unit	Land-use data: Major land use group	Chemical data: Arsenic (mg/L)	Chemical data: Iron (mg/L)	Chemical data: Manganese (mg/L)
MASSACHUSETTS--*Continued*								
2037026-01G	422909	0713210	M_s	OZn	Undev	<0.005	--	--
2037028-01G	422857	0713053	M_s	OZn	Urb	<0.005	--	--
2141004-01G	422357	0713556	M_s	OZn	Undev	<0.005	--	--
2141004-02G	422359	0713558	M_s	OZn	Undev	<0.005	--	--
2286002-01G	422613	0713101	M_s	OZn	Undev	<0.005	--	--
2286005-01G	422629	0713027	M_s	OZn	Undev	<0.005	--	--
2286006-01G	422614	0713113	M_s	OZn	Undev	<0.005	--	--
2286007-01G	422615	0713032	M_s	OZn	Urb	<0.005	--	--
2286018-01G	422625	0713015	M_s	OZn	Undev	<0.005	--	--
2286018-02G	422626	0713013	M_s	OZn	Undev	<0.005	--	--
2286021-01G	422609	0713024	M_s	OZn	Urb	<0.005	--	--
2286022-01G	422609	0713024	M_s	OZn	Urb	<0.005	--	--
2330002-01G	423442	0712350	M_s	OZn	Undev	<0.005	--	--
2330020-01G	423406	0712442	M_s	OZn	Urb	<0.005	--	--
3051012-01G	423147	0712107	M_s	OZn	Undev	<0.005	--	--
4146005-01G	415107	0705653	M_{md}	Pr	Urb	<0.005	--	--
4146031-01G	415159	0705711	M_{md}	Pr	Ag	<0.005	--	--
4146045-01G	415300	0705550	M_{md}	Pr	Undev	<0.005	--	--
4146045-02G	415256	0705552	M_{md}	Pr	Undev	<0.005	--	--
4247001-01G	415052	0711431	M_{md}	Pr	Ag	<0.005	--	--
4247004-01G	415410	0711259	M_{md}	Pr	Urb	<0.005	--	--
4247015-01G	414925	0711634	M_{md}	Pr	Urb	<0.005	--	--
4247011-01G	415202	0711523	M_{md}	Pd	Urb	<0.005	--	--
4247049-01G	415149	0711415	M_{md}	Pd	Undev	<0.005	--	--
2034004-03G	422617	0713906	M_c	So	Urb	<0.005	0.13	<0.03
2034004-04G	422558	0713850	M_c	So	Undev	<0.005	<0.05	<0.03
2034004-05G	422545	0713924	M_c	So	Undev	<0.005	--	--
2034022-01G	422726	0713833	M_c	So	Ag	<0.005	--	--
2125002-01G	422918	0713716	M_c	So	Ag	<0.005	--	--
2125002-02G	422916	0713722	M_c	So	Ag	<0.005	--	--
2125002-03G	422916	0713726	M_c	So	Ag	<0.005	--	--
2125002-04G	422911	0713716	M_c	So	Urb	<0.005	--	--
2125008-01G	422908	0713717	M_c	So	Undev	<0.005	--	--
2125008-02G	422908	0713718	M_c	So	Undev	<0.005	--	--
2125011-01G	422859	0713721	M_c	So	Undev	<0.005	--	--
2125011-02G	422859	0713720	M_c	So	Undev	<0.005	--	--
2270009-01G	423814	0713621	M_c	So	Undev	<0.005	--	--
2270009-02G	423815	0713618	M_c	So	Undev	<0.005	--	--
2301014-01G	424039	0712531	M_c	Sb	Urb	<0.005	--	--
2301027-01G	423916	0712600	M_c	Sb	Undev	<0.005	--	--
2301027-02G	423915	0712600	M_c	Sb	Undev	<0.005	--	--

Appendix 1. Geologic, land-use, and chemical data for bedrock wells in the New England Coastal Basins study unit—Continued

Unique well identification No.	Latitude (° ′ ″)	Longitude (° ′ ″)	Geologic data		Land-use data	Chemical data		
			Major litho-geochemical group	Bedrock map unit	Major land use group	Arsenic (mg/L)	Iron (mg/L)	Manganese (mg/L)
				MASSACHUSETTS--*Continued*				
2301027-03G	423915	0712602	M_c	Sb	Undev	<0.005	--	--
2301032-01G	424024	0712529	M_c	Sb	Undev	<0.005	0.51	0.29
2301033-01G	424011	0712512	M_c	Sb	Undev	0.020	--	--
2301033-02G	424011	0712511	M_c	Sb	Undev	0.020	--	--
2301035-01G	424039	0712440	M_c	Sb	Undev	<0.005	--	--
2301036-01G	424057	0712445	M_c	Sb	Undev	<0.005	--	--
2301037-02G	424148	0712634	M_c	Sb	Urb	0.025	--	--
2301037-03G	424148	0712634	M_c	Sb	Urb	0.025	--	--
2301038-01G	424103	0712654	M_c	Sb	Undev	<0.005	--	--
2301038-02G	424108	0712651	M_c	Sb	Undev	<0.005	--	--
3269024-01G	421450	0712212	I_m	Zv	Urb	<0.005	--	--
2179001-01G	420614	0713311	I_m	Zb	Urb	<0.005	--	--
2179019-01G	420708	0713509	I_m	Zb	Undev	<0.005	--	--
2188005-01G	420142	0713447	I_m	Zb	Urb	<0.005	--	--
3038020-01G	423836	0705831	I_m	Ssqd	Undev	<0.005	<0.05	<0.03
2286019-01G	422418	0713138	I_m	OZnb	Urb	<0.005	--	--
3038001-03G	424107	0710008	I_m	OZnb	Undev	<0.005	0.05	5.88
2077005-02G	420521	0714640	I_f	Zsg	Undev	<0.005	<0.05	<0.03
2077006-01G	420044	0714620	I_f	Zsg	Undev	<0.005	--	--
2110003-01G	421058	0713840	I_f	Zsg	Undev	<0.005	--	--
4003002-01G	414400	0705322	I_f	Zpgr	Ag	<0.005	--	--
4003002-02G	414359	0705323	I_f	Zpgr	Ag	<0.005	--	--
4003004-01G	414355	0705440	I_f	Zpgr	Urb	<0.005	--	--
2304008-01G	420621	0713632	I_f	Zpg	Undev	<0.005	--	--
2304009-01G	420343	0714006	I_f	Zpg	Undev	<0.005	--	--
2110002-01G	421151	0714040	I_f	Zhg	Ag	<0.005	--	--
2290015-01G	420859	0714411	I_f	Zhg	Urb	<0.005	--	--
2290015-02G	420858	0714410	I_f	Zhg	Urb	<0.005	--	--
2290015-03G	420858	0714410	I_f	Zhg	Urb	<0.005	--	--
2139001-01G	421336	0712807	I_f	Zgr	Undev	<0.005	--	--
2139007-01G	421541	0713221	I_f	Zgr	Undev	<0.005	--	--
2139007-02G	421542	0713222	I_f	Zgr	Undev	<0.005	--	--
2139007-03G	421543	0713222	I_f	Zgr	Undev	<0.005	--	--
2139008-01G	421543	0713139	I_f	Zgr	Undev	<0.005	--	--
4052043-01G	415510	0704815	I_f	Zgg	Undev	<0.005	--	--
4052046-01G	415543	0704841	I_f	Zgg	Ag	<0.005	--	--
4052050-01G	415452	0704812	I_f	Zgg	Undev	<0.005	--	--
4052051-01G	415600	0704841	I_f	Zgg	Undev	<0.005	--	--
4052051-02G	415600	0704841	I_f	Zgg	Undev	<0.005	--	--
4052056-01G	415307	0704554	I_f	Zgg	Undev	<0.005	--	--
4052059-01G	415032	0704448	I_f	Zgg	Urb	<0.005	--	--

Appendix 1. Geologic, land-use, and chemical data for bedrock wells in the New England Coastal Basins study unit—Continued

Unique well identification No.	Latitude (° ′ ″)	Longitude (° ′ ″)	Geologic data		Land-use data	Chemical data		
			Major litho-geochemical group	Bedrock map unit	Major land use group	Arsenic (mg/L)	Iron (mg/L)	Manganese (mg/L)
MASSACHUSETTS--*Continued*								
4052061-01G	415326	0704613	I_f	Zgg	Undev	<0.005	--	--
4146009-02G	415028	0705646	I_f	Zfgr	Undev	<0.005	--	--
4146044-01G	414836	0705828	I_f	Zfgr	Undev	<0.005	--	--
4182003-01G	414925	0705301	I_f	Zfgr	Undev	<0.005	--	--
4182006-01G	414950	0705258	I_f	Zfgr	Undev	<0.005	--	--
3078001-01G	421429	0711633	I_f	Zdgr	Urb	<0.005	--	--
3078007-01G	421413	0711633	I_f	Zdgr	Urb	<0.005	--	--
4334059-02G	413332	0710723	I_f	Zagr	Undev	<0.005	--	--
4334059-03G	413332	0710723	I_f	Zagr	Undev	<0.005	--	--
3205001-03G	424747	0705214	I_f	SOngd	Ag	<0.005	--	--
2002012-02G	423045	0712522	I_f	SOagr	Undev	<0.005	--	--
2002012-03G	423045	0712522	I_f	SOagr	Undev	<0.005	--	--
2002012-04G	423044	0712521	I_f	SOagr	Undev	<0.005	--	--
3295002-01G	423535	0711221	I_f	SOagr	Undev	<0.005	--	--
2301034-02G	423710	0712930	I_f	SOad	Urb	<0.005	<0.05	0.76
2330019-01G	423621	0712928	I_f	SOad	Ag	0.025	--	--
2330019-02G	423621	0712928	I_f	SOad	Ag	0.025	--	--
3164000-05G	423333	0710300	I_f	Sgr	Undev	<0.005	--	--
3164000-06G	423337	0710256	I_f	Sgr	Undev	<0.005	--	--
3164000-07G	423340	0710252	I_f	Sgr	Undev	<0.005	--	--
3164000-08G	423339	0710302	I_f	Sgr	Undev	<0.005	--	--
3160001-01G	423853	0712035	I_f	Sagr	Urb	<0.005	--	--
3160001-02G	423853	0712037	I_f	Sagr	Urb	<0.005	--	--
2125003-01G	423154	0713439	I_f	Sacgr	Ag	<0.005	--	--
2125005-01G	423117	0713352	I_f	Sacgr	Undev	<0.005	<0.05	<0.03
2125012-01G	423152	0713451	I_f	Sacgr	Undev	<0.005	--	--
2125013-01G	423202	0713444	I_f	Sacgr	Undev	1.100	--	--
2012002-01G	424043	0714926	I_f	Dfgrg	Urb	<0.005	<0.05	<0.03
2241007-01G	422656	0715236	I_f	Dfgrg	Urb	<0.005	--	--
2241015-01G	422524	0715243	I_f	Dfgrg	Undev	<0.005	--	--
2012006-01G	424146	0714708	I_f	Dfgr	Ag	<0.005	--	--
2241003-01G	422632	0715036	I_f	Dfgr	Urb	0.077	<0.05	<0.03
2299002-01G	423937	0714724	I_f	Dfgr	Undev	<0.005	--	--
2299003-01G	423911	0714602	I_f	Dfgr	Undev	<0.005	--	--
2299003-02G	423918	0714540	I_f	Dfgr	Undev	<0.005	--	--
2241010-01G	422939	0715300	I_f	Dfgds	Undev	<0.005	--	--
2301020-01G	424018	0712450	I_f	Dcgr	Undev	<0.005	--	--
2301020-02G	424017	0712446	I_f	Dcgr	Undev	<0.005	--	--
2301020-03G	424019	0712447	I_f	Dcgr	Undev	<0.005	--	--

