

National Water-Quality Assessment Program

**Quality of Water from Crystalline Rock Aquifers in
New England, New Jersey, and New York, 1995–2007**



Scientific Investigations Report 2011–5220

Cover. Photographs show a bedrock outcrop near the intersection of Post Road and Daniel Webster Highway (New Hampshire State Route 3) in Hooksett, New Hampshire. During the winter (left), groundwater flows out of the open fractures and forms a frozen waterfall over the exposed bedrock. During the summer (right), groundwater stains the exposed bedrock with precipitated iron oxides.

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By Sarah M. Flanagan, Joseph D. Ayotte, and Gilpin R. Robinson, Jr.

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**U.S. Department of the Interior
U.S. Geological Survey**

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Foreword

The U.S. Geological Survey (USGS) is committed to providing the Nation with reliable scientific information that helps to enhance and protect the overall quality of life and that facilitates effective management of water, biological, energy, and mineral resources (<http://www.usgs.gov/>). Information on the Nation's water resources is critical to ensuring long-term availability of water that is safe for drinking and recreation and is suitable for industry, irrigation, and fish and wildlife. Population growth and increasing demands for water make the availability of that water, measured in terms of quantity and quality, even more essential to the long-term sustainability of our communities and ecosystems.

The USGS implemented the National Water-Quality Assessment (NAWQA) Program in 1991 to support national, regional, State, and local information needs and decisions related to water-quality management and policy (<http://water.usgs.gov/nawqa>). The NAWQA Program is designed to answer: What is the quality of our Nation's streams and groundwater? How are conditions changing over time? How do natural features and human activities affect the quality of streams and groundwater, and where are those effects most pronounced? By combining information on water chemistry, physical characteristics, stream habitat, and aquatic life, the NAWQA Program aims to provide science-based insights for current and emerging water issues and priorities. From 1991 to 2001, the NAWQA Program completed interdisciplinary assessments and established a baseline understanding of water-quality conditions in 51 of the Nation's river basins and aquifers, referred to as Study Units (http://water.usgs.gov/nawqa/studies/study_units.html).

In the second decade of the Program (2001–2012), a major focus is on regional assessments of water-quality conditions and trends. These regional assessments are based on major river basins and principal aquifers, which encompass larger regions of the country than the Study Units. Regional assessments extend the findings in the Study Units by filling critical gaps in characterizing the quality of surface water and groundwater, and by determining water-quality status and trends at sites that have been consistently monitored for more than a decade. In addition, the regional assessments continue to build an understanding of how natural features and human activities affect water quality. Many of the regional assessments employ modeling and other scientific tools, developed on the basis of data collected at individual sites, to help extend knowledge of water quality to unmonitored, yet comparable areas within the regions. The models thereby enhance the value of our existing data and our understanding of the hydrologic system. In addition, the models are useful in evaluating various resource-management scenarios and in predicting how our actions, such as reducing or managing nonpoint and point sources of contamination, land conversion, and altering flow and (or) pumping regimes, are likely to affect water conditions within a region.

Other activities planned during the second decade include continuing national syntheses of information on pesticides, volatile organic compounds (VOCs), nutrients, trace elements, and aquatic ecology; and continuing national topical studies on the fate of agricultural chemicals, effects of urbanization on stream ecosystems, bioaccumulation of mercury in stream ecosystems, effects of nutrient enrichment on stream ecosystems, and transport of contaminants to public-supply wells.

The USGS aims to disseminate credible, timely, and relevant science information to address practical and effective water-resource management and strategies that protect and restore water quality. We hope this NAWQA publication will provide you with insights and information to meet your needs, and will foster increased citizen awareness and involvement in the protection and restoration of our Nation's waters.

The USGS recognizes that a national assessment by a single program cannot address all water-resource issues of interest. External coordination at all levels is critical for cost-effective management, regulation, and conservation of our Nation's water resources. The NAWQA Program, therefore, depends on advice and information from other agencies—Federal, State, regional, interstate, Tribal, and local—as well as nongovernmental organizations, industry, academia, and other stakeholder groups. Your assistance and suggestions are greatly appreciated.

William H. Werkheiser
USGS Associate Director for Water

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Contents

Foreword	iii
Acknowledgments	v
Abstract	1
Introduction.....	2
Purpose and Scope	2
Description of Study Area	4
Previous Investigations.....	4
Study Design.....	5
Data from USGS NAWQA Domestic Wells.....	5
Quality Assurance and Quality Control of USGS NAWQA Samples.....	9
Blank Samples.....	9
Replicate Samples	9
Spiked Samples.....	9
Data from USEPA SDWA Public-Supply Wells	11
Treatment and Statistical Analysis of Water-Quality Data	12
Explanatory Variables	12
Categories of Land Use and Land Cover.....	13
Categories of Population Density.....	15
Categories of Well Depth and Casing Length	15
Major Lithology Categories and Lithology Groups.....	16
Quality of Water in New England Crystalline Rock Aquifers.....	19
Dissolved Gases and Apparent Age of Groundwater.....	19
Physiochemical Properties	21
Nutrients.....	21
Major Ions.....	30
Sodium and Chloride	32
Fluoride	35
Trace Elements.....	39
Iron and Manganese	39
Aluminum, Barium, and Strontium	43
Boron, Lithium, and Molybdenum	43
Beryllium and Chromium	45
Copper, Lead, Nickel, and Zinc	45
Arsenic.....	45
Radionuclides	51
Gross Alpha- and Gross Beta-Particle Activity	51
Radium	53
²²² Radon.....	53
Uranium	53
Co-occurrence of Selected Radionuclides and Lead.....	60
Organic Compounds.....	60
Pesticides.....	60
Volatile Organic Compounds.....	63

Chloroform	63
Methyl <i>tert</i> -Butyl Ether	66
Temporal Variability of Selected Water-Quality Constituents in Groundwater from New England Crystalline Rock Aquifers.....	66
Summary and Conclusions.....	72
References Cited.....	74
Appendixes 1–11	81

Figures

1. Map showing location of 117 domestic wells completed in New England crystalline rock aquifers in New England, New Jersey, and New York, and sampled for the U.S. Geological Survey National Water-Quality Assessment Program, 1995–2007	3
2. Maps showing location of 4,775 <i>A</i> , community, <i>B</i> , transient noncommunity, and <i>C</i> , nontransient noncommunity wells used for public supply, completed in New England crystalline rock aquifers in New England, and sampled for the U.S. Environmental Protection Agency Safe Drinking Water Act Program, 1997–2007	7
3. Boxplots showing distributions of <i>A</i> , undeveloped, <i>B</i> , developed, and <i>C</i> , agricultural land uses within 500-meter radius of the public-supply and domestic wells, by percentage of area, in New England crystalline rock aquifers for the year 2001	13
4. Boxplots showing distribution of population densities, by persons per square kilometer, in a 500-meter radius of the public-supply and domestic wells in New England crystalline rock aquifers for the year 2000.....	15
5. Maps showing general distribution of <i>A</i> , major lithology categories and <i>B</i> , of lithology groups of New England crystalline rock aquifers, in New England, New Jersey, and New York	18
6. Map showing spatial distribution of pH values in water samples collected from domestic and public-supply wells in New England crystalline rock aquifers, 1995–2007	22
7. Boxplots showing distribution of <i>A</i> , pH values and <i>B</i> , concentrations of dissolved oxygen in water samples collected from public-supply and domestic wells in New England crystalline rock aquifers, 1995–2007	23
8. Maps showing spatial distributions of <i>A</i> , concentrations of nitrate in water samples from domestic and public-supply wells in New England crystalline rock aquifers, 1995–2007, and <i>B</i> , population density in New England and parts of New Jersey and New York for the year 2000	27
9. Bar graphs showing distribution of percentages of water samples with concentrations of nitrate greater than 1 milligram per liter collected from public-supply and domestic wells in New England crystalline rock aquifers, by categories of population density, 1995–2007	28
10. Bar graphs showing distribution of percentages of water samples with concentrations of nitrate greater than 1 milligram per liter collected from public-supply and domestic wells in New England crystalline rock aquifers, by major category of land use within a 500-meter radius of the sampled wells, 1995–2007.....	29
11. Bar graph showing distribution of percentages of water samples with concentrations of nitrate greater than 1 milligram per liter collected from public-supply and domestic wells in New England crystalline rock aquifers, by categories of well depth and casing length, 1995–2007.....	29
12. Bar graphs showing distribution of percentages of water samples with concentrations of nitrate greater than <i>A</i> , 0.5, <i>B</i> , 3, and <i>C</i> , 6 milligrams per liter collected from public-supply and domestic wells in New England crystalline rock aquifers, 1995–2007.....	30

13.	Trilinear diagram showing relations among major ions in water samples collected from domestic wells in New England crystalline rock aquifers, 1995–2000	31
14.	Map showing dominant water types in water samples collected from domestic wells in New England crystalline rock aquifers, 1995–2000	32
15.	Map showing spatial distribution of chloride concentrations in water samples collected from domestic and public-supply wells in New England crystalline rock aquifers, 1995–2007	33
16.	Boxplots showing distribution of sodium and chloride concentrations in water samples collected from public-supply and domestic wells in New England crystalline rock aquifers, by categories of land use, 1995–2007	34
17.	Boxplots showing distribution of sodium and chloride concentrations in water samples collected from public-supply and domestic wells in New England crystalline rock aquifers, by categories of population density, 1995–2007	34
18.	Scatterplots showing chloride to bromide mass ratios in relation to <i>A</i> , chloride concentrations, <i>B</i> , sodium to chloride molar ratios, and <i>C</i> , pH in water samples collected from domestic wells in New England crystalline rock aquifers, 1995–2000 ...	36
19.	Map showing spatial distribution of fluoride concentrations in water samples collected from domestic and public-supply wells in New England crystalline rock aquifers, 1995–2007	37
20.	Boxplots showing distribution of <i>A</i> , concentrations of fluoride in water samples collected from public-supply and domestic wells in New England crystalline rock aquifers and <i>B</i> , bar graph showing percentages of these samples with concentrations of fluoride greater than the U.S. Environmental Protection Agency maximum contaminant level of 4 milligrams per liter, by lithology group, 1995–2007	38
21.	Map showing spatial distribution of manganese concentrations in water samples collected from domestic and public-supply wells in New England crystalline rock aquifers, 1995–2007	42
22.	Map showing spatial distributions of arsenic concentrations in water samples collected from domestic and public-supply wells in New England crystalline rock aquifers, 1995–2007	46
23.	Bar graph showing distribution of percentages of water samples with concentrations of arsenic greater than 10 micrograms per liter collected from domestic wells in New England crystalline rock aquifers, by the National Water-Quality Assessment Program well network, 1995–2000	48
24.	Bar graph showing distribution of percentages of water samples with concentrations of arsenic greater than 10 micrograms per liter collected from public-supply and domestic wells in New England crystalline rock aquifers, by categories of well depth and casing length, 1995–2007	48
25.	Boxplots showing distributions of <i>A</i> , concentrations of arsenic in water samples collected from public-supply and domestic wells in New England crystalline rock aquifers and <i>B</i> , bar graph showing percentages of these samples with concentrations of arsenic greater than the U.S. Environmental Protection Agency maximum contamination level of 10 micrograms per liter, by lithology group, 1995–2007	49
26.	Scatterplots showing relations of concentrations of arsenic in water samples collected from domestic wells in New England crystalline rock aquifers to <i>A</i> , pH, and <i>B</i> , concentrations of nitrate, 1995–2000	50
27.	Bar graph showing distribution of percentages of water samples collected from public-supply and domestic wells in New England crystalline rock aquifers with concentrations of arsenic greater than the U.S. Environmental Protection Agency maximum contaminant level of 10 micrograms per liter, by categories of pH and nitrate concentrations, 1995–2007	51

28.	Map showing spatial distribution of gross alpha-particle activities in water samples collected from domestic and public-supply wells in New England crystalline rock aquifers, 1999–2007	52
29.	Map showing spatial distribution of combined radium activities in water samples collected from domestic and public-supply wells in New England crystalline rock aquifers, 1999–2007	54
30.	Map showing spatial distribution of ²²² radon activities in water samples collected from domestic and public-supply wells in New England crystalline rock aquifers, 1995–2007	55
31.	Boxplots showing distribution of <i>A</i> , activities of ²²² radon in water samples collected from public-supply and domestic wells in New England crystalline rock aquifers, and <i>B</i> , bar graph showing percentages of these samples with activities of ²²² radon greater than the proposed alternative U.S. Environmental Protection Agency maximum contaminant level of 4,000 picocuries per liter, by lithology group, 1995–2007	56
32.	Map showing spatial distribution of uranium concentrations in water samples collected from domestic and public-supply wells in New England crystalline rock aquifers, 1995–2007	57
33.	Boxplots showing distribution of concentrations of uranium in water samples collected from domestic wells in New England crystalline rock aquifers, by the National Water-Quality Assessment Program well network, 1995–2000	58
34.	Boxplots showing distribution of <i>A</i> , concentrations of uranium in water samples collected from public-supply and domestic wells in New England crystalline rock aquifers and <i>B</i> , bar graph showing percentages of these samples with concentrations of uranium greater than the U.S. Environmental Protection Agency maximum contaminant level of 30 micrograms per liter, by lithology group, 1995–2007	59
35.	Bar graph showing detection frequencies for the nine most common volatile organic compounds in water samples collected from domestic wells in New England crystalline rock aquifers, 1995–2000	64
36.	Map showing spatial distribution of chloroform concentrations in water samples collected from domestic wells in New England crystalline rock aquifers, 1995–2000	65
37.	Map showing spatial distribution of methyl <i>tert</i> -butyl ether concentration in water samples collected from domestic and public-supply wells in New England crystalline rock aquifers, 1995–2007	67
38.	Bar graphs showing distribution of percentages of water samples collected from public-supply and domestic wells in New England crystalline rock aquifers with concentrations of methyl <i>tert</i> -butyl ether greater than 1 microgram per liter, by categories of <i>A</i> , population density and <i>B</i> , land use, 1995–2007	68
39.	Scatterplots showing concentrations of methyl <i>tert</i> -butyl ether in water samples collected from domestic wells in New England crystalline rock aquifers in relation to <i>A</i> , apparent year of recharge; <i>B</i> , dissolved oxygen concentrations; <i>C</i> , field pH; <i>D</i> , depth to groundwater table; <i>E</i> , depth to bottom of well casing; and <i>F</i> , well depth, 1995–2000	69
40.	Map showing location of six domestic trend wells in New England crystalline rock aquifers that were sampled biannually for the National Water-Quality Assessment Program to determine trends in selected physiochemical properties and water-quality constituents, 1999–2007	70
41.	Plots showing <i>A</i> , water levels, <i>B</i> , pH, and concentrations of <i>C</i> , dissolved oxygen, <i>D</i> , nitrate, <i>E</i> , arsenic, and <i>F</i> , methyl <i>tert</i> -butyl ether in water samples collected from six domestic trend wells in New England crystalline rock aquifers, 1999–2007	71

Tables

1.	Sources of data used in this study, 1995–2007	6
2.	Summary data on the 4,892 wells sampled, by state, source of data, and type of water system in New England, New Jersey, and New York, 1995–2007	8
3.	Inorganic and organic constituents detected in blank samples collected by the National Water-Quality Assessment Program studies in New England crystalline rock aquifers, in New England, New Jersey, and New York, 1995–2000.....	10
4.	Number of untreated, unfiltered water samples analyzed for selected water-quality properties and constituents, collected for the U.S. Environmental Protection Agency Safe Drinking Water Act Program from public-supply wells in New England crystalline rock aquifers, by State, 1997–2007	11
5.	Distribution of domestic and public-supply wells in New England crystalline rock aquifers, by major categories of land use, population density, and well-construction properties	14
6.	Summary statistics for selected well-construction properties of the domestic and public-supply wells in New England crystalline rock aquifers, 1995–2007.....	16
7.	Generalized description of the major lithology categories and lithology groups in the New England crystalline rock aquifers used in this report	17
8.	Summary statistics for selected physiochemical properties and water-quality constituents in water samples collected from domestic and public-supply wells in New England crystalline rock aquifers, 1995–2007.....	20
9.	Concentrations of selected water-quality constituents in water samples collected from domestic wells for the U.S. Geological Survey National Water-Quality Assessment Program and public-supply wells for the U.S. Environmental Protection Agency Safe Drinking Water Act Program in New England crystalline rock aquifers, 1995–2007, with exceedances of human health benchmarks and non-health guidelines.	24
10.	Sources and quantities of nitrogen inputs in New England States and in New Jersey, 2002 and 2004	26
11.	Rho values from Spearman correlations of selected physiochemical properties, major ions, dissolved gases, and trace elements with trace-element data in groundwater collected for the U.S. Geological Survey National Water-Quality Assessment Program from domestic wells in New England crystalline rock aquifers, 1995–2000.	40
12.	Arsenic occurrence in groundwater at concentrations greater than the U.S. Environmental Protection Agency Maximum Contaminant Level, by previous studies	44
13.	Rho and probability values from Spearman correlations among selected radionuclides and lead in groundwater collected from domestic and public-supply wells in New England crystalline rock aquifers, 1995–2007.....	61
14.	Summary of 344 water samples collected from domestic and public-supply wells in New England crystalline rock aquifers with co-occurrence of uranium concentrations, gross alpha activities, and ²²² Rn activities exceeding existing or proposed human-health benchmarks, by lithology group, 1999–2007	62

Conversion Factors and Abbreviations

Multiply	By	To obtain
Length		
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
Area		
square kilometer (km ²)	0.3861	square mile (mi ²)
Volume		
liter (L)	0.2642	gallon (gal)
cubic meter (m ³)	264.2	gallon (gal)
cubic centimeter (cm ³)	0.06102	cubic inch (in ³)
Flow rate		
liter per second (L/s)	15.85	gallon per minute (gal/min)
cubic meter per day (m ³ /d)	264.2	gallon per day (gal/d)
millimeter per year (mm/yr)	0.03937	inch per year (in/yr)
Mass		
gram (g)	0.03527	ounce, avoirdupois (oz)
kilogram (kg)	2.205	pound avoirdupois (lb)
metric ton per year	1.102	ton per year (ton/yr)
Radioactivity		
becquerel per liter (Bq/L)	27.027	picocurie per liter (pCi/L)

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

$$^{\circ}\text{F}=(1.8\times^{\circ}\text{C})+32$$

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

$$^{\circ}\text{C}=(^{\circ}\text{F}-32)/1.8$$

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius ($\mu\text{S}/\text{cm}$ at 25°C).