Appendix 1. Geologic, land-use, and chemical data for bedrock wells in the New England Coastal Basins study unit—Continued

Unique well identification No.	Latitude (° ′ ″)	Longitude (° ′ ″)	Geologic data: Major litho-geochemical group	Geologic data: Bedrock map unit	Land-use data: Major land use group	Chemical data: Arsenic (mg/L)	Chemical data: Iron (mg/L)	Chemical data: Manganese (mg/L)
				MAINE				
94413101	443839	0700837	M_u	Ssa	Undev	<0.005	<0.05	<0.03
95630101	442929	0702015	M_u	Ssa	Undev	<0.005	<0.05	0.05
290101	434530	0700055	M_u	OZce	Urb	<0.005	<0.05	0.09
95530101	440221	0694548	M_u	OZce	Undev	<0.005	0.46	0.10
6816101	451258	0702841	M_u	OCAdq	Urb	<0.005	0.08	0.06
94493101	452717	0695139	M_u	OCAdp	Undev	0.015	6.16	0.07
7731101	432032	0705610	M_u	DSra	Undev	0.005	0.18	0.28
3282101	444801	0701338	M_u	Dsd	Undev	0.005	<0.05	<0.03
94456101	442652	0704836	M_u	Dl	Undev	<0.005	<0.05	0.03
94601101	443007	0705048	M_u	Dl	Undev	0.008	<0.05	<0.03
7182101	452736	0693513	M_u	Dcm	Urb	<0.005	<0.05	<0.03
673101	444151	0702503	M_u	Dc	Urb	<0.005	0.88	0.35
8694101	443130	0702757	M_u	Dc	Urb	<0.005	0.26	0.12
100272101	434601	0702834	M_u	Sw	Urb	0.042	<0.05	0.03
148101	433858	0703233	M_u	Sw	Urb	0.176	<0.05	<0.03
5192101	443148	0694257	M_u	Sw	Undev	0.010	0.06	0.03
587101	442626	0694447	M_u	Sw	Undev	0.008	<0.05	<0.03
7245101	445447	0691556	M_u	Sw	Undev	0.007	<0.05	0.13
8778101	434150	0703555	M_u	Sw	Urb	<0.005	0.51	<0.03
93808101	445518	0691559	M_u	Sw	Urb	<0.005	<0.05	0.03
94255101	443815	0693058	M_u	Sw	Ag	0.007	<0.05	0.17
94527101	440213	0701527	M_u	Sw	Undev	0.017	0.24	<0.03
94627101	445459	0691555	M_u	Sw	Ag	0.006	0.07	<0.03
92290101	442731	0704859	M_s	Ssf	Ag	<0.005	<0.05	0.03
337101	432405	0705440	M_s	DSt	Urb	0.007	0.47	0.03
90525101	444055	0700848	M_s	Dst	Undev	<0.005	0.41	0.12
92145101	444055	0700847	M_s	Dst	Undev	<0.005	0.41	0.11
216101	430909	0704750	M_c	SZk	Urb	0.007	0.10	0.05
4400101	430802	0704201	M_c	SZk	Undev	<0.005	0.05	<0.03
4529101	430828	0704140	M_c	SZk	Urb	0.015	0.12	0.22
94404101	432459	0703001	M_c	SZk	Undev	0.006	0.05	<0.03
12101	432647	0703221	M_c	SZb	Urb	0.018	0.06	<0.03
17265101	431658	0704907	M_c	SZb	Undev	0.007	0.10	0.03
87101	431720	0704933	M_c	SZb	Urb	0.025	0.10	0.03
15101	445528	0694020	M_c	Sspm	Urb	<0.005	<0.05	0.07
151101	450123	0692714	M_c	Sspm	Undev	0.008	<0.05	<0.03
156101	444549	0693418	M_c	Sspm	Urb	0.005	<0.05	<0.03
20180101	441759	0702146	M_c	Sspm	Ag	0.034	<0.05	<0.03
23304101	445531	0694025	M_c	Sspm	Undev	0.006	0.07	<0.03
4591101	441450	0701704	M_c	Sspm	Undev	<0.005	0.07	0.05
9087101	440353	0701823	M_c	Sspm	Undev	0.009	<0.05	<0.03

Appendix 1. Geologic, land-use, and chemical data for bedrock wells in the New England Coastal Basins study unit—Continued

Unique well identification No.	Latitude (° ′ ″)	Longitude (° ′ ″)	Geologic data		Land-use data	Chemical data		
			Major litho-geochemical group	Bedrock map unit	Major land use group	Arsenic (mg/L)	Iron (mg/L)	Manganese (mg/L)
MAINE--*Continued*								
9171101	441419	0700416	M_c	Sspm	Undev	0.016	<0.05	<0.03
92150101	441609	0701621	M_c	Sspm	Urb	<0.005	<0.05	0.05
93849101	444607	0693341	M_c	Sspm	Undev	0.007	<0.05	0.04
94022101	441436	0700329	M_c	Sspm	Undev	<0.005	2.78	0.08
94219101	442646	0694959	M_c	Sspm	Urb	<0.005	<0.05	<0.03
94511101	442617	0701347	M_c	Sspm	Undev	<0.005	--	--
95010101	441102	0700946	M_c	Sspm	Undev	0.019	<0.05	<0.03
9728101	442350	0695717	M_c	Sspm	Ag	0.019	<0.05	<0.03
193827101	442116	0700414	M_c	Ssl	Urb	0.006	<0.05	<0.03
623101	442143	0702307	M_c	Ssal	Undev	<0.005	<0.05	<0.03
17508101	441606	0701603	M_c	Ss	Undev	<0.005	<0.05	<0.03
242101	442427	0700223	M_c	Ss	Undev	<0.005	<0.05	<0.03
3116101	441610	0701336	M_c	Ss	Urb	<0.005	<0.05	0.04
3543101	441111	0701413	M_c	Ss	Undev	<0.005	0.06	0.07
380101	442615	0701207	M_c	Ss	Undev	<0.005	0.06	0.15
415101	440700	0701958	M_c	Ss	Undev	0.023	<0.05	0.03
530101	442218	0695627	M_c	Ss	Urb	0.051	2.51	0.13
556101	445417	0692514	M_c	Ss	Undev	0.006	<0.05	0.03
639101	441600	0701341	M_c	Ss	Undev	<0.005	0.19	0.09
7157101	440804	0700737	M_c	Ss	Undev	<0.005	2.45	0.10
83101	442712	0695002	M_c	Ss	Ag	<0.005	<0.05	<0.03
9166101	445837	0693257	M_c	Ss	Undev	<0.005	<0.05	<0.03
93894101	441527	0701528	M_c	Ss	Urb	0.009	<0.05	<0.03
94371101	443242	0694106	M_c	Ss	Urb	<0.005	<0.05	<0.03
94433101	441618	0701319	M_c	Ss	Urb	<0.005	0.10	<0.03
951101	444350	0695733	M_c	Ss	Ag	<0.005	<0.05	<0.03
95260101	443019	0694741	M_c	Ss	Undev	0.006	<0.05	<0.03
95600101	442455	0695518	M_c	Ss	Undev	0.007	<0.05	<0.03
95610101	443652	0694046	M_c	Ss	Undev	0.005	<0.05	<0.03
9731101	441610	0701329	M_c	Ss	Undev	<0.005	0.35	0.06
112825101	433510	0704227	M_c	SOv	Undev	0.013	0.05	0.07
117877101	434042	0703514	M_c	SOv	Urb	0.056	0.73	0.36
145101	444123	0692525	M_c	SOv	Ag	<0.005	0.11	0.05
146101	433647	0703236	M_c	SOv	Urb	<0.005	0.05	<0.03
149101	434049	0703501	M_c	SOv	Urb	0.013	<0.05	<0.03
15854101	444929	0691411	M_c	SOv	Ag	<0.005	0.07	<0.03
175101	442624	0693137	M_c	SOv	Undev	<0.005	<0.05	<0.03
3377101	435924	0700229	M_c	SOv	Undev	<0.005	<0.05	<0.03
3554101	443710	0692008	M_c	SOv	Urb	<0.005	<0.05	<0.03
377101	440756	0695800	M_c	SOv	Urb	0.058	<0.05	0.07
389101	433006	0703515	M_c	SOv	Undev	0.006	0.12	0.22

Appendix 1. Geologic, land-use, and chemical data for bedrock wells in the New England Coastal Basins study unit—Continued

Unique well identification No.	Latitude (° ′ ″)	Longitude (° ′ ″)	Geologic data		Land-use data	Chemical data		
			Major litho-geochemical group	Bedrock map unit	Major land use group	Arsenic (mg/L)	Iron (mg/L)	Manganese (mg/L)
MAINE--*Continued*								
4101	443154	0692625	M_c	SOv	Ag	0.007	<0.05	0.04
4600101	435733	0700101	M_c	SOv	Undev	<0.005	7.42	0.09
613101	445353	0690624	M_c	SOv	Ag	0.007	<0.05	<0.03
642101	443619	0692002	M_c	SOv	Undev	0.007	<0.05	0.04
648101	442352	0694229	M_c	SOv	Urb	0.005	<0.05	<0.03
900642101	443625	0691957	M_c	SOv	Ag	<0.005	<0.05	<0.03
91860101	443641	0692026	M_c	SOv	Undev	<0.005	<0.05	0.03
92190101	443643	0692036	M_c	SOv	Undev	0.007	<0.05	<0.03
92270101	444410	0691220	M_c	SOv	Undev	<0.005	<0.05	<0.03
93297101	444621	0691249	M_c	SOv	Undev	0.005	<0.05	<0.03
93795101	442617	0693910	M_c	SOv	Ag	<0.005	<0.05	<0.03
93874101	442623	0693125	M_c	SOv	Undev	<0.005	<0.05	<0.03
94004101	442142	0694437	M_c	SOv	Urb	0.014	0.56	0.10
94298101	442148	0694433	M_c	SOv	Urb	<0.005	<0.05	<0.03
94320101	433646	0703248	M_c	SOv	Urb	0.007	0.16	0.11
94514101	443644	0692018	M_c	SOv	Urb	<0.005	0.43	<0.03
94563101	444925	0691502	M_c	SOv	Urb	<0.005	0.21	<0.03
94569101	433606	0703219	M_c	SOv	Urb	0.019	0.90	<0.03
95170101	442731	0693642	M_c	SOv	Urb	0.011	0.33	0.03
95570101	443658	0692055	M_c	SOv	Undev	0.007	<0.05	<0.03
107379101	433855	0703925	M_c	DSrb	Undev	0.034	0.69	0.39
12821101	435302	0704809	M_c	DSrb	Undev	<0.005	0.34	<0.03
18559101	433922	0705026	M_c	DSrb	Ag	0.006	0.05	0.06
367101	434344	0704235	M_c	DSrb	Urb	<0.005	0.27	0.23
482101	434536	0705542	M_c	DSrb	Urb	<0.005	<0.05	<0.03
656101	433212	0704324	M_c	DSrb	Undev	0.006	0.12	0.05
94489101	433915	0704747	M_c	DSrb	Undev	0.006	<0.05	<0.03
559101	445414	0701611	M_c	DSm	Urb	0.010	1.29	1.21
90535101	444050	0700845	M_c	DSm	Undev	0.006	0.41	0.11
94174101	445310	0700541	M_c	DSm	Undev	<0.005	<0.05	<0.03
94247101	444819	0700715	M_c	DSm	Undev	0.005	0.13	0.06
104101	440159	0695740	I_m	OZc	Undev	<0.005	0.10	0.09
289101	435015	0695500	I_m	OZc	Undev	<0.005	<0.05	0.09
3374101	435654	0695918	I_m	OZc	Undev	<0.005	<0.05	<0.03
5825101	441209	0694524	I_m	OZc	Ag	0.007	<0.05	<0.03
94414101	432746	0704527	I_m	K8	Undev	0.006	0.12	0.22
104540101	431039	0703759	I_f	K1a	Undev	<0.005	<0.05	<0.03
94557101	441920	0695027	I_f	D4c(m)	Undev	0.052	0.16	<0.03
95697101	442032	0694652	I_f	D4c(m)	Undev	<0.005	<0.05	<0.03
17998101	442354	0703848	I_f	D3	Undev	<0.005	<0.05	<0.03
94213101	442359	0704215	I_f	D3	Urb	<0.005	4.23	2.00