Concentrations of chemical constituents in water or air are given in milligrams per liter (mg/L), micrograms per liter ($\mu\text{g}/\text{L}$), parts per billion (ppb), milliequivalents per liter (mEq), or grams per kilogram (g/kg).

List of Abbreviations

Al	aluminum
AMCL	alternative maximum contaminant level
Ar	argon gas
As	arsenic
B	boron
Ba	barium
Be	beryllium
Br	bromide
BTEX	benzene, toluene, ethylbenzene, and xylene
Ca	calcium
CaCO ₃	calcium carbonate
CFC-11	trichlorofluoromethane
CFC-12	dichlorodifluoromethane
CFC-113	1,1,2-trichlorotrifluoroethane
CH ₄	methane gas
CIAT	deethylatrazine, 2-chloro-4-isopropylamino-6-amino-s-triazine
CONN	Connecticut, Housatonic, and Thames River Basin
CO ₂	carbon dioxide gas
CO ₃	carbonate
Cr	chromium
DBCP	dibromochloropropane
DCPA	dimethyl tetrachloroterephthalate, trade name "Dacthal"
1,1-DCA	1,1-dichloroethane
1,1-DCE	1,1-dichloroethene
1,2-DCE	<i>cis</i> -1,2-dichloroethene
DIPE	diisopropyl ether
DO or O ₂	dissolved oxygen
DOC	dissolved organic carbon
E	estimated concentration
EDB	ethylene dibromide
EtBE	ethyl- <i>tert</i> -butyl ether
F	fluoride
Fe	iron
Fe ²⁺	ferrous iron
² H	deuterium, or hydrogen-2
HBSL	health-based screening level
HCO ₃	bicarbonate
K	potassium
Li	lithium

LINJ	Long Island-New Jersey coastal drainages
LRL	laboratory reporting level
MCL	maximum contaminant level
MEK	methyl ethyl ketone, 2-butanone
Mg	magnesium
MIBK	methyl isobutyl ketone
Mn	manganese
MtBE	methyl- <i>tert</i> -butyl ether, methyl <i>tertiary</i> -butyl ether
N	nitrogen
N ₂	nitrogen gas
Na	sodium
NAWQA	National Water-Quality Assessment Program
NECB	New England coastal basins study unit
NECR	New England crystalline bedrock
NH ₄	ammonium
NO ₂	nitrite
NO ₃	nitrate
NWQL	National Water Quality Laboratory
¹⁸ O	oxygen-18 isotope
Pb	lead
pCi/L	picocuries per liter
PCE	perchloroethene (perc), perchloroethylene, or tetrachloroethylene
p-DCB	1,4-dichlorobenzene
PO ₄	orthophosphate
p,p'-DDE	p,p-dichlorodiphenyldichloroethylene
²²⁴ Ra	²²⁴ radium, radium-224
²²⁶ Ra	²²⁶ radium, radium, 226
²²⁸ Ra	²²⁸ radium, radium-228
REDOX	reduction-oxidation potential
²²² Rn	radon, ²²² radon, radon-222
SDWA	Safe Drinking Water Act
SO ₄	sulfate
TAME	<i>tert</i> -amyl methyl ether
TCA	1,1,1-trichloroethane
TCE	trichloroethene or trichloroethylene
TDS	total dissolved solids
U	uranium
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
VOC	volatile organic compound
VSMOW	Vienna standard mean ocean water

Quality of Water from Crystalline Rock Aquifers in New England, New Jersey, and New York, 1995–2007

By Sarah M. Flanagan, Joseph D. Ayotte, and Gilpin R. Robinson, Jr.

Abstract

Crystalline bedrock aquifers in New England and parts of New Jersey and New York (NECR aquifers) are a major source of drinking water. Because the quality of water in these aquifers is highly variable, the U.S. Geological Survey (USGS) statistically analyzed chemical data on samples of untreated groundwater collected from 117 domestic bedrock wells in New England, New York, and New Jersey, and from 4,775 public-supply bedrock wells in New England to characterize the quality of the groundwater. The domestic-well data were from samples collected by the USGS National Water-Quality Assessment (NAWQA) Program from 1995 through 2007. The public-supply-well data were from samples collected for the U.S. Environmental Protection Agency (USEPA) Safe Drinking Water Act (SDWA) Program from 1997 through 2007. Chemical data compiled from the domestic wells include pH, specific conductance, dissolved oxygen, alkalinity, and turbidity; 6 nitrogen and phosphorus compounds, 14 major ions, 23 trace elements, ²²²radon gas (radon), 48 pesticide compounds, and 82 volatile organic compounds (VOCs). Additional samples were collected from the domestic wells for the analysis of gross alpha- and gross beta-particle radioactivity, radium isotopes, chlorofluorocarbon isotopes, and the dissolved gases methane, carbon dioxide, nitrogen, and argon. Chemical data compiled from the public-supply wells include pH, specific conductance, nitrate, iron, manganese, sodium, chloride, fluoride, arsenic, uranium, radon, combined radium (²²⁶radium plus ²²⁸radium), gross alpha-particle radioactivity, and methyl *tert*-butyl ether (MtBE).

Patterns in fluoride, arsenic, uranium, and radon distributions were discernable when the data were compared to lithology groupings of the bedrock, indicating that the type of bedrock has an effect on the quality of groundwater from NECR aquifers. Fluoride concentrations were significantly higher in groundwater samples from the alkali granite, peraluminous granite, and metaluminous granite lithology groups than from samples in the other lithology groups. Water samples from 1.4 percent of 2,167 studied wells had fluoride concentrations that were equal to or greater than the maximum contaminant level (MCL) of 4 milligrams per liter (mg/L) and 7.5 percent of the wells had fluoride concentrations that were equal to or greater than the secondary MCL of 2 mg/L. For arsenic, groundwater samples from the calcareous

metasedimentary rocks in the New Hampshire-Maine geologic province, peraluminous granite, and pelitic rocks lithology groups had higher concentrations than did samples from the other lithology groups. Water samples from 13.3 percent of 2,054 studied wells had arsenic concentrations that were equal to or greater than the MCL of 10 micrograms per liter ($\mu\text{g/L}$), about double the national rate of occurrence in community-supply systems and in domestic wells of the United States. Uranium concentrations were significantly higher in groundwater samples from the peraluminous granite, alkali granite, and calcareous metasedimentary rocks in the New Hampshire-Maine geologic province lithology groups than from samples in the other lithology groups. Water samples from 14.2 percent of 556 studied wells had uranium concentrations equal to or greater than the MCL of 30 $\mu\text{g/L}$. Radon activities were equal to or greater than the proposed MCL of 300 picocuries per liter (pCi/L) in 95 percent of 943 studied wells, and 33 percent of the wells had radon activities equal to or greater than the proposed alternative maximum contaminant level (AMCL) of 4,000 pCi/L. Radon activities exceeded the proposed AMCL in 20 percent or more of groundwater samples in each of the studied lithology groups with a minimum of 9 samples, but radon activities were significantly higher in groundwater samples from the alkali granite, peraluminous granite, and Narragansett basin metasedimentary rocks lithology groups. Water samples from 3.2 percent of 564 studied wells had combined radium activities equal to or greater than the MCL of 5 pCi/L; however, combined radium activities were not significantly different among the studied lithology groups.

Land use and population density also were evaluated to explain patterns in water quality. Concentrations of nitrate, sodium, chloride, and MtBE from the studied wells were significantly greater in areas of high population density (≥ 50 persons per square kilometer) than in areas of low population density (< 50 persons per square kilometer). Concentrations of sodium, chloride, and MtBE from the studied wells were significantly greater in areas classified as developed (urban lands) than in areas classified as undeveloped (forested), agricultural, or mixed (no dominant land use). Nitrate concentrations from the public-supply wells were not significantly different among the four land use categories, but nitrate concentrations from the domestic wells were significantly greater in areas classified as developed than in areas classified as undeveloped, agricultural, or mixed.

Chloride to bromide mass ratios in the domestic well samples indicate that the groundwater was probably affected by at least three halogen sources: local precipitation and recharge waters, remnant seawater and connate waters evolved from seawater, and recharge waters affected by road salt. The groundwater in the NECR aquifers generally contained low concentrations of nitrate, VOCs, and pesticides. Less than 1 percent of water samples from 4,781 studied wells had concentrations of nitrate greater than the MCL of 10 mg/L. Less than 1 percent of water samples from 1,299 studied wells exceeded the USEPA advisory level of 20 to 40 µg/L for M₇BE. None of the other studied VOCs exceeded a human health benchmark. M₇BE (36 percent frequency detection) and chloroform (32.9 percent frequency detection) were the most frequently detected (>0.02 µg/L) VOCs in the domestic wells. M₇BE was detected more often in water samples with apparent ages of less than 25 years than in water samples with apparent ages greater than 25 years. This finding is consistent with the time period of high M₇BE use in areas in the United States where reformulated gasoline was mandated. The largest pesticide concentration was an estimated concentration of 0.06 µg/L for the herbicide metolachlor. Deethylatrazine, a degradate of atrazine, (18 percent frequency detection) and atrazine (8 percent frequency detection) were the only pesticide compounds detected (>0.001 µg/L) in more than 3 percent of the domestic wells. None of the detected pesticide compounds exceeded human health benchmarks.

Concentrations of nitrate and gross alpha-particle activities were significantly greater in the water samples from the domestic wells than in samples from the public-supply wells. Concentrations of sodium, chloride, iron, manganese, and uranium were significantly greater in the water samples from the public-supply wells than in the samples from the domestic wells. One possible explanation may be related to differences in field processing (filtered samples from the domestic wells compared to unfiltered samples from the public-supply wells).

The high frequency of detections for a wide variety of manmade and naturally occurring contaminants in both domestic and public-supply wells shows the vulnerability of NECR aquifers to contamination. The highly variable water quality and the association with highly variable lithology of crystalline bedrock underscores the importance of testing individual wells to determine if concentrations for the most commonly detected contaminants exceed human health benchmarks.

Introduction

The U.S. Geological Survey (USGS) National Water-Quality Assessment (NAWQA) Program assesses groundwater-quality conditions and trends in 19 principal aquifers across the Nation that are major sources of public and domestic-supply drinking water (Lapham and others, 2005). These regional-scale aquifer assessments complement and extend the findings of small-scale studies. One of the

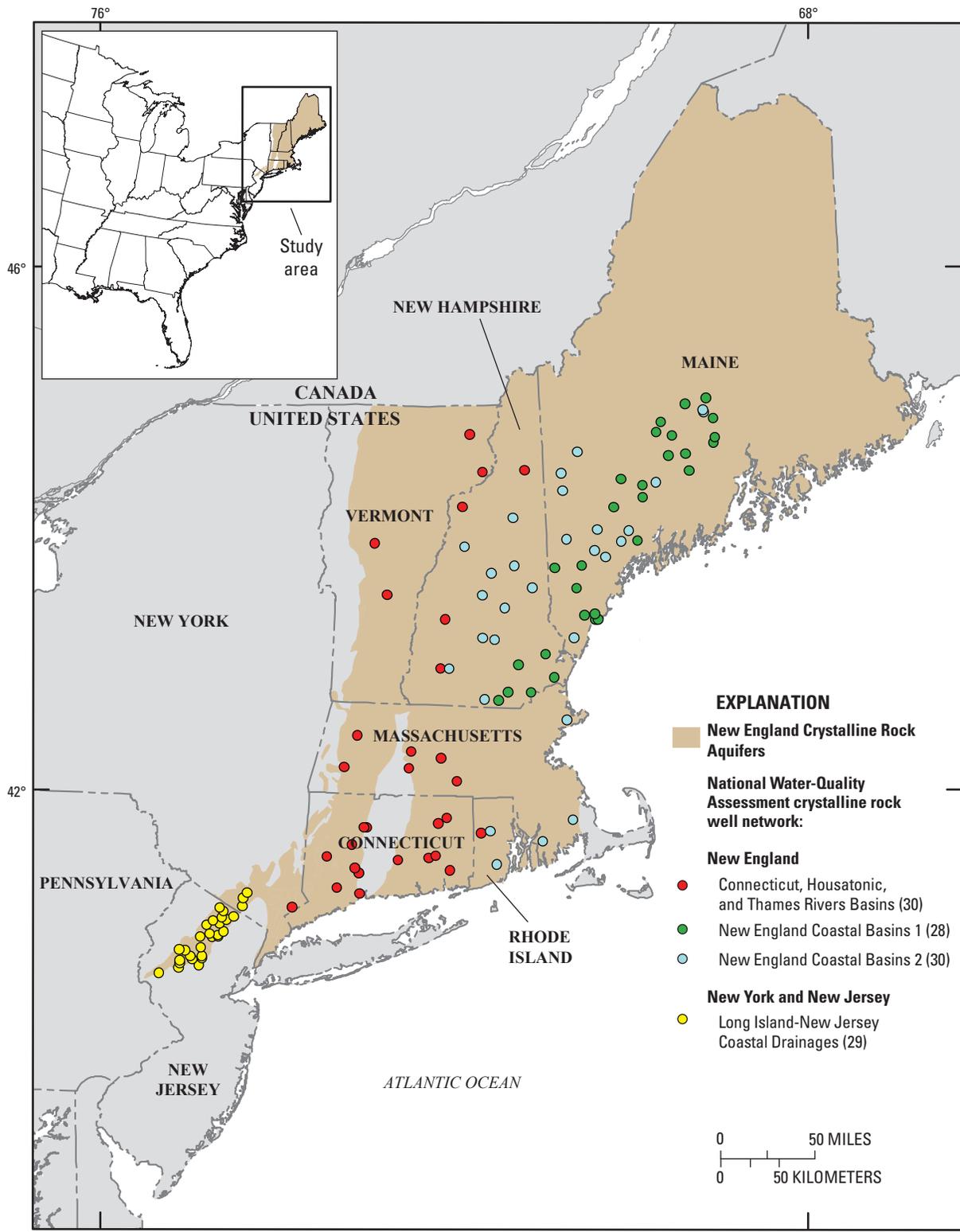
groups of principal aquifers being studied are the New England crystalline rock (NECR) aquifers (fig. 1). Often called “fractured bedrock,” crystalline rock aquifers are the most extensive and widely available aquifers in New England, in a small part of northern New Jersey, and in north-central New York. About 74 million gallons of groundwater were withdrawn per day (Mgal/d) from NECR aquifers for public supply, 49 Mgal/d for domestic supply, 12 Mgal/d for self-supplied industrial use, and 11 Mgal/d for irrigation use (Maupin and Barber, 2005; Maupin and Arnold, 2010). The U.S. Environmental Protection Agency (USEPA) has estimated that about 2.3 million people (about 20 percent New England’s population) obtain drinking water from their own private (domestic) well (accessed April 15, 2012, at http://www.epa.gov/region1/eco/drinkwater/private_well_owners.html) and NECR aquifers are the dominant source of water to these wells.

Yields and quality of groundwater from wells completed in New England bedrock aquifers are greatly affected by the hydraulic properties of the aquifer, which include the degree of foliation in the bedrock formations and the extent, size, and number of water-bearing fractures. The quality of natural bedrock groundwater also is affected by the chemistry of precipitation (primary source of recharge), biological processes, characteristics of soil and surficial sediments, length of residence time in the aquifer, and aquifer materials.

In part because of the complex geology, fracture heterogeneity, and tectonic history of crystalline rock in New England, the water quality of the NECR aquifers is highly variable, and the chemistry of the groundwater can differ substantially from well to well, even among wells that are in close proximity. Thus, a framework approach for assessing NECR aquifers on a regional scale was prepared (Harte and others, 2008) and used to evaluate available water-quality data.

Purpose and Scope

This report summarizes water-quality data for domestic and public-supply wells completed in the NECR principal aquifer system in the six New England States and a small part of northern New Jersey and southern New York. The data from the domestic wells were from water samples collected for the NAWQA Program during 1995–2000, and the data from the public-supply wells were from water samples collected for the USEPA Safe Drinking Water Act (SDWA) Program during 1997–2007. The report describes the occurrence of contaminants—arsenic, uranium, fluoride, gas (²²²radon), combined radium (²²⁶Ra + ²²⁸Ra), and gross alpha-particle activity—in the context of a regional lithologic and geochemical framework. Nitrate, sodium, chloride, and M₇BE are examined by categories of land use and population density. Major ion chemistry, selected trace elements, volatile organic compounds (VOCs), and pesticides also are evaluated. Factors that relate to constituent concentrations greater than selected threshold levels are evaluated. The report provides a preliminary assessment of trends in water quality based on water samples collected biennially for six domestic wells during 1999–2007.



Base from U.S. Geological Survey digital data, 1:2,000,000, Albers Projection

Study area modified from U.S. Geological Survey Ground Water Atlas of the United States (Olcott, 1995).