Appendix 1. Geologic, land-use, and chemical data for bedrock wells in the New England Coastal Basins study unit—Continued

Unique well identification No.	Latitude (° ′ ″)	Longitude (° ′ ″)	Geologic data		Land-use data	Chemical data		
			Major litho-geochemical group	Bedrock map unit	Major land use group	Arsenic (mg/L)	Iron (mg/L)	Manganese (mg/L)
			MAINE--*Continued*					
18775101	444942	0702125	I_f	D2(m)	Undev	<0.005	0.09	<0.03
23435101	435703	0705331	I_f	D2	Ag	<0.005	0.42	<0.03
8665101	442153	0693807	I_f	D2	Urb	<0.005	<0.05	<0.03
95685101	442030	0693943	I_f	D2	Urb	<0.005	<0.05	<0.03
340101	441744	0700706	I_f	D1(m)	Ag	0.005	<0.05	<0.03
91900101	432121	0703940	I_f	D1(m)	Urb	<0.005	0.05	<0.03
93887101	443642	0700206	I_f	D1(m)	Undev	<0.005	0.13	0.06
93963101	441806	0700813	I_f	D1(m)	Ag	<0.005	0.33	0.03
94059101	441617	0701254	I_f	D1(m)	Undev	<0.005	0.43	<0.03
585101	433157	0705106	I_f	D1	Ag	0.006	0.20	0.05
594101	443812	0694933	I_f	D1	Ag	0.012	<0.05	<0.03
8656101	440942	0700342	I_f	D1	Ag	<0.005	0.07	0.12
11861101	435313	0702757	I_f	C1b(m)	Urb	<0.005	0.10	<0.03
1412101	441031	0705339	I_f	C1b(m)	Undev	<0.005	0.19	0.03
16686101	435859	0703345	I_f	C1b(m)	Undev	<0.005	<0.05	<0.03
16804101	440012	0703923	I_f	C1b(m)	Undev	<0.005	<0.05	<0.03
195101	435751	0705143	I_f	C1b(m)	Undev	<0.005	<0.05	0.03
198212101	435636	0703720	I_f	C1b(m)	Urb	<0.005	<0.05	<0.03
23878101	435901	0703811	I_f	C1b(m)	Urb	<0.005	<0.05	<0.03
259101	440654	0705835	I_f	C1b(m)	Urb	<0.005	<0.05	<0.03
293101	440509	0704030	I_f	C1b(m)	Undev	<0.005	<0.05	<0.03
3837101	435950	0703929	I_f	C1b(m)	Urb	<0.005	<0.05	<0.03
386101	440720	0705409	I_f	C1b(m)	Ag	<0.005	<0.05	0.23
428101	435902	0701725	I_f	C1b(m)	Undev	0.006	<0.05	<0.03
497101	440352	0702352	I_f	C1b(m)	Urb	0.006	<0.05	<0.03
5028101	435753	0703439	I_f	C1b(m)	Urb	<0.005	0.15	<0.03
5039101	440142	0701814	I_f	C1b(m)	Undev	<0.005	<0.05	<0.03
529101	435614	0702645	I_f	C1b(m)	Undev	<0.005	0.06	<0.03
5665101	440912	0703004	I_f	C1b(m)	Undev	<0.005	<0.05	0.06
658101	441123	0704323	I_f	C1b(m)	Undev	<0.005	<0.05	<0.03
8643101	435353	0701142	I_f	C1b(m)	Undev	0.006	<0.05	<0.03
9192101	435905	0703051	I_f	C1b(m)	Undev	<0.005	<0.05	<0.03
93886101	435750	0701701	I_f	C1b(m)	Urb	<0.005	<0.05	0.09
93972101	440259	0703112	I_f	C1b(m)	Undev	<0.005	0.06	<0.03
93981101	440024	0702302	I_f	C1b(m)	Undev	0.006	<0.05	<0.03
94037101	440044	0703127	I_f	C1b(m)	Ag	<0.005	<0.05	<0.03
94318101	435435	0703030	I_f	C1b(m)	Undev	<0.005	<0.05	<0.03
94457101	435730	0703428	I_f	C1b(m)	Undev	<0.005	<0.05	<0.03
94488101	440031	0703126	I_f	C1b(m)	Ag	<0.005	<0.05	<0.03
94505101	435925	0703840	I_f	C1b(m)	Urb	<0.005	0.67	0.51
94540101	441132	0704158	I_f	C1b(m)	Ag	<0.005	<0.05	<0.03

Appendix 1. Geologic, land-use, and chemical data for bedrock wells in the New England Coastal Basins study unit—Continued

Unique well identification No.	Latitude (° ′ ″)	Longitude (° ′ ″)	Geologic data		Land-use data	Chemical data		
			Major litho-geochemical group	Bedrock map unit	Major land use group	Arsenic (mg/L)	Iron (mg/L)	Manganese (mg/L)
MAINE--*Continued*								
98213101	435612	0703711	I_f	C1b(m)	Urb	<0.005	<0.05	<0.03
108180101	433244	0703536	I_f	C1(m)	Undev	<0.005	0.09	<0.03
12826101	432914	0703803	I_f	C1(m)	Undev	0.006	0.08	0.05
92070101	433412	0703945	I_f	C1(m)	Urb	<0.005	0.31	0.15
NEW HAMPSHIRE								
L15582-1	432836	0713222	M_u	Srl	Urb	0.012	0.09	<0.03
L16357-1	432634	0713101	M_u	Srl	Undev	<0.005	0.09	<0.03
L16517-1	431836	0712029	M_u	Srl	Ag	0.010	0.11	<0.03
L17179-1	432848	0712737	M_u	Srl	Undev	<0.005	0.13	0.03
L19398-1	432724	0713351	M_u	Srl	Urb	<0.005	0.40	0.09
L19519-1	432753	0713325	M_u	Srl	Undev	<0.005	0.09	0.08
L23601-1	432634	0713101	M_u	Srl	Undev	<0.005	0.05	<0.03
L30383-1	432811	0713229	M_u	Srl	Urb	<0.005	<0.05	0.40
L30987-1	432840	0712805	M_u	Srl	Undev	<0.005	0.67	0.15
L33155-3	430839	0712948	M_u	Srl	Undev	0.009	0.05	0.35
L34643-1	432634	0713101	M_u	Srl	Undev	<0.005	0.09	<0.03
L35735-1	432913	0712946	M_u	Srl	Undev	0.007	<0.05	0.21
L36294-1	431754	0712847	M_u	Srl	Urb	0.018	0.75	0.17
L36295-1	431755	0712836	M_u	Srl	Undev	0.008	<0.05	<0.03
L37717-2	432642	0713716	M_u	Srl	Undev	<0.005	0.05	0.13
L39789-3	430053	0713059	M_u	Srl	Urb	<0.005	0.76	0.12
L41568-1	432617	0711142	M_u	Srl	Undev	<0.005	0.08	<0.03
L42127-3	431911	0713349	M_u	Srl	Undev	0.032	<0.05	<0.03
L42658-2	431924	0712851	M_u	Srl	Undev	0.011	<0.05	0.04
L42856-2	432604	0711216	M_u	Srl	Undev	0.010	<0.05	<0.03
L42857-1	431355	0712145	M_u	Srl	Undev	0.010	0.28	0.23
L42901-2	432944	0713503	M_u	Srl	Urb	<0.005	0.34	0.07
L43845-1	432617	0713345	M_u	Srl	Ag	<0.005	1.13	0.23
L44594-3	432500	0712903	M_u	Srl	Undev	0.005	<0.05	<0.03
L45617-2	432701	0713315	M_u	Srl	Undev	<0.005	0.09	0.04
L46018-3	430626	0712845	M_u	Srl	Undev	0.021	<0.05	0.04
L47609-3	432900	0713212	M_u	Srl	Ag	<0.005	<0.05	<0.03
L47866-1	432828	0713353	M_u	Srl	Undev	<0.005	0.08	0.03
L5141-1	433002	0713035	M_u	Srl	Urb	<0.005	0.13	0.03
L5581-1	432730	0713233	M_u	Srl	Undev	<0.005	0.06	0.04
L7689-1	432924	0710129	M_u	Srl	Undev	<0.005	<0.05	<0.03
L26020-1	433231	0712501	M_u	Sp	Urb	<0.005	0.27	0.03
L30668-1	432524	0711955	M_u	Sp	Ag	0.016	0.08	0.06
L50345-1	430847	0711608	M_u	Sp	Urb	<0.005	0.08	<0.03
L6247-1	435307	0713537	M_u	Sp	Undev	<0.005	0.17	<0.03
L42493-3	444651	0710815	M_u	O-Cd	Urb	<0.005	0.06	<0.03

Appendix 1. Geologic, land-use, and chemical data for bedrock wells in the New England Coastal Basins study unit—Continued