Figure 1. Location of 117 domestic wells completed in New England crystalline rock aquifers in New England, New Jersey, and New York, and sampled for the U.S. Geological Survey National Water-Quality Assessment Program, 1995–2007. The Connecticut, Housatonic, and Thames Rivers Basins and the Long Island-New Jersey Coastal Drainages well networks comprise undifferentiated crystalline rock; the New England Coastal Basins well network 1 comprises predominantly calcareous metasedimentary rocks; and the New England Coastal Basins well network 2 comprises predominantly felsic igneous and pelitic rocks.

Description of Study Area

NECR aquifers underlie an area of approximately 72,000 square miles (Harte and others, 2008). It includes a small area in northern New Jersey, a narrow band across southern New York, and a majority of the land area in the New England States of Connecticut, Massachusetts, Maine, New Hampshire, Rhode Island, and Vermont (fig. 1). A large area of crystalline bedrock occurs in northern New York (Harte and others, 2008), but was not evaluated in this study.

Areas of New England bedrock that are not considered crystalline were not studied. These areas include (1) Cape Cod and the major offshore islands in southeastern Massachusetts where the bedrock is overlain with thick deposits of unconsolidated glacial sediments, (2) the clastic sedimentary and igneous rocks in the Mesozoic basins in central Connecticut and Massachusetts that are layered and largely unmetamorphosed, and (3) the predominantly unmetamorphosed bedded carbonate rocks in western parts of Connecticut, Massachusetts, and Vermont that are part of the “Grenville Shelf Sequence” geologic province (Robinson and Kapo, 2003; fig. 1).

A wide variety of igneous and metamorphic rocks of various metamorphic grades compose NECR aquifers (Zimmerman and others, 1996; Robinson, 1997; Flanagan and others, 1999). These rocks, ranging in age from the Precambrian to the Cretaceous, are folded, faulted, and foliated. They commonly exhibit preferential joint and stress-relief fractures as a result of tectonic activity, cooling stresses associated with igneous intrusion, rock erosion, and most recently, the melting of glacial ice sheets that once covered New England (Hanson and Simcox, 1994; Flanagan and others, 1999; Harte and others, 2008). Harte and others (2008) describes in detail the physical setting and geohydrology of NECR aquifers.

Much of New England is thinly mantled by glacial till, and many of the glacially broadened valleys have glacial outwash deposits overlain with thin soils. Where glacial deposits are thin or nonexistent, crystalline rock is the primary source of groundwater. The glacially derived soils of New England are generally deficient in nutrients, but they are well suited for forest growth because of the area’s humid, temperate climate of warm, moist summers and cold, snowy winters (Flanagan and others, 1999). Mean annual precipitation (1961–90) is relatively high, ranging from less than 34 to about 50 inches per year, and increases toward the Atlantic coast and at higher elevations (Harte and others, 2008). New England has some of the highest rates of runoff in the United States due to the relatively high topographic relief in the Green Mountains, White Mountains, and Appalachian Mountains in Maine, New Hampshire, and Vermont (Kontis and others, 2004). High runoff rates, combined with a glaciated terrain dominated by thin soils, result in a landscape that contains numerous rivers, streams, lakes, ponds, and wetlands.

The dominant land cover overlying the NECR aquifers in New England is forested land, primarily in the States of Maine, New Hampshire, and Vermont, which covers about

61 percent of New England (U.S. Geological Survey, 2006; Harte and others, 2008). Open waters cover 13 percent, and wetlands cover about 7 percent. Developed (or urban) land accounts for about 8 percent; agricultural land, about 7 percent; and shrub land, about 4 percent (U.S. Geological Survey, 2006). Although developed and agricultural lands combined cover less than 15 percent of New England, these uses of the land can have a disproportionately greater effect on groundwater quality than other land uses (Robinson and others, 2004).

The spatial distribution of these land uses and land cover in New England is highly variable. The densely populated urban areas in the southern New England States of Connecticut, Rhode Island, and Massachusetts include the major cities of Hartford, Providence, and Boston; nearby cities; and suburban areas. High-traffic interstate highways are present in these areas. Many small cities were, over a century ago, factory or mill towns that took advantage of New England’s hydropower resources to power the region’s paper mills and factories (Zimmerman and others, 1996; Flanagan and others, 1999). Small farms are scattered throughout the valley lowland and coastal areas of New England, but they are located primarily in western Vermont, northeastern Maine, and the Connecticut River valley in Massachusetts and Connecticut (Harte and others, 2008). The small part of the study area in northern New Jersey and southern New York consists of densely populated suburban lands that have developed as expansions of the nearby cities of New York and Philadelphia (Ayers and others, 2000).

Previous Investigations

Harte and others (2008) summarizes the results of many small-scale studies that focused on water-availability issues and selected contaminants in NECR aquifers. Recent small-scale (county) and multi-State-scale studies of individual contaminants have shown that the NECR aquifers are vulnerable to contamination by arsenic (Peters and others, 1999; Montgomery and others, 2003; Moore, 2004; Ayotte and others, 2006) and methyl *tert*-butyl ether (MtBE) (Maine Department of Human Services, 1998; Peckenham, 2002; Ayotte and others, 2004, 2005, 2008). Ayotte and others (1999) examined relations among arsenic (As), iron (Fe), and manganese (Mn) concentrations in groundwater from bedrock aquifers in eastern New England with rock type and generalized geologic lithology. The MtBE studies found that MtBE concentrations in private bedrock wells in New Hampshire and Maine were related to urban factors, such as population density, housing density, and the percentages of urban land use and roads within 500-meter (m) radius surrounding the wells. The arsenic studies identified bedrock lithology and redox conditions as important explanatory variables in predicting arsenic concentrations. In particular, high arsenic concentrations [>10 micrograms per liter ($\mu\text{g/L}$)] were associated with a lithostratigraphic belt of calcareous

metasedimentary rocks in eastern New England, high pH (7.0–8.5) and low dissolved oxygen (DO) concentrations [<1 milligram per liter (mg/L)].

On a national scale, the NAWQA Program conducted an assessment by DeSimone (2009) of water-quality conditions in about 2,170 domestic wells sampled for the NAWQA Program, in all major aquifer systems across the United States. DeSimone and others (2009) provide an overview of major findings for this study. Zogorski and others (2006) and Gilliom and others (2006) describe the major findings of the NAWQA Program on volatile organic compounds in samples from public-supply and domestic wells, and on pesticides in surface water and groundwater from local-scale NAWQA studies. These and other studies done by the NAWQA Program on the occurrence, distribution, fate, and other factors relating to the concentrations of nutrients, trace elements, VOCs, and pesticides in groundwater in the United States are available at <http://water.usgs.gov/nawqa/>.

Study Design

The design of this study was based on including as many drinking-water supply wells as possible to assess the ambient groundwater-quality of NECR aquifers on a regional scale. As a result, the data used in this study are biased towards areas where the aquifer is most used for public drinking-water supply. The groundwater-quality data analyzed in this report are for 117 domestic wells sampled by the USGS NAWQA Program during 1995–2007 (fig. 1, table 1) and for 4,775 public-supply wells sampled by the USEPA Safe Drinking Water Act (SDWA) Program during 1997–2007 (fig. 2, table 1). The SDWA Program provided the additional water-quality data in order to allow, where available, a regional comparison of water-quality data from domestic and public-supply wells in New England. Some of those SDWA data have limitations, such as incomplete water-quality datasets or higher laboratory reporting levels (LRLs) than the NAWQA data, but the data were nonetheless available for expanding the spatial coverage of water-quality conditions for many water-quality constituents. Analyses reported here are for untreated groundwater and exclude treated (finished) water produced by municipal water-treatment or in-home water-treatment systems. Municipal water-treatment plants or in-home systems produce water that may be chemically different from that described in this report. Where applicable, water-quality data from the domestic and public-supply well samples are compared to USEPA proposed and enforceable maximum contaminant levels (MCLs) and secondary MCLs (SMCLs), which technically apply only to community water systems (U.S. Environmental Protection Agency, 2009).

Harte and others (2008) suggest that the relation between physical and chemical processes may be useful for the analysis of factors controlling the quality of groundwater from NECR aquifers. The framework approach described in Harte and

others (2008) incorporates explanatory variables (features), including (1) geologic factors, (2) aquifer hydraulics, (3) land use and land cover, and (4) geochemical factors. On a regional scale, these features may be related to indicators of natural and anthropogenic sources of contaminants, as well as indicators of the physical characteristics of the aquifer systems that affect groundwater chemistry. In this study, water-quality concentrations of some constituents were compared to some of these variables to determine relations among the regional groundwater quality and these variables.

Data from USGS NAWQA Domestic Wells

The 117 domestic wells sampled by the three NAWQA studies were selected randomly, without consideration of the surrounding land uses, within each NAWQA study boundary in accordance with NAWQA protocols (Lapham and others, 1995) using procedures described by Scott (1990). Thirty domestic wells, primarily in Connecticut and Massachusetts, were sampled in 1995 for the Connecticut, Housatonic, and Thames Rivers Basins (CONN) NAWQA well network (fig. 1, tables 1–2) (Garabedian and others, 1998). For the CONN study, wells were selected randomly in areas of crystalline rock (described by Grady and Mullany, 1998) without consideration of the underlying geology. Twenty-six domestic wells in New Jersey and three domestic wells in New York were sampled in 1997 for the Long Island-New York-New Jersey Coastal Drainages (LINJ) well network (fig. 1, tables 1–2) (Ayers and others, 2000). For the LINJ study, wells within a small area of crystalline rock in northern New Jersey and in southeastern New York were selected (fig. 1).