Unique well identification No.	Latitude (° ′ ″)	Longitude (° ′ ″)	Geologic data		Land-use data	Chemical data		
			Major litho-geochemical group	Bedrock map unit	Major land use group	Arsenic (mg/L)	Iron (mg/L)	Manganese (mg/L)
NEW HAMPSHIRE--*Continued*								
L42494-3	444649	0710811	M_u	O-Cd	Urb	<0.005	<0.05	<0.03
L43251-3	444710	0710729	M_u	O-Cd	Undev	<0.005	<0.05	0.03
L51208-3	444649	0710811	M_u	O-Cd	Urb	<0.005	<0.05	<0.03
L51209-3	444651	0710815	M_u	O-Cd	Urb	<0.005	<0.05	<0.03
L14614-1	425415	0720235	M_u	Dlu	Ag	<0.005	<0.05	<0.03
L24243-1	425423	0720323	M_u	Dlu	Ag	<0.005	<0.05	<0.03
L27945-1	434444	0714555	M_u	Dlu	Urb	<0.005	<0.05	0.09
L36157-1	434028	0714529	M_u	Dlu	Undev	<0.005	<0.05	<0.03
L36222-3	433650	0714753	M_u	Dlu	Undev	<0.005	0.50	<0.03
L45990-2	434745	0714837	M_u	Dlu	Urb	<0.005	0.13	0.35
L8075-1	433921	0714415	M_u	Dlu	Undev	<0.005	0.07	<0.03
L13248-1	434831	0714032	M_u	Dll	Urb	<0.005	<0.05	<0.03
L32527-1	435515	0714016	M_u	Dll	Undev	<0.005	<0.05	<0.03
L33746-2	425422	0720343	M_u	Dll	Ag	<0.005	<0.05	<0.03
L6430-1	425444	0720404	M_u	Dll	Undev	<0.005	<0.05	0.06
L6432-1	425436	0720405	M_u	Dll	Undev	<0.005	<0.05	0.26
L13777-1	434959	0711942	M_u	Dl	Undev	<0.005	0.62	<0.03
L50459-1	435350	0710912	M_u	Dl	Undev	<0.005	0.30	0.05
L10662-1	433732	0714358	M_s	Ssf	Undev	<0.005	1.41	0.30
L18488-1	441137	0711346	M_s	Ssf	Undev	<0.005	2.25	0.08
L18489-1	440933	0711025	M_s	Ssf	Undev	<0.005	0.12	0.15
L25000-1	432254	0714314	M_s	Ssf	Undev	<0.005	<0.05	<0.03
L42123-2	434655	0713955	M_s	Ssf	Undev	<0.005	0.09	<0.03
L47544-2	441147	0711404	M_s	Ssf	Undev	<0.005	0.12	0.06
L14249-1	433348	0712636	M_s	Sru	Urb	<0.005	0.16	0.05
L14612-1	425640	0720537	M_s	Sru	Urb	<0.005	1.84	0.59
L16322-1	432631	0711804	M_s	Sru	Urb	0.010	0.05	0.06
L23634-1	433341	0712641	M_s	Sru	Urb	<0.005	0.13	<0.03
L24784-1	433127	0713916	M_s	Sru	Undev	<0.005	0.27	0.03
L25715-1	433405	0712534	M_s	Sru	Undev	<0.005	0.14	0.06
L27714-1	433344	0712539	M_s	Sru	Urb	<0.005	0.28	0.04
L28033-1	425014	0715858	M_s	Sru	Undev	0.018	0.97	0.09
L3230-1	433219	0712408	M_s	Sru	Urb	<0.005	0.27	0.03
L33079-1	433440	0712424	M_s	Sru	Urb	<0.005	0.15	0.03
L36514-2	433239	0712410	M_s	Sru	Urb	<0.005	0.07	0.06
L36515-1	433236	0712425	M_s	Sru	Urb	<0.005	0.22	0.07
L36674-2	433405	0712534	M_s	Sru	Undev	<0.005	0.12	0.06
L45567-2	430921	0712222	M_s	Sru	Urb	<0.005	<0.05	<0.03
L51227-1	432955	0712732	M_s	Sru	Undev	<0.005	<0.05	0.03
L6509-1	433416	0712421	M_s	Sru	Undev	<0.005	0.56	0.07
L7311-1	433406	0712430	M_s	Sru	Urb	<0.005	0.53	0.26

Appendix 1. Geologic, land-use, and chemical data for bedrock wells in the New England Coastal Basins study unit—Continued

Unique well identification No.	Latitude (° ′ ″)	Longitude (° ′ ″)	Geologic data: Major litho-geochemical group	Geologic data: Bedrock map unit	Land-use data: Major land use group	Chemical data: Arsenic (mg/L)	Chemical data: Iron (mg/L)	Chemical data: Manganese (mg/L)
NEW HAMPSHIRE--*Continued*								
L7312-1	433405	0712408	M_s	Sru	Undev	<0.005	0.42	0.06
L14613-1	424504	0714944	M_s	Sr	Urb	<0.005	1.38	0.18
L18444-1	441526	0711516	M_s	Sr	Undev	<0.005	<0.05	<0.03
L23718-1	441158	0711408	M_s	Sr	Undev	<0.005	<0.05	<0.03
L24294-1	424520	0715105	M_s	Sr	Undev	<0.005	4.69	0.15
L37842-3	424855	0710600	M_s	SOec	Urb	0.013	0.06	0.10
L7309-1	425025	0710520	M_s	SOec	Urb	<0.005	0.05	0.04
L11819-1	425949	0705643	M_c	SOk	Ag	<0.005	0.11	0.05
L24580-1	425652	0705206	M_c	SOk	Urb	<0.005	<0.05	<0.03
L31131-1	425635	0705202	M_c	SOk	Undev	<0.005	0.40	0.10
L33844-1	425505	0705150	M_c	SOk	Undev	0.013	0.15	0.08
L43510-1	425508	0705141	M_c	SOk	Undev	0.007	0.16	0.05
L46619-2	425420	0705501	M_c	SOk	Ag	0.008	0.39	0.28
L46620-1	425359	0705453	M_c	SOk	Ag	0.024	0.25	0.12
L46621-2	425416	0705501	M_c	SOk	Ag	0.009	0.12	0.21
L46627-2	425420	0705458	M_c	SOk	Ag	0.014	0.25	0.45
L19165-1	425854	0710434	M_c	SOe	Undev	<0.005	<0.05	<0.03
L19785-1	430222	0705446	M_c	SOe	Undev	<0.005	<0.05	<0.03
L25745-1	425455	0705916	M_c	SOe	Ag	0.009	<0.05	0.06
L2845-3	430209	0710344	M_c	SOe	Undev	0.007	0.07	0.14
L30259-1	425939	0705542	M_c	SOe	Urb	<0.005	<0.05	<0.03
L3365-1	425131	0710433	M_c	SOe	Urb	0.015	<0.05	0.03
L36786-1	430222	0710051	M_c	SOe	Undev	0.044	<0.05	<0.03
L36943-1	430059	0710132	M_c	SOe	Urb	<0.005	0.07	<0.03
L42723-1	425543	0705635	M_c	SOe	Urb	0.010	0.06	0.07
L42725-1	425456	0705932	M_c	SOe	Ag	<0.005	0.56	0.20
L45752-1	430238	0705326	M_c	SOe	Ag	<0.005	<0.05	<0.03
L46623-2	425418	0705506	M_c	SOe	Ag	0.009	0.73	0.46
L48854-1	430806	0705812	M_c	SOe	Ag	0.011	<0.05	0.04
L50793-3	425252	0705751	M_c	SOe	Urb	0.024	0.13	0.06
L51433-2	425953	0705513	M_c	SOe	Urb	<0.005	<0.05	0.03
L5641-1	430020	0705410	M_c	SOe	Urb	<0.005	0.89	0.34
L10351-1	425347	0712308	M_c	SObc	Urb	0.008	0.59	0.59
L13948-1	425741	0711550	M_c	SObc	Urb	0.007	0.07	0.03
L16079-1	424423	0713524	M_c	SObc	Urb	<0.005	0.06	<0.03
L34528-1	430325	0710908	M_c	SObc	Ag	<0.005	0.57	0.09
L35539-1	424442	0713516	M_c	SObc	Undev	0.005	0.12	<0.03
L35540-1	424442	0713516	M_c	SObc	Undev	0.006	0.08	<0.03
L37468-3	424428	0713546	M_c	SObc	Undev	0.024	0.09	<0.03
L37893-1	425359	0712037	M_c	SObc	Urb	0.008	<0.05	0.05
L40785-1	425739	0711549	M_c	SObc	Urb	0.007	<0.05	<0.03

Appendix 1. Geologic, land-use, and chemical data for bedrock wells in the New England Coastal Basins study unit—Continued

Unique well identification No.	Latitude (° ′ ″)	Longitude (° ′ ″)	Geologic data		Land-use data	Chemical data		
			Major litho-geochemical group	Bedrock map unit	Major land use group	Arsenic (mg/L)	Iron (mg/L)	Manganese (mg/L)
NEW HAMPSHIRE--*Continued*								
L8478-1	425735	0711545	M_c	SObc	Urb	<0.005	<0.05	<0.03
L8480-1	425729	0711531	M_c	SObc	Urb	0.016	<0.05	<0.03
L8481-1	425734	0711537	M_c	SObc	Urb	0.023	<0.05	0.07
L11121-1	425154	0712027	M_c	SOb	Ag	0.005	0.24	0.12
L15667-1	430010	0710918	M_c	SOb	Undev	<0.005	<0.05	3.53
L16025-1	424930	0712434	M_c	SOb	Undev	0.008	0.06	<0.03
L16168-1	425052	0710556	M_c	SOb	Undev	<0.005	2.10	0.24
L17184-1	425450	0711221	M_c	SOb	Undev	<0.005	<0.05	<0.03
L17826-1	424850	0711432	M_c	SOb	Undev	<0.005	0.11	0.10
L17992-1	424759	0711249	M_c	SOb	Undev	<0.005	<0.05	<0.03
L18025-1	424807	0711254	M_c	SOb	Undev	<0.005	0.07	0.10
L25345-1	425350	0711611	M_c	SOb	Urb	0.015	<0.05	0.15
L28275-2	430937	0710010	M_c	SOb	Undev	0.008	0.44	0.07
L28981-2	425009	0710603	M_c	SOb	Undev	<0.005	0.17	<0.03
L28982-2	425013	0710608	M_c	SOb	Undev	<0.005	0.14	0.07
L29373-1	425327	0711237	M_c	SOb	Undev	<0.005	0.13	<0.03
L32226-1	425334	0711745	M_c	SOb	Urb	<0.005	<0.05	<0.03
L34767-1	424415	0711933	M_c	SOb	Urb	<0.005	0.09	0.05
L35651-2	424753	0712154	M_c	SOb	Undev	0.009	<0.05	<0.03
L35768-1	424734	0711822	M_c	SOb	Undev	<0.005	0.05	<0.03
L35776-1	430747	0710020	M_c	SOb	Urb	0.037	<0.05	<0.03
L36517-1	425923	0710826	M_c	SOb	Urb	<0.005	0.12	0.06
L36950-1	430902	0710049	M_c	SOb	Undev	0.018	<0.05	<0.03
L3785-1	430906	0710112	M_c	SOb	Undev	<0.005	0.13	0.06
L40784-1	425127	0710234	M_c	SOb	Urb	0.018	0.08	0.05
L40829-1	430831	0710054	M_c	SOb	Undev	0.015	<0.05	<0.03
L41863-1	424839	0711551	M_c	SOb	Urb	<0.005	0.22	0.05
L42022-1	430906	0710147	M_c	SOb	Undev	<0.005	<0.05	<0.03
L42495-1	425240	0711802	M_c	SOb	Undev	<0.005	<0.05	<0.03
L44539-1	424946	0712313	M_c	SOb	Urb	<0.005	<0.05	0.24
L44541-1	424952	0712307	M_c	SOb	Urb	<0.005	0.06	<0.03
L45321-2	430903	0710119	M_c	SOb	Urb	<0.005	0.08	0.03
L45800-2	430912	0710131	M_c	SOb	Urb	<0.005	0.06	0.06
L46483-1	425905	0710752	M_c	SOb	Urb	<0.005	0.15	0.12
L51466-1	424538	0711527	M_c	SOb	Undev	0.018	0.08	0.16
L51937-1	424331	0711905	M_c	SOb	Urb	<0.005	0.07	<0.03
L5807-1	425041	0711326	M_c	SOb	Undev	<0.005	<0.05	0.09
L6066-1	424401	0711852	M_c	SOb	Undev	<0.005	<0.05	<0.03
L8784-1	424836	0712531	M_c	SOb	Urb	<0.005	<0.05	<0.03
L5815-1	433354	0712019	I_m	J5	Undev	0.006	0.07	<0.03
L16578-1	425813	0705940	I_m	De9	Urb	<0.005	<0.05	<0.03

Appendix 1. Geologic, land-use, and chemical data for bedrock wells in the New England Coastal Basins study unit—Continued

Unique well identification No.	Latitude (° ′ ″)	Longitude (° ′ ″)	Geologic data		Land-use data	Chemical data		
			Major litho-geochemical group	Bedrock map unit	Major land use group	Arsenic (mg/L)	Iron (mg/L)	Manganese (mg/L)
NEW HAMPSHIRE--*Continued*								
L3262-1	430035	0705855	I_m	De9	Undev	<0.005	<0.05	<0.03
L34175-1	430038	0705810	I_m	De9	Undev	0.007	0.85	0.17
L18147-1	425814	0713017	I_f	Zmz	Undev	<0.005	<0.05	0.04
L18158-1	425814	0713017	I_f	Zmz	Undev	<0.005	0.17	0.04
L19544-1	424922	0713642	I_f	Zmz	Undev	<0.005	<0.05	<0.03
L19939-1	425721	0713015	I_f	Zmz	Urb	<0.005	<0.05	<0.03
L2554-1	425642	0713114	I_f	Zmz	Urb	<0.005	<0.05	0.03
L33095-1	425721	0713015	I_f	Zmz	Urb	<0.005	<0.05	<0.03
L33493-3	425458	0712742	I_f	Zmz	Undev	<0.005	<0.05	<0.03
L34636-3	430333	0711644	I_f	Zmz	Urb	<0.005	0.06	<0.03
L3917-1	424914	0713625	I_f	Zmz	Ag	<0.005	<0.05	<0.03
L41764-1	430110	0712234	I_f	Zmz	Undev	<0.005	<0.05	<0.03
L41917-1	425719	0713029	I_f	Zmz	Undev	<0.005	0.08	<0.03
L6660-1	425129	0713755	I_f	Zmz	Undev	<0.005	<0.05	<0.03
L8782-1	425612	0713013	I_f	Zmz	Urb	<0.005	0.47	0.06
L8783-1	425611	0713015	I_f	Zmz	Undev	<0.005	0.24	0.04
L9091-1	425720	0713007	I_f	Zmz	Urb	<0.005	0.16	<0.03
L9092-1	425620	0712809	I_f	Zmz	Urb	<0.005	<0.05	<0.03
L9577-1	425529	0713158	I_f	Zmz	Undev	<0.005	0.13	0.06
L9578-1	425618	0713134	I_f	Zmz	Urb	<0.005	<0.05	<0.03
L10661-1	435540	0710614	I_f	PM1m	Undev	<0.005	<0.05	<0.03
L19732-1	434037	0710505	I_f	PM1m	Undev	<0.005	<0.05	<0.03
L23835-1	434205	0710639	I_f	PM1m	Undev	<0.005	<0.05	<0.03
L24291-1	434053	0710623	I_f	PM1m	Undev	<0.005	0.10	<0.03
L45074-2	434206	0710642	I_f	PM1m	Undev	<0.005	<0.05	<0.03
L46605-1	435911	0710246	I_f	PM1m	Urb	<0.005	0.06	<0.03
L8335-1	434039	0710457	I_f	PM1m	Undev	<0.005	<0.05	<0.03
L10354-1	424829	0713907	I_f	P1m	Undev	<0.005	<0.05	0.03
L37282-1	424422	0714000	I_f	P1m	Undev	<0.005	<0.05	0.07
L3918-1	424927	0713437	I_f	P1m	Undev	<0.005	<0.05	<0.03
L41466-3	424336	0713802	I_f	P1m	Undev	<0.005	4.12	0.44
L5281-1	424834	0713849	I_f	P1m	Urb	<0.005	<0.05	<0.03
L7043-1	424335	0713812	I_f	P1m	Undev	<0.005	2.69	0.24
L16048-1	443340	0711011	I_f	Oo2bx	Undev	<0.005	<0.05	<0.03
L11348-1	440722	0711301	I_f	Jo1h	Undev	<0.005	<0.05	<0.03
L13702-1	440356	0713622	I_f	Jo1h	Undev	<0.005	<0.05	<0.03
L18360-1	440726	0711027	I_f	Jo1h	Undev	<0.005	0.76	0.19
L18362-1	440725	0711028	I_f	Jo1h	Undev	<0.005	0.48	<0.03
L19287-1	440752	0711130	I_f	Jo1h	Undev	<0.005	<0.05	0.09
L19288-1	440753	0711201	I_f	Jo1h	Undev	0.006	<0.05	<0.03
L19289-1	440751	0711130	I_f	Jo1h	Undev	<0.005	<0.05	0.09

Appendix 1. Geologic, land-use, and chemical data for bedrock wells in the New England Coastal Basins study unit—Continued

Unique well identification No.	Latitude (° ′ ″)	Longitude (° ′ ″)	Geologic data		Land-use data	Chemical data		
			Major litho-geochemical group	Bedrock map unit	Major land use group	Arsenic (mg/L)	Iron (mg/L)	Manganese (mg/L)
NEW HAMPSHIRE--*Continued*								
L19292-1	440610	0711207	I_f	Jo1h	Undev	<0.005	<0.05	<0.03
L24650-1	440716	0711222	I_f	Jo1h	Undev	<0.005	<0.05	0.21
L45727-2	440804	0711113	I_f	Jo1h	Undev	<0.005	0.05	0.11
L5401-1	440759	0711128	I_f	Jo1h	Undev	<0.005	0.09	0.15
L19167-1	440341	0710943	I_f	Jc1b	Urb	0.006	0.24	<0.03
L19291-1	440405	0711606	I_f	Jc1b	Undev	0.008	0.10	<0.03
L35218-1	440405	0711606	I_f	Jc1b	Undev	<0.005	0.05	<0.03
L36050-1	440155	0710836	I_f	Jc1b	Undev	<0.005	<0.05	<0.03
L36051-2	440701	0710842	I_f	Jc1b	Undev	<0.005	<0.05	<0.03
L38333-1	440455	0711341	I_f	Jc1b	Urb	<0.005	0.26	<0.03
L38334-2	440452	0711300	I_f	Jc1b	Undev	<0.005	<0.05	<0.03
L43141-1	440258	0710928	I_f	Jc1b	Undev	<0.005	<0.05	<0.03
L46661-2	440417	0711542	I_f	Jc1b	Undev	<0.005	<0.05	0.13
L44422-2	433309	0712201	I_f	J7x	Urb	<0.005	<0.05	<0.03
L7027-1	433306	0712150	I_f	J7x	Urb	<0.005	<0.05	<0.03
L13392-1	434458	0712408	I_f	Dw3A	Urb	0.018	1.65	0.57
L14247-1	433814	0710928	I_f	Dw3A	Undev	<0.005	0.19	<0.03
L14672-1	434457	0712411	I_f	Dw3A	Undev	0.007	0.21	0.18
L19897-1	433502	0712234	I_f	Dw3A	Urb	<0.005	0.18	0.10
L19898-1	433503	0712235	I_f	Dw3A	Undev	<0.005	0.13	0.06
L28111-2	435010	0711603	I_f	Dw3A	Urb	<0.005	0.20	<0.03
L35233-1	432957	0711416	I_f	Dw3A	Undev	0.006	<0.05	<0.03
L35443-1	433411	0712033	I_f	Dw3A	Urb	0.007	<0.05	<0.03
L3568-1	433425	0712050	I_f	Dw3A	Undev	<0.005	<0.05	0.03
L3569-1	433426	0712050	I_f	Dw3A	Urb	<0.005	<0.05	0.03
L36673-3	433411	0712039	I_f	Dw3A	Undev	<0.005	7.11	0.10
L37162-3	434239	0712253	I_f	Dw3A	Undev	<0.005	<0.05	<0.03
L4320-1	433623	0712632	I_f	Dw3A	Urb	<0.005	0.12	<0.03
L45231-3	434821	0712629	I_f	Dw3A	Urb	<0.005	<0.05	0.85
L12403-1	425144	0714609	I_f	Ds1-6	Ag	<0.005	<0.05	<0.03
L12814-1	431247	0714330	I_f	Ds1-6	Undev	0.033	<0.05	<0.03
L14371-1	435256	0713934	I_f	Ds1-6	Undev	<0.005	0.05	0.07
L23307-1	430213	0714041	I_f	Ds1-6	Undev	<0.005	<0.05	<0.03
L23959-1	431130	0714451	I_f	Ds1-6	Urb	0.016	0.06	0.05
L24246-1	424859	0715109	I_f	Ds1-6	Ag	0.023	0.57	0.24
L31775-1	424443	0714905	I_f	Ds1-6	Undev	<0.005	<0.05	<0.03
L31776-1	424529	0715108	I_f	Ds1-6	Undev	<0.005	0.17	0.06
L36220-2	435310	0713941	I_f	Ds1-6	Ag	<0.005	0.22	0.04
L37185-1	424437	0714610	I_f	Ds1-6	Urb	<0.005	<0.05	0.04
L45319-2	430053	0715254	I_f	Ds1-6	Urb	0.015	<0.05	<0.03
L45600-1	425328	0714043	I_f	Ds1-6	Undev	<0.005	<0.05	<0.03

Appendix 1. Geologic, land-use, and chemical data for bedrock wells in the New England Coastal Basins study unit—Continued