During 1999 and 2000, the New England Coastal Basins (NECB) study sampled 58 domestic bedrock wells, primarily in Maine and New Hampshire (fig. 1, tables 1–2) (Robinson and others, 2004). Although the CONN wells were randomly chosen from all areas of crystalline bedrock within the study boundary, the wells sampled by the NECB study were randomly chosen within selected geologic lithologies. One NECB well network consists of 28 domestic bedrock wells in Maine and New Hampshire (fig. 1), in areas where the geologic units are dominated by calcareous metasedimentary rocks and where arsenic is likely to occur in groundwater (Ayotte and others, 2003; Robinson and others, 2004). Six of the 28 wells in this network also were sampled up to four times from 2003 to 2007. The other NECB well network consists of 30 domestic bedrock wells in Maine, New Hampshire, Massachusetts, and Rhode Island (fig. 1), in areas where the geologic units are dominated by felsic igneous and pelitic rocks and where uranium (U) and other radiochemicals are likely to occur in groundwater (Robinson and others, 2004). Ayotte and others (2003) analyzed, in detail, factors related to arsenic occurrence in these two well networks.

NAWQA water samples were collected and analyzed to determine physiochemical properties (dissolved oxygen, pH, specific conductance, water temperature, and turbidity) and

Table 1. Sources of data used in this study, 1995–2007.

[NAWQA, U.S. Geological Survey National Water-Quality Assessment Program; CONN, Connecticut, Housatonic, and Thames Rivers Basins study unit; LINJ, Long Island-New Jersey Coastal Drainages study unit; NECB, New England Coastal Basins study units; USEPA SDWA, U.S. Environmental Protection Agency Safe Drinking Water Act Program; VOC, volatile organic compound; CFC, chlorofluorocarbon. All wells used for this study are drilled wells completed in New England crystalline rock aquifers. The locations of the NAWQA wells are shown in figure 1, and the locations of the SDWA wells are shown in figure 2]

Source of data	Purpose of program	Number of wells	Sample period	Frequency of sampling	Water-quality properties and constituents	Well-selection design
NAWQA CONN	Untreated groundwater samples collected from randomly selected domestic wells to measure water-quality conditions as part of the U.S. Geological Survey National Water-Quality Assessment Program.	30	1995	Once	Filtered, untreated groundwater samples preserved and analyzed according to laboratory protocols for nutrients, major ions, trace elements (boron, arsenic, and uranium), organic carbon, and pesticides. Nonfiltered groundwater samples analyzed for physiochemical properties (pH, specific conductance, dissolved oxygen, and water temperature), radon, and VOCs.	Domestic wells randomly selected from areas of crystalline bedrock in western New England, without consideration of underlying geology (Garabedian and others, 1998).
NAWQA LINJ	do.	29	1997	Once	Filtered, untreated groundwater samples preserved and analyzed according to laboratory protocols for nutrients, major ions, trace elements, organic carbon, and pesticides. Nonfiltered groundwater samples analyzed for physiochemical properties (pH, specific conductance, dissolved oxygen, and water temperature), radon, and VOCs.	Domestic wells randomly selected from areas of crystalline bedrock in northern New Jersey and southeastern New York, without consideration of underlying geology (Ayers and others, 2000).
NAWQA NECB1	do.	28	1999–2007	Once (six wells sampled up to four times)	Filtered, untreated groundwater samples preserved and analyzed according to laboratory protocols for nutrients, major ions, trace elements, radium species, gross alpha and gross beta radioactivity, organic carbon, and pesticides. Nonfiltered groundwater samples analyzed for physiochemical properties (pH, specific conductance, dissolved oxygen, and water temperature), radon, CFCs (age-date samples), deuterium, ¹⁸ oxygen, and VOCs.	Domestic wells randomly selected from areas of crystalline bedrock in eastern New England, in geologic units dominated by variably calcareous, metasedimentary rocks (Robinson and others, 2004).
NAWQA NECB2	do.	30	2000	Once	do.	Domestic wells randomly selected from areas of crystalline bedrock in eastern New England, in geologic units dominated by felsic igneous and pelitic rocks (Robinson and others, 2004).
USEPA SDWA	Untreated water samples collected from community water systems as part of compliance monitoring required under the U.S. Environmental Protection Agency's Safe Drinking Water Act of 1972.	4,775	1997–2007	Multiple times (with the most recent value selected for each studied constituent per well)	Nonfiltered, untreated groundwater samples preserved and analyzed according to laboratory protocols for physiochemical properties (pH and specific conductance), nitrate, major ions (sodium, chloride, fluoride, iron, and manganese), trace elements (arsenic and uranium), radon, combined radium (radium-226 plus radium-228), gross alpha activity, and the VOC methyl <i>tert</i> -butyl ether.	Individual public-supply wells completed in crystalline bedrock in New England.

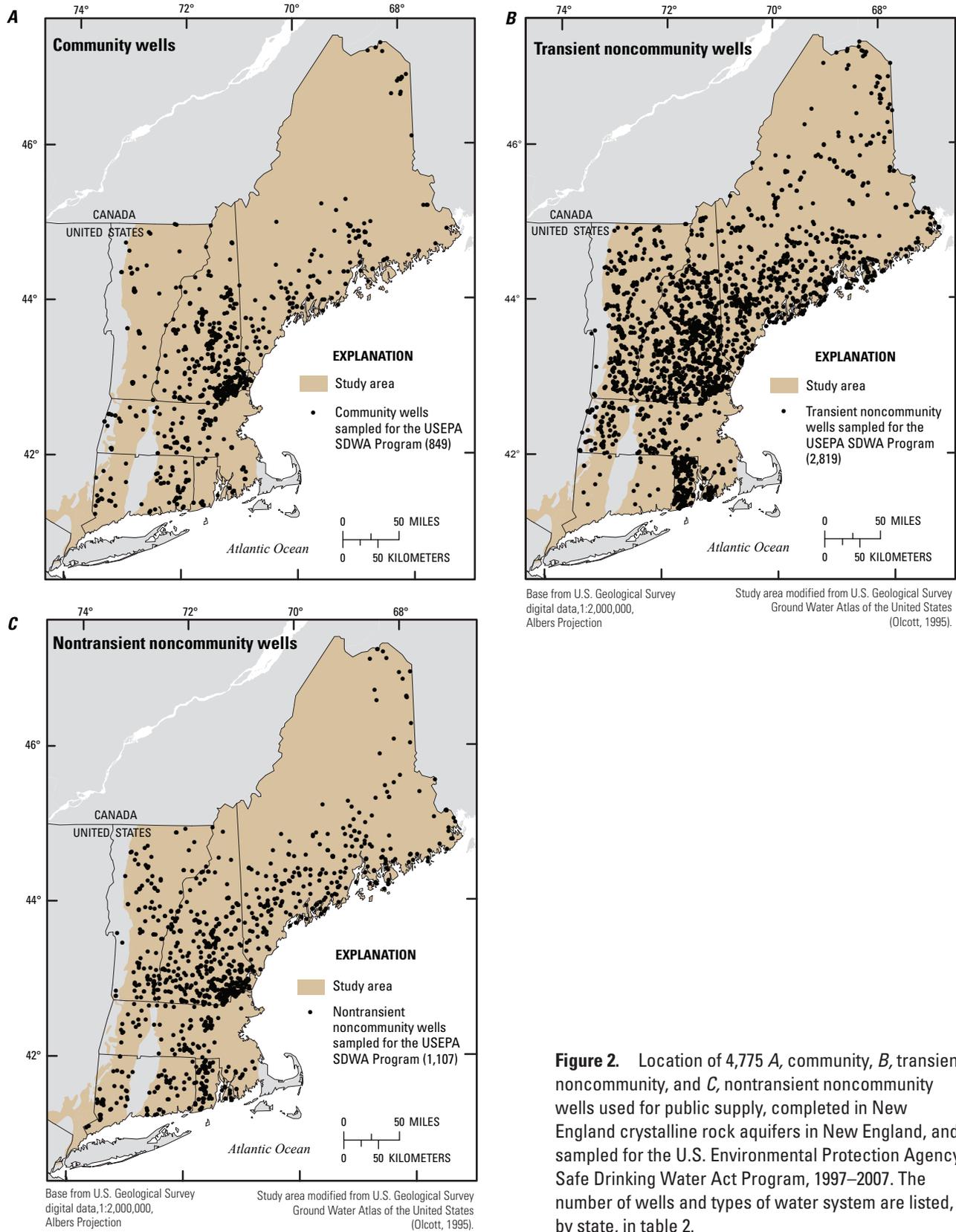


Figure 2. Location of 4,775 *A*, community, *B*, transient noncommunity, and *C*, nontransient noncommunity wells used for public supply, completed in New England crystalline rock aquifers in New England, and sampled for the U.S. Environmental Protection Agency Safe Drinking Water Act Program, 1997–2007. The number of wells and types of water system are listed, by state, in table 2.

8 Quality of Water from Crystalline-Rock Aquifers in New England, New Jersey, and New York, 1995–2007

Table 2. Summary data on the 4,892 wells sampled, by state, source of data, and type of water system in New England, New Jersey, and New York, 1995–2007.

[N, number of sampled wells; USGS NAWQA, U.S. Geological Survey National Water-Quality Assessment; USEPA SDWA, U.S. Environmental Protection Agency Safe Drinking Water Act; LINJ, Long Island-New Jersey Coastal Drainages; CONN, Connecticut, Housatonic, and Thames Rivers Basins; NECB, New England Coastal Basins; COM, community water system; TNC, transient, noncommunity water system; NTNC, nontransient noncommunity water system]

State	Domestic water supply (N)				Public water supply (N)				Total wells in this study
	USGS NAWQA Program				USEPA SDWA Program				
	Total wells (LINJ, NECB, CONN)	New York and New Jersey (LINJ)	New England (CONN) (NECB)		Total wells (COM, TNC, NTNC)	Type of water system (COM) (TNC) (NTNC)			
Connecticut	14	0	14	0	162	61	16	85	176
Massachusetts	9	0	6	3	455	122	232	101	464
Maine	36	0	0	36	1,185	133	795	257	1,221
New Hampshire	21	0	4	17	2,067	476	1,122	469	2,088
Rhode Island	3	0	1	2	418	14	313	91	421
Vermont	4	0	4	0	488	43	341	104	492
New York	4	3	1	0	0	0	0	0	4
New Jersey	26	26	0	0	0	0	0	0	26
Total for study	117	29	30	58	4,775	849	2,819	1,107	4,892

concentrations of major ions, nitrogen (N) and phosphorus (P) compounds, trace elements, dissolved organic carbon (DOC), selected pesticides and pesticide degradates, and selected VOCs, using field procedures described in the USGS national field manual (U.S. Geological Survey, variously dated) and in accordance with NAWQA protocols (Koterba and others, 1995; Lapham and others, 1995). In addition, personnel from the NECB study collected water samples for the analysis of gross alpha- and gross beta-particle radioactivity, radium species (^{224}Ra , ^{226}Ra , and ^{228}Ra), dissolved atmospheric gases [Argon (Ar), carbon dioxide (CO_2), methane (CH_4), and nitrogen (N_2)], the stable isotopes deuterium (^2H) and ^{18}O (^{18}O), and chlorofluorocarbons (CFCs).

NAWQA water samples were collected as close to the wellhead as possible, before household treatment, and just prior to the pressure tank. Specific conductance, pH, dissolved oxygen (DO), and water temperature were measured in the absence of air until readings were stable (Koterba and others, 1995). Once measurements stabilized, water samples were then collected in pre-cleaned bottles, processed, and preserved according to NAWQA protocols (Koterba and others, 1995).

Most of the NAWQA inorganic and pesticide data are from filtered water samples because some laboratory equipment requires sediment removal prior to analysis and filtration removes the sediment bias that might occur when these data are analyzed on national or regional scales. Filtered samples for nutrients, major ions, and trace elements were analyzed for at the USGS National Water Quality Laboratory (NWQL) in Denver, Colorado, using inductively coupled

plasma mass spectrometry (ICP/MS). Filtered samples for pesticides and pesticide-degradates were analyzed for at the USGS NWQL using C-18 solid phase extraction and capillary-column gas chromatograph/mass spectrometry (Furlong and others, 2001). Filtered samples for dissolved organic carbon were analyzed for at the USGS NWQL using ultraviolet light-promoted persulfate oxidation and nondispersive infrared spectrometry (Brenton and Arnett, 1993). Filtered samples for gross alpha- and gross beta-particle radioactivity were analyzed for at the USGS NWQL using low background Planchet counting post-evaporation (USEPA method 900.0; U.S. Environmental Protection Agency, 1980). Filtered samples for selected isotopes of radium species (^{226}Ra and ^{228}Ra) were analyzed for at Severn Trent Laboratories in Richland, Washington, using methods described by McCurdy and others (2008) or by alpha and gamma spectral methods (Focazio and others, 2001; Szabo and others, 2005; Zoltan Szabo, U.S. Geological Survey, written commun., 2007).

Unfiltered samples for VOCs were analyzed at the USGS NWQL using purge and trap capillary-column gas chromatography/mass spectrometry (Rose and Schroeder, 1995; Conner and others, 1998). Unfiltered, stable isotope samples were analyzed for ^2H and ^{18}O at the USGS Reston Stable Isotope Laboratory in Reston, Virginia, using the methods described in Epstein and Mayeda (1953) and Coplen and others (1991). ^2H and ^{18}O are reported as ratios per mill (‰, or per thousand) of $^2\text{H}/^1\text{H}$ (δD) and $^{18}\text{O}/^{16}\text{O}$ ($\delta^{18}\text{O}$), respectively, and are referenced to Vienna Standard Mean Ocean Water (VSMOW; δD and $\delta^{18}\text{O} = 0\text{‰}$).

Measurements of the concentrations of atmospheric gases and CFCs were used to interpret the apparent residence times (ages) of groundwater in 55 unfiltered water samples from domestic wells in the NECB study (table 1). For data in this study, the apparent ages of groundwater were calculated from water samples collected from wells with open boreholes and, thus, may represent a mix of waters with different ages. All ages are regarded as apparent ages because they are based on an interpretation of measured concentrations of environmental tracers in groundwater (Plummer and others, 1993; Plummer and Busenberg, 2000). A detailed analysis of the estimates of tracer-based ages of groundwater done for the NAWQA program is described by Hinkle and others (2010).

Quality Assurance and Quality Control of USGS NAWQA Samples

Documented quality-assurance practices for the collection and analysis of water-quality data have been implemented for the NAWQA samples. The quality-control (QC) samples collected by the USGS NAWQA Program, which are used to assess the reliability of sample processing and analytical methods, included equipment blanks, field blanks, source-solution blanks, and replicate samples. In addition, field matrix spikes (FMSs) and laboratory matrix spikes (LMSs) were collected to assess the extent, if any, that variability, degradation, and matrix effects have on VOC and pesticide data.

Blank Samples

Blank samples were collected to determine the occurrence and magnitude of the contamination of the environmental sample during cleaning of the equipment; during collecting, processing, and transport; and during laboratory analysis (Mueller and Titus, 2005; Apodaca and others, 2006; Bender and others, 2011). Blank samples were collected and analyzed for nutrients (N and P compounds), pesticides and volatile organic compounds, major ions, and trace elements. Results of analyses of inorganic and organic field-blank samples are summarized in table 3. Concentrations of analytes detected in field-blank samples were compared to concentrations of analytes in the NAWQA environmental samples to determine the potential for contamination of the environmental samples. If the concentration of a constituent in the blank samples approaches or exceeds the concentration of the constituent in the environmental samples, then the environmental water-quality data could be biased by sampling contamination. No compounds were detected in any of the six blank samples collected for pesticide analysis. Concentrations of ammonia (NH₃), orthophosphate (PO₄), aluminum (Al), boron, copper (Cu), lead (Pb), zinc (Zn), and toluene in at least one blank sample were greater than the smallest concentration reported for the environmental samples (table 3). Therefore, it may not be possible to distinguish between “true” aquifer conditions and sampling contamination at small concentrations for these constituents. However, relatively few or none of the

other analytes were detected in the blank samples; therefore, equipment decontamination and sample-handling procedures adequately prevented positive bias of reported concentrations for nearly all constituents.

Replicate Samples

Replicate samples are two environmental samples collected sequentially to determine the variability of the data as a result of sampling and analytical procedures. The relative percentage difference (*RPD*) between concentrations of paired replicate samples was calculated using the formula

$$RPD = \frac{|Sample1 - Sample2|}{((Sample1 + Sample2) / 2)} * 100 \quad (1)$$

When there is no variability between the paired analyses, the *RPD* is zero. The *RPD* was not calculated if one or more of the paired samples was censored below the LRL or identified as estimated by the USGS NWQL.

Two to four pairs of sequential replicate samples were collected for the analysis of inorganic constituents. Sequential replicates are multiple samples collected as closely as possible to the same location but at different times (in this study, one set of samples right after the other, but with dedicated filters). The individual constituents with the largest *RPDs* among the paired samples were nickel (71.4 percent), copper (70.3 percent), lead (45 percent), zinc (42.8 percent), aluminum (20.7 percent), cobalt (12.7 percent), and fluoride (9.95 percent). In most cases, the largest *RPDs* were for constituents that were present in small concentrations. Small differences in concentrations, when concentrations themselves are small, can produce large *RPDs*. The nutrients and major ion replicates generally had lower *RPDs* than did the trace-element replicates.