Unique well identification No.	Latitude (° ′ ″)	Longitude (° ′ ″)	Geologic data		Land-use data	Chemical data		
			Major litho-geochemical group	Bedrock map unit	Major land use group	Arsenic (mg/L)	Iron (mg/L)	Manganese (mg/L)
NEW HAMPSHIRE--*Continued*								
L4566-1	424905	0714439	I_f	Ds1-6	Ag	<0.005	1.29	<0.03
L50623-1	431439	0714514	I_f	Ds1-6	Urb	<0.005	0.17	<0.03
L50624-1	431430	0714458	I_f	Ds1-6	Undev	0.026	0.20	<0.03
L8761-1	431845	0714307	I_f	Ds1-6	Undev	<0.005	0.12	0.19
L13393-1	434443	0713709	I_f	Dk2x	Urb	<0.005	0.06	<0.03
L18569-1	430233	0713945	I_f	Dk2x	Urb	0.018	<0.05	<0.03
L23903-1	430634	0720045	I_f	Dk2x	Undev	<0.005	<0.05	<0.03
L23905-1	430642	0720044	I_f	Dk2x	Undev	<0.005	<0.05	<0.03
L24201-1	430802	0714205	I_f	Dk2x	Undev	<0.005	0.70	<0.03
L26217-1	430439	0715804	I_f	Dk2x	Urb	<0.005	0.06	0.06
L28679-2	433745	0713133	I_f	Dk2x	Undev	<0.005	<0.05	<0.03
L30004-1	434109	0712728	I_f	Dk2x	Urb	<0.005	<0.05	<0.03
L30005-1	434109	0712729	I_f	Dk2x	Urb	<0.005	<0.05	<0.03
L34530-1	433820	0712912	I_f	Dk2x	Undev	0.005	<0.05	<0.03
L34531-1	433819	0712910	I_f	Dk2x	Undev	<0.005	<0.05	<0.03
L34740-2	433817	0712934	I_f	Dk2x	Urb	<0.005	<0.05	<0.03
L34742-1	430939	0715353	I_f	Dk2x	Undev	<0.005	<0.05	<0.03
L34743-1	430907	0715329	I_f	Dk2x	Urb	0.006	<0.05	<0.03
L34744-1	430911	0715307	I_f	Dk2x	Urb	<0.005	0.10	<0.03
L34866-1	433809	0713038	I_f	Dk2x	Undev	<0.005	0.06	<0.03
L34868-1	433814	0713045	I_f	Dk2x	Undev	0.016	<0.05	<0.03
L35370-1	434114	0712721	I_f	Dk2x	Undev	<0.005	<0.05	<0.03
L36224-2	433127	0715116	I_f	Dk2x	Undev	<0.005	<0.05	<0.03
L36280-1	425504	0715420	I_f	Dk2x	Undev	<0.005	<0.05	<0.03
L36366-1	431554	0715614	I_f	Dk2x	Undev	0.011	0.26	<0.03
L37513-1	431612	0715739	I_f	Dk2x	Urb	<0.005	0.07	<0.03
L37984-1	433823	0713033	I_f	Dk2x	Undev	<0.005	<0.05	<0.03
L42659-3	430534	0715738	I_f	Dk2x	Undev	<0.005	0.43	0.13
L42660-2	430642	0720044	I_f	Dk2x	Undev	<0.005	<0.05	<0.03
L45232-3	434001	0712944	I_f	Dk2x	Urb	<0.005	0.17	0.09
L45233-3	434000	0712927	I_f	Dk2x	Urb	<0.005	0.07	0.05
L47657-1	433745	0713133	I_f	Dk2x	Undev	<0.005	<0.05	<0.03
L51931-1	431646	0714029	I_f	Dk2x	Undev	0.005	<0.05	<0.03
L7310-1	433817	0712934	I_f	Dk2x	Urb	<0.005	<0.05	<0.03
L8121-1	425703	0715223	I_f	Dk2x	Undev	0.005	0.25	<0.03
L8760-1	431955	0715720	I_f	Dk2x	Undev	<0.005	0.06	<0.03
L10775-1	430912	0713640	I_f	Dc1m	Undev	0.009	0.23	0.56
L13768-1	431307	0710208	I_f	Dc1m	Undev	<0.005	0.72	0.03
L13830-1	431304	0711245	I_f	Dc1m	Urb	<0.005	0.16	0.08
L13831-1	431306	0711232	I_f	Dc1m	Urb	<0.005	0.07	0.03
L14119-1	431507	0713209	I_f	Dc1m	Undev	<0.005	<0.05	<0.03

Appendix 1. Geologic, land-use, and chemical data for bedrock wells in the New England Coastal Basins study unit—Continued

Unique well identification No.	Latitude (° ′ ″)	Longitude (° ′ ″)	Geologic data: Major litho-geochemical group	Geologic data: Bedrock map unit	Land-use data: Major land use group	Chemical data: Arsenic (mg/L)	Chemical data: Iron (mg/L)	Chemical data: Manganese (mg/L)
NEW HAMPSHIRE--*Continued*								
L15657-1	431051	0714724	I_f	Dc1m	Undev	0.008	<0.05	<0.03
L15658-1	431102	0714729	I_f	Dc1m	Urb	<0.005	<0.05	<0.03
L15932-1	431552	0705517	I_f	Dc1m	Undev	<0.005	0.09	0.50
L28044-2	430842	0710635	I_f	Dc1m	Undev	0.012	<0.05	0.05
L30971-1	430923	0712427	I_f	Dc1m	Urb	0.035	0.41	0.10
L34486-1	430710	0712545	I_f	Dc1m	Undev	0.034	0.06	0.13
L35528-1	431707	0712829	I_f	Dc1m	Undev	0.005	<0.05	0.03
L36516-2	431019	0713209	I_f	Dc1m	Urb	0.038	<0.05	<0.03
L37973-3	431012	0713139	I_f	Dc1m	Urb	0.013	<0.05	0.05
L38483-1	430838	0711255	I_f	Dc1m	Undev	<0.005	<0.05	<0.03
L38590-2	434436	0714546	I_f	Dc1m	Undev	<0.005	0.23	0.12
L47001-3	431401	0710053	I_f	Dc1m	Undev	<0.005	<0.05	<0.03
L50575-1	431612	0710743	I_f	Dc1m	Urb	<0.005	1.15	0.23
L9895-1	431023	0713146	I_f	Dc1m	Urb	0.015	1.50	0.06
RHODE ISLAND								
1858415-1	412523	0714736	M_u	Zp	Urb	<0.005	--	--
1858417-1	412514	0714728	M_u	Zp	Urb	<0.005	--	--
2000145-1	412519	0714716	M_u	Zp	Urb	<0.005	--	--
2000083-1	415436	0713308	M_{md}	PZmc	Ag	<0.005	7.59	0.62
2000083-2	415437	0713309	M_{md}	PZmc	Ag	<0.005	38.92	0.62
1000007-1	413557	0711838	M_{md}	Pnbr	Undev	<0.005	0.07	<0.03
1592023-5	413602	0711846	M_{md}	Pnbr	Undev	0.016	0.19	<0.03
1592023-7	413626	0711845	M_{md}	Pnbr	Undev	<0.005	<0.05	<0.03
1592023-8	413714	0711846	M_{md}	Pnbr	Undev	<0.005	1.09	0.23
1592023-9	413714	0711846	M_{md}	Pnbr	Undev	<0.005	0.48	0.19
2051311-1	413630	0711131	M_{md}	Pnbr	Undev	<0.005	0.90	0.29
2753326-1	412959	0711622	M_{md}	Pnbr	Ag	<0.005	<0.05	0.04
2753326-3	412956	0711621	M_{md}	Pnbr	Ag	<0.005	0.07	0.05
2980003-1	413623	0711142	M_{md}	Pnbpu	Urb	<0.005	--	--
1000025-1	415613	0712649	M_c	Zbs	Urb	<0.005	--	--
1000042-1	415945	0713307	I_m	Zbu	Undev	<0.005	--	--
1559519-1	415902	0713725	I_m	Zbu	Undev	<0.005	0.31	<0.03
1559519-2	415903	0713724	I_m	Zbu	Undev	<0.005	0.24	0.08
1592014-1	420007	0713315	I_m	Zbu	Undev	<0.005	--	--
1592019-1	415733	0713845	I_m	Zbu	Urb	<0.005	<0.05	0.03
1592019-2	415733	0713846	I_m	Zbu	Urb	<0.005	1.50	<0.03
1900028-1	415850	0713726	I_m	Zbu	Undev	<0.005	0.34	<0.03
2942515-1	415852	0713054	I_m	Zbu	Urb	<0.005	--	--
2980146-1	415417	0714016	I_m	Zbu	Undev	<0.005	0.81	0.04
2980146-3	415418	0714016	I_m	Zbu	Urb	<0.005	0.12	0.03
2980258-1	420034	0713237	I_m	Zbu	Urb	0.038	0.10	<0.03

Appendix 1. Geologic, land-use, and chemical data for bedrock wells in the New England Coastal Basins study unit—Continued

Unique well identification No.	Latitude (° ′ ″)	Longitude (° ′ ″)	Geologic data		Land-use data	Chemical data		
			Major litho-geochemical group	Bedrock map unit	Major land use group	Arsenic (mg/L)	Iron (mg/L)	Manganese (mg/L)
RHODE ISLAND--*Continued*								
2980258-2	420034	0713238	I_m	Zbu	Urb	0.038	<0.05	<0.03
2980258-5	420034	0713237	I_m	Zbu	Urb	0.046	--	--
2980301-1	415952	0713246	I_m	Zbu	Undev	<0.005	0.05	<0.03
2980311-1	415836	0713754	I_m	Zbu	Urb	<0.005	--	--
2000084-1	415253	0713431	I_m	DZgd	Ag	<0.005	--	--
1000045-1	412548	0714733	I_f	Zsgg	Urb	<0.005	0.07	<0.03
1000045-2	412547	0714735	I_f	Zsgg	Urb	<0.005	16.48	0.12
1592027-2	413004	0713947	I_f	Zsgg	Ag	0.013	21.60	0.33
1592027-3	413004	0713947	I_f	Zsgg	Ag	<0.005	0.40	0.19
2980127-1	412607	0714742	I_f	Zsgg	Undev	<0.005	--	--
1858425-2	413034	0711027	I_f	Zsepg	Urb	<0.005	--	--
2980001-1	413705	0710958	I_f	Zseg	Undev	<0.005	0.05	<0.03
2980138-1	413414	0710941	I_f	Zseg	Undev	<0.005	--	--
2980340-1	413820	0710834	I_f	Zseg	Ag	<0.005	0.06	<0.03
1000043-2	412927	0714418	I_f	Zsag	Undev	0.008	0.17	0.33
1000043-3	412926	0714416	I_f	Zsag	Undev	<0.005	0.42	0.07
1647525-3	412659	0713921	I_f	Zsag	Undev	<0.005	0.16	<0.03
1647525-4	412700	0713921	I_f	Zsag	Undev	<0.005	0.07	<0.03
1858414-1	412950	0714513	I_f	Zsag	Undev	<0.005	<0.05	<0.03
1900025-2	412925	0714429	I_f	Zsag	Undev	<0.005	0.18	0.06
1900027-3	412454	0713853	I_f	Zsag	Undev	<0.005	<0.05	0.09
1900035-1	412950	0714502	I_f	Zsag	Undev	<0.005	0.57	0.13
1900048-2	412927	0714415	I_f	Zsag	Undev	<0.005	0.06	0.19
2000133-1	412925	0714413	I_f	Zsag	Undev	<0.005	--	--
2674925-1	412520	0713952	I_f	Zsag	Urb	<0.005	0.06	<0.03
2674925-2	412521	0713951	I_f	Zsag	Urb	<0.005	0.12	<0.03
2980134-1	415318	0713546	I_f	Zhw	Urb	<0.005	--	--
1592017-1	415715	0713253	I_f	Zha	Undev	<0.005	--	--
1900038-1	415411	0713851	I_f	Zha	Undev	<0.005	--	--
1900044-1	415019	0713813	I_f	Zha	Urb	<0.005	--	--
2000059-1	415456	0713738	I_f	Zha	Undev	<0.005	0.05	<0.03
2000059-2	415457	0713739	I_f	Zha	Undev	<0.005	0.25	<0.03
2980277-1	415657	0713838	I_f	Zha	Urb	<0.005	--	--
2980278-1	415651	0713844	I_f	Zha	Urb	<0.005	--	--
2415415-1	415012	0714036	I_f	Zegg	Undev	<0.005	<0.05	<0.03
2519424-1	415358	0713941	I_f	Zegg	Undev	<0.005	0.05	0.29
2519424-3	415358	0713941	I_f	Zegg	Undev	<0.005	<0.05	<0.03
2943224-8	415356	0713956	I_f	Zegg	Undev	<0.005	0.13	0.09
1615614-2	420000	0713501	I_f	Zeg	Urb	<0.005	0.13	<0.03
1647517-1	415852	0713702	I_f	Zeg	Undev	<0.005	--	--
1900026-1	415627	0713218	I_f	Zeg	Undev	<0.005	1.62	3.29

Appendix 1. Geologic, land-use, and chemical data for bedrock wells in the New England Coastal Basins study unit—Continued

Unique well identification No.	Latitude (° ′ ″)	Longitude (° ′ ″)	Geologic data: Major litho-geochemical group	Geologic data: Bedrock map unit	Land-use data: Major land use group	Chemical data: Arsenic (mg/L)	Chemical data: Iron (mg/L)	Chemical data: Manganese (mg/L)
RHODE ISLAND--*Continued*								
2942518-1	415738	0712926	I_f	Zeg	Undev	<0.005	<0.05	<0.03
2973119-4	415909	0713636	I_f	Zeg	Undev	<0.005	0.37	0.18
2980036-1	420019	0713507	I_f	Zeg	Urb	<0.005	--	--
2980135-1	415149	0713002	I_f	Zeg	Undev	<0.005	--	--
1000009-1	415106	0714411	I_f	Zeag	Undev	<0.005	0.28	<0.03
1000009-4	415104	0714411	I_f	Zeag	Undev	<0.005	0.09	<0.03
1583823-1	414850	0714359	I_f	Zeag	Undev	<0.005	--	--
1583827-1	415445	0714007	I_f	Zeag	Urb	<0.005	--	--
1583829-4	415159	0714302	I_f	Zeag	Urb	<0.005	0.91	<0.03
1583829-5	415200	0714303	I_f	Zeag	Urb	<0.005	0.77	0.03
1583829-6	415202	0714302	I_f	Zeag	Urb	<0.005	0.69	<0.03
1583829-7	415158	0714304	I_f	Zeag	Urb	<0.005	0.17	<0.03
1647526-1	415530	0714302	I_f	Zeag	Urb	<0.005	--	--
1647529-1	412657	0713812	I_f	Zeag	Undev	<0.005	0.05	<0.03
1858435-1	414734	0714317	I_f	Zeag	Undev	<0.005	--	--
1900040-2	420032	0714019	I_f	Zeag	Undev	<0.005	0.86	0.03
2585312-2	413151	0713243	I_f	Zeag	Undev	<0.005	0.46	0.03
2788010-1	414947	0714517	I_f	Zeag	Undev	<0.005	--	--
2788012-1	414934	0714422	I_f	Zeag	Undev	<0.005	--	--
2882117-4	413012	0713348	I_f	Zeag	Undev	<0.005	--	--
2980192-1	413116	0713319	I_f	Zeag	Undev	<0.005	0.12	0.12
2980192-2	413115	0713320	I_f	Zeag	Undev	<0.005	<0.05	0.09
2980264-1	413333	0713234	I_f	Zeag	Undev	<0.005	0.10	<0.03
1559513-4	412110	0714326	I_f	Pnpg	Undev	<0.005	0.60	0.04
1559513-5	412116	0714312	I_f	Pnpg	Undev	<0.005	0.29	0.09
1000035-3	412339	0713710	I_f	Png	Undev	<0.005	0.07	<0.03
1000035-4	412337	0713715	I_f	Png	Urb	<0.005	<0.05	0.04
1000035-5	412337	0713706	I_f	Png	Urb	<0.005	<0.05	<0.03
2674928-1	412149	0714111	I_f	Png	Ag	<0.005	--	--
2980017-1	412305	0713748	I_f	Png	Ag	<0.005	1.19	0.06
2980019-1	412208	0713936	I_f	Png	Urb	<0.005	--	--
1000020-1	414929	0713653	I_f	Dsg	Undev	<0.005	2.32	0.64
1000020-2	414929	0713651	I_f	Dsg	Undev	<0.005	0.98	0.84
1000020-3	414929	0713654	I_f	Dsg	Undev	<0.005	0.21	0.59
1559510-1	413646	0713814	I_f	Dsg	Undev	<0.005	--	--
1583819-3	413558	0713840	I_f	Dsg	Undev	<0.005	0.36	<0.03
1583819-4	413602	0713837	I_f	Dsg	Undev	<0.005	0.08	<0.03
1583820-1	413507	0713709	I_f	Dsg	Undev	<0.005	--	--
1583825-1	415828	0713737	I_f	Dsg	Undev	<0.005	--	--
1615611-1	414620	0714018	I_f	Dsg	Undev	<0.005	--	--
1615612-4	414927	0713715	I_f	Dsg	Urb	<0.005	0.14	<0.03

Appendix 1. Geologic, land-use, and chemical data for bedrock wells in the New England Coastal Basins study unit—Continued

Unique well identification No.	Latitude (° ′ ″)	Longitude (° ′ ″)	Geologic data		Land-use data	Chemical data		
			Major litho-geochemical group	Bedrock map unit	Major land use group	Arsenic (mg/L)	Iron (mg/L)	Manganese (mg/L)
RHODE ISLAND--*Continued*								
1615612-5	414927	0713718	I_f	Dsg	Undev	<0.005	0.05	<0.03
1615612-6	414930	0713715	I_f	Dsg	Undev	<0.005	0.15	<0.03
1647527-1	414146	0714122	I_f	Dsg	Undev	<0.005	5.48	2.85
1900003-1	414318	0713553	I_f	Dsg	Urb	<0.005	0.08	<0.03
1900003-2	414317	0713548	I_f	Dsg	Urb	<0.005	0.68	<0.03
1900003-3	414320	0713552	I_f	Dsg	Urb	<0.005	1.06	<0.03
1900003-4	414319	0713556	I_f	Dsg	Undev	<0.005	4.47	0.32
1900024-1	413625	0713816	I_f	Dsg	Undev	<0.005	0.16	0.06
1900024-2	413621	0713816	I_f	Dsg	Undev	<0.005	0.28	0.18
1900024-3	413623	0713816	I_f	Dsg	Undev	<0.005	0.06	<0.03
2000110-1	414443	0713444	I_f	Dsg	Undev	<0.005	--	--
2000135-1	413849	0713637	I_f	Dsg	Undev	<0.005	--	--
2000165-1	413248	0713701	I_f	Dsg	Undev	<0.005	<0.05	<0.03
2000176-1	414137	0712952	I_f	Dsg	Undev	<0.005	--	--
2519426-1	413958	0714004	I_f	Dsg	Undev	<0.005	--	--
2585313-1	413550	0713913	I_f	Dsg	Undev	<0.005	<0.05	<0.03
2814410-3	413650	0713957	I_f	Dsg	Undev	<0.005	0.05	<0.03
2942525-1	413258	0713731	I_f	Dsg	Undev	<0.005	0.25	0.20
2942525-3	413305	0713728	I_f	Dsg	Undev	<0.005	0.95	0.52
2980145-1	413601	0714253	I_f	Dsg	Undev	<0.005	--	--
2980276-1	413827	0713229	I_f	Dsg	Undev	<0.005	0.07	0.03
2980276-2	413826	0713228	I_f	Dsg	Undev	<0.005	0.06	0.03
2980323-1	415003	0713501	I_f	Dsg	Urb	<0.005	--	--
1900023-1	414444	0713213	I_f	Dsa	Undev	<0.005	0.05	<0.03
1900023-2	414443	0713213	I_f	Dsa	Undev	<0.005	0.05	<0.03
1900023-3	414448	0713215	I_f	Dsa	Undev	<0.005	<0.05	<0.03
1900023-4	414447	0713214	I_f	Dsa	Undev	<0.005	0.10	<0.03
1900023-5	414446	0713213	I_f	Dsa	Undev	<0.005	<0.05	<0.03
2051719-1	414656	0713318	I_f	Dsa	Urb	<0.005	<0.05	0.03
2051719-2	414656	0713316	I_f	Dsa	Urb	<0.005	<0.05	0.03
2051719-3	414654	0713320	I_f	Dsa	Urb	<0.005	0.23	0.09
2051719-4	414652	0713322	I_f	Dsa	Urb	<0.005	<0.05	<0.03
2980084-2	414951	0713126	I_f	Dsa	Urb	<0.005	--	--

Appendix 2. Chemical data for surficial wells in the New England Coastal Basins study unit

[No., number; ft, feet; ° ′ ″, degrees, minutes, seconds; mg/L, milligrams per liter; minus sign indicates below detection level; --, no data available]

Unique well identification No.	Depth (ft)	Latitude (° ′ ″)	Longitude (° ′ ″)	Chemical data		
				Arsenic (mg/L)	Iron (mg/L)	Manganese (mg/L)
			MAINE			
304601	10.00	433757	0703614	-0.005	-0.05	-0.03
3639601	9.00	441221	0700441	0.052	0.05	-0.03
90180201	--	450232	0695251	-0.005	-0.05	-0.03
90210201	--	440110	0695626	-0.005	-0.05	-0.03
91110201	--	444312	0694847	0.007	-0.05	-0.03
91302201	--	434745	0703915	-0.005	-0.05	-0.03
91360601	16.00	433645	0704857	-0.005	-0.05	0.04
91370201	-9.00	440458	0694652	-0.005	-0.05	-0.03
91460201	70.00	445620	0695156	-0.005	-0.05	-0.03
91480201	45.00	435016	0700645	-0.005	-0.05	-0.03
91520201	75.00	450821	0702540	-0.005	-0.05	-0.03
91530201	69.00	444750	0701310	-0.005	-0.05	-0.03
91600201	--	441907	0703334	-0.005	-0.05	-0.03
91870601	--	442309	0704244	-0.005	-0.05	-0.03
92288201	--	432443	0703943	0.006	0.12	0.22
93273601	--	440804	0702814	-0.005	-0.05	-0.03
94495601	6.00	434455	0704049	-0.005	0.15	-0.03
94559601	--	432754	0704744	-0.005	0.13	0.52
95510201	100.00	435836	0703401	-0.005	-0.05	0.03
95615201	74.00	441311	0701534	-0.005	0.12	-0.03
			NEW HAMPSHIRE			
L12520-1	--	430918	705322	0.009	--	--
L15078-1	--	431202	714018	-0.005	--	--
L18490-1	--	440524	711820	-0.005	--	--
L22052-1	--	431650	714922	-0.01	--	--
L29972-1	--	440726	711245	-0.005	--	--
L3178-1	--	440027	710539	-0.005	--	--
L34578-2	--	443023	710926	-0.005	--	--
L34974-1	--	442955	710938	-0.005	--	--
L35775-1	--	433847	705940	-0.005	--	--
L40502-3	--	434825	710135	-0.005	--	--
L40502-7	--	434825	710135	-0.005	--	--
L42710-3	--	430906	705319	-0.005	--	--
L43001-3	--	432744	713922	-0.005	--	--
L43001-7	--	432744	713922	-0.005	--	--
L43132-2	--	435948	710153	-0.005	--	--
L43346-7	--	431154	712907	-0.005	--	--
L44270-2	--	424216	713327	-0.005	--	--
L44271-2	--	424227	713319	-0.005	--	--
L45073-2	--	432153	713851	-0.005	--	--

Appendix 2. Chemical data for surficial wells in the New England Coastal Basins study unit—Continued

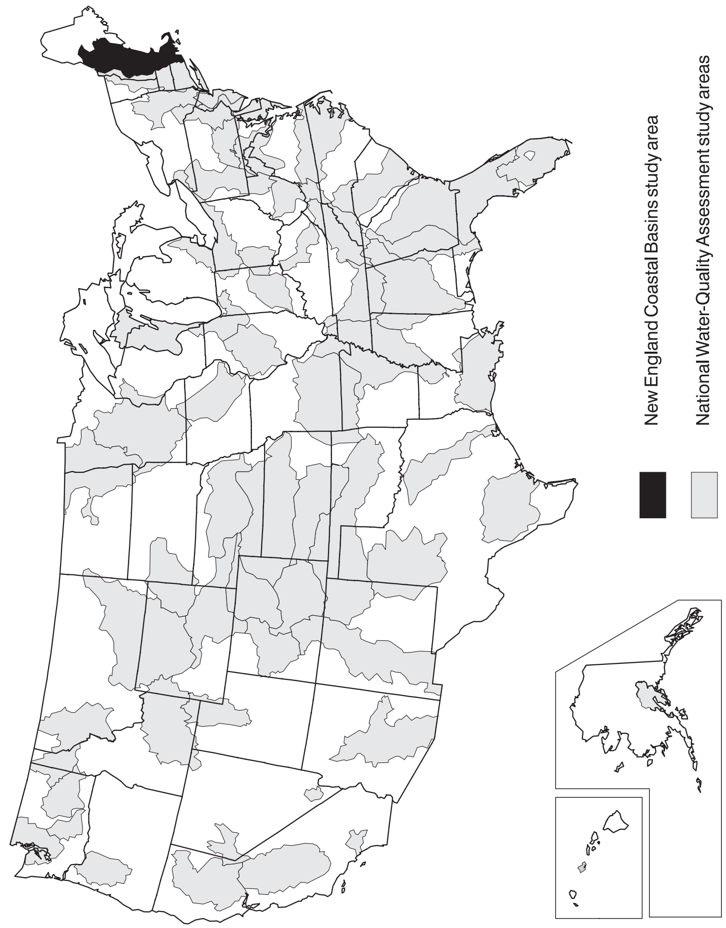
Unique well identification No.	Depth (ft)	Latitude (° ′ ″)	Longitude (° ′ ″)	Chemical data		
				Arsenic (mg/L)	Iron (mg/L)	Manganese (mg/L)
NEW HAMPSHIRE--*Continued*						
L45443-1	--	424958	713033	-0.005	--	--
L45444-1	--	424928	713100	-0.005	--	--
L45445-1	--	425218	712907	-0.005	--	--
L45447-1	--	425220	712905	-0.005	--	--
L46503-1	--	424437	713313	-0.005	--	--
L46622-3	--	425337	705451	-0.005	--	--
L46624-2	--	425311	705400	-0.005	--	--
L46625-2	--	425315	705408	-0.005	--	--
L46626-2	--	425336	705447	-0.005	--	--
L47994-2	--	440558	711142	-0.005	--	--
L49486-3	--	434604	714101	-0.005	--	--
L5448-3	--	430116	713704	-0.005	--	--
L7493-1	--	435721	713052	-0.005	--	--
L7755-1	--	435727	713048	-0.005	--	--
L9206-1	--	433801	714631	-0.005	--	--
L9248-1	--	430433	704908	-0.005	--	--
L9249-1	--	430149	704948	-0.005	--	--
L9649-1	--	430906	705319	-0.005	--	--
L9650-1	--	430900	705321	-0.005	--	--
L9677-1	--	432715	711339	-0.005	--	--
L9690-1	--	432759	711404	-0.005	--	--
RHODE ISLAND						
1000039-1	70.00	412900	0713415	-0.005	--	--
1000040-1	65.00	413209	0714147	-0.005	-0.05	0.03
1000040-2	54.00	413209	0714145	-0.005	0.1	-0.03
1000098-1	43.00	412841	0714356	-0.005	0.16	0.04
1000098-2	42.00	412841	0714357	0.009	0.17	0.05
1559511-1	118.00	413809	0712803	-0.005	0.07	-0.03
1559511-2	79.00	414041	0713421	-0.005	0.35	0.17
1559511-3	75.00	413942	0713602	-0.005	-0.05	0.15
1559511-4	88.00	413946	0713557	-0.005	0.51	0.14
1559512-1	71.00	412331	0715018	0.037	-0.05	-0.03
1559512-2	71.00	412330	0715017	-0.005	-0.05	0.54
1559512-3	74.00	412331	0715020	-0.005	-0.05	-0.03
1559512-4	73.00	412351	0715029	-0.005	0.15	0.05
1559512-5	75.00	412353	0715028	-0.005	0.09	-0.03
1559512-6	75.00	412352	0715029	-0.005	0.07	-0.03
1559512-7	73.00	412337	0715025	0.043	-0.05	-0.03
1559512-8	82.00	412339	0714517	0.045	-0.05	-0.03
1559512-9	69.00	412307	0714547	0.047	-0.05	-0.03
1559513-1	27.00	412109	0714327	-0.005	2.08	-0.03
1559513-2	45.00	412110	0714326	-0.005	0.72	-0.03
1559516-1	80.00	412354	0714731	-0.005	2.46	0.12

Appendix 2. Chemical data for surficial wells in the New England Coastal Basins study unit—Continued

Unique well identification No.	Depth (ft)	Latitude (° ′ ″)	Longitude (° ′ ″)	Chemical data		
				Arsenic (mg/L)	Iron (mg/L)	Manganese (mg/L)
RHODE ISLAND--*Continued*						
1559516-2	75.00	412354	0714731	-0.005	0.18	-0.03
1559517-1	50.00	413322	0712859	0.006	-0.05	-0.03
1559517-2	56.00	413319	0712857	-0.005	0.05	-0.03
1559517-3	66.00	413132	0712650	-0.005	0.75	0.08
1559517-4	68.00	413310	0712901	-0.005	0.07	-0.03
1559517-5	72.00	413259	0712914	-0.005	-0.05	-0.03
1559517-6	85.00	413543	0712928	-0.005	0.34	0.13
1559517-7	118.00	413808	0712805	-0.005	0.18	-0.03
1559517-8	107.00	413805	0712810	-0.005	-0.05	-0.03
1559517-9	--	413131	0712654	-0.005	0.05	-0.03
1592012-2	55.00	413327	0713254	-0.005	0.5	-0.03
1592015-1	64.00	415924	0713504	-0.005	--	--
1592020-1	41.00	415752	0714156	-0.005	1.03	0.04
1592020-2	57.00	415750	0714158	-0.005	-0.05	0.04
1592021-2	69.00	415419	0712300	-0.005	0.07	0.45
1592021-3	43.00	415428	0712301	-0.005	-0.05	-0.03
1592021-4	82.00	415434	0712257	-0.005	-0.05	-0.03
1592021-5	62.00	415435	0712307	-0.005	0.1	-0.03
1592021-6	55.00	415454	0712259	-0.005	0.11	0.79
1592021-7	49.00	415504	0712300	-0.005	0.1	0.29
1592021-8	89.00	415512	0712259	-0.005	0.15	0.23
1592021-9	56.00	415516	0712257	-0.005	-0.05	-0.03
1592025-2	97.00	412354	0714731	-0.005	0.57	0.03
1615614-1	--	415944	0713523	-0.005	0.42	0.04
1615614-5	--	420007	0713410	-0.005	0.05	-0.03
1615617-1	68.00	412902	0713405	-0.005	--	--
1615623-1	57.00	412316	0713603	-0.005	0.72	0.06
1615623-2	56.00	412320	0713601	-0.005	0.79	-0.03
1615624-1	55.00	412606	0713214	-0.005	-0.05	-0.03
1615624-2	55.00	412604	0713219	-0.005	-0.05	-0.03
1615624-3	55.00	412606	0713211	-0.005	0.17	-0.03
1615624-4	98.00	412558	0713306	-0.005	0.05	-0.03
1615624-5	84.00	412556	0713312	-0.005	-0.05	-0.03
1615624-7	66.00	412607	0713203	-0.005	0.05	-0.03
1615626-1	40.00	414202	0711424	-0.005	6.59	0.14
1615626-2	46.00	414202	0711425	-0.005	2	0.05
1647512-1	20.00	412030	0714224	-0.005	0.33	0.15
1647512-2	28.00	412030	0714226	-0.005	0.17	0.07
1647513-3	63.00	412431	0714515	-0.005	0.15	0.04
1647515-5	--	414345	0711850	-0.005	2.13	0.26
1647515-6	84.50	414348	0711901	-0.005	7.57	0.64
1647530-1	55.00	415752	0712750	-0.005	-0.05	0.76
1647530-3	50.00	415707	0712302	-0.005	2.39	0.49

Appendix 2. Chemical data for surficial wells in the New England Coastal Basins study unit—Continued

Unique well identification No.	Depth (ft)	Latitude (° ′ ″)	Longitude (° ′ ″)	Chemical data		
				Arsenic (mg/L)	Iron (mg/L)	Manganese (mg/L)
RHODE ISLAND--*Continued*						
1647530-4	50.00	415708	0712304	-0.005	0.71	0.52
1647530-5	86.00	415755	0712751	-0.005	0.05	0.4
1858411-1	34.00	415742	0714008	-0.005	0.06	0.05
1858411-2	36.00	415737	0714007	-0.005	0.41	0.03
1858421-1	64.00	412857	0713300	-0.005	0.15	0.03
1858421-2	65.00	412852	0713305	-0.005	-0.05	0.06
1858422-1	132.00	412924	0713247	-0.005	-0.05	-0.03
1858422-2	138.00	412922	0713245	-0.005	0.15	-0.03
1858422-3	95.00	412925	0713240	-0.005	-0.05	0.23
1858423-5	--	415407	0712419	-0.005	0.09	0.16
1900020-1	65.00	414221	0713648	-0.005	--	--
1900034-1	40.00	415800	0713604	-0.005	0.05	-0.03
1900034-2	40.00	415800	0713604	-0.005	0.05	-0.03
2000142-4	35.00	412659	0714344	-0.005	-0.05	0.08
2674924-1	146.00	412326	0713827	-0.005	0.08	-0.03
2882117-3	32.00	413011	0713345	-0.005	-0.05	0.08
2973130-1	--	415704	0713807	0.01	1.5	0.16
2973130-2	--	415703	0713806	-0.005	0.95	0.19
2973130-3	--	415705	0713808	-0.005	0.5	0.15
2980185-2	135.00	412657	0714155	-0.005	-0.05	-0.03
2980185-3	135.00	412656	0714154	-0.005	0.2	-0.03



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