Spiked Samples

Matrix spike quality-control samples measure the bias caused by analyte degradation or sample matrix interference (Rowe and others, 2005; Martin and others, 2009; Martin and Eberle, 2011). The term “matrix” indicates that the spiked solution has been added to an environmental water sample. Groundwater is collected from the well and processed by use of standard operating procedures to produce two samples (Koterba and others, 1995). Spike solution is added to one of the two water samples, resulting in a spiked sample and paired with an un-spiked environmental (or “background”) sample (Rowe and others, 2005; Martin and others, 2009). Most of the pesticide and volatile organic compound matrix spikes were spiked at the field site (field matrix spikes). A few matrix spike samples were spiked by in the laboratory before analysis (laboratory matrix spikes). The amount of a pesticide or VOC measured (recovered) in a FMS or LMS sample is expressed as a percentage (percent recovery) of the known amount of the analyte added to the sample. The percent recovery is considered a primary measure of the performance of the analytical method (Rowe and others, 2005; Martin and others,

Table 3. Inorganic and organic constituents detected in blank samples collected by the National Water-Quality Assessment Program studies in New England crystalline rock aquifers, in New England, New Jersey, and New York, 1995–2000.

[USGS NWIS, U.S. Geological Survey National Water Information System; N, nitrogen; P, phosphorus; E, estimated concentration; +, plus; <, less than; mg/L, milligrams per liter; µg/L, micrograms per liter. The following constituents were not detected in any blank samples: antimony, arsenic, barium, beryllium, bromide, cadmium, chloride, cobalt, fluoride, manganese, molybdenum, nitrite, phosphorus, silver, sulfate, thallium, uranium, and vanadium. No pesticide compounds were detected in any of the six blank samples. All inorganic blank samples were filtered through a single-use, 0.45-micron capsule filter. Volatile organic compound blank samples were not filtered. Pesticide blank samples were filtered through a single use, 0.7-micron glass-fiber filter. Blank samples were analyzed by the U.S. Geological Survey National Water-Quality Laboratory in Denver, Colorado]

Water-quality constituent	USGS NWIS parameter code	Number of detections/ number of blank samples	Units	Maximum concentration in blank samples	Minimum concentration in environmental samples
Nutrients					
Ammonia, as N	00608	1/12	mg/L	0.02	<0.02
Ammonia + organic nitrogen, as N	00623	1/12	mg/L	E.081	<0.1
Nitrate + nitrite, as N	00631	1/12	mg/L	E.024	<0.05
Orthophosphate, as P	00671	3/12	mg/L	0.012	<0.01
Major ions					
Calcium	00915	5/19	mg/L	E.017	2.72
Magnesium	00925	1/19	mg/L	E.009	0.36
Sodium	00930	6/19	mg/L	0.14	1.83
Silica	00955	5/19	mg/L	E.086	5.9
Trace elements					
Aluminum	01106	7/22	µg/L	9.28	<1
Boron	01020	8/24	µg/L	13.5	<12
Chromium	01030	4/22	µg/L	E.75	<0.8
Copper	01040	3/22	µg/L	2.16	<1
Lead	01049	2/22	µg/L	20	<1
Lithium	01130	1/14	µg/L	0.47	<0.6
Iron	01046	1/19	µg/L	E3	<10
Nickel	01065	1/22	µg/L	0.07	<1
Selenium	01145	1/22	µg/L	E.40	<0.7
Strontium	01080	2/22	µg/L	E.11	17.45
Zinc	01090	4/22	µg/L	7.08	<1
Volatile organic compounds					
Benzene	34030	1/19	µg/L	E.01	E.01
Carbon disulfide	77041	1/17	µg/L	E.012	E.006
Dichloromethane	34423	1/19	µg/L	E.014	E.018
Ethylbenzene	34371	1/19	µg/L	E.01	<0.03
Toluene	34010	8/19	µg/L	0.13	0.006
<i>m</i> - and <i>p</i> -xylene	85795	1/17	µg/L	E.03	0.02
<i>o</i> -xylene	77135	1/17	µg/L	E.01	0.055

2009). FMSs measure the bias and variability of the analytical method plus any potential effects caused by (1) degradation of the organic compound during shipment to the laboratory and (2) interferences from other water-quality characteristic of the environmental sample, such as hydrogen sulfide. LMSs measure the bias and variability of the analytical method at a particular concentration. Rowe and others (2005) analyzed in detail all VOC spike matrix samples collected for the NAWQA Program from groundwater wells and surface-water sites for the period 1997 to 2001. Rowe and others (2005) reported that 87 percent of the individual VOC recoveries were within acceptable ranges and demonstrate that low VOC concentrations can routinely and accurately be measured by the analytical methods used by the NWQL. Martin and others (2009) and Martin and Eberle (2011) analyzed in detail all pesticide spike matrix samples collected for the NAWQA program from groundwater wells and surface-water sites for the period 1992 to 2010 to examine temporal changes in the recovery of 44 pesticide and 8 pesticide degradates.

Data from USEPA SDWA Public-Supply Wells

For the purpose of this study, water samples collected from public-supply wells for compliance with the USEPA SDWA Program (table 2), were selected using the following criteria: (1) wells were completed in crystalline bedrock,

(2) water-quality data could be attributed to a single well, and (3) the data are from untreated (and unfiltered) samples that represent the quality of the source aquifer. For each water-quality constituent and associated SDWA well, only the most recent value in the dataset was selected.

Using the above selection criteria, a total of 4,775 public-supply wells (table 2) completed in crystalline rock in New England with at least one water-quality measurement for nitrate (NO₃), chloride (Cl), fluoride (F), sodium (Na), Mn, Fe, As, U, ²²²radon gas (radon), gross alpha-particle radioactivity (gross alpha), combined radium (²²⁸Ra plus ²²⁶Ra), or MtBE were compiled for this study (table 4). Data on the physiochemical properties pH and specific conductance (SC) also were compiled. In New Hampshire, there were 2,067 public-supply bedrock wells with available water-quality data, followed by Maine with 1,185 wells, Vermont with 488 wells, Massachusetts with 455 wells, Rhode Island with 418 wells, and Connecticut with 162 wells (table 2). The number of samples of untreated groundwater analyzed for a particular constituent is greatest for NO₃, and the constituent with the fewest number of samples is for U (table 4). The number of samples analyzed for a particular constituent varies because the requirements for compliance monitoring depend on the contaminant being measured and the type of the community water system being monitored. Also, the requirements for the compilation of data from untreated samples may differ by State.

Table 4. Number of untreated, unfiltered water samples analyzed for selected water-quality properties and constituents, collected for the U.S. Environmental Protection Agency Safe Drinking Water Act Program from public-supply wells in New England crystalline rock aquifers, by State, 1997–2007.

[--, no data; Combined radium is equal to ²²⁶radium plus ²²⁸radium; Gross alpha, gross alpha-particle radioactivity; MtBE, methyl *tert*-butyl ether]

Water-quality physical property or constituent	Number of untreated water samples						Total for study
	Connecticut	Massachusetts	Maine	New Hampshire	Rhode Island	Vermont	
pH	161	--	272	1,287	125	63	1,908
Specific conductance	14	--	22	636	20	12	704
Nitrate	154	441	1,169	2,014	414	472	4,664
Chloride	147	--	342	1,121	66	74	1,750
Sodium	150	412	389	1,261	124	68	2,404
Fluoride	141	211	399	997	189	113	2,050
Iron	21	89	403	821	66	114	1,514
Manganese	14	90	403	905	67	163	1,642
Arsenic	144	242	414	781	190	166	1,937
Uranium	58	30	27	317	7	--	439
Combined radium	59	95	26	228	44	56	508
Gross alpha	59	195	43	472	66	--	835
²²² Radon	--	45	91	637	57	1	831
MtBE	--	298	340	215	220	111	1,184

About 18 percent of the 4,775 public-supply wells used in this study are classified as community (COM) water systems (for example, municipalities) (fig. 2A; table 2). Community water systems serve a minimum of 25 persons year round or have at least 15 service connections used by residents all year. Twenty-three percent of the public-supply wells are nontransient noncommunity (NTNC) water systems (for example, schools) (fig. 2B; table 2). NTNC systems serve 25 persons or more at least 6 months of the year. Nearly 60 percent of the public-supply wells are transient, noncommunity (TNC) water systems (for example, restaurants or campgrounds), defined as serving 25 different persons at least 60 days per year (fig. 2C; table 2).

The SDWA Program for each New England State requires the use of methods of analysis approved by the USEPA (at http://water.epa.gov/scitech/drinkingwater/labcert/methods_index.cfm). State certification programs regularly audit their certified (accredited) laboratories to make certain that laboratories meet the performance criteria for the constituents they are certified to analyze. Of the constituents used in this report, only pH is exempt from laboratory certification; nonlaboratory personnel are permitted to collect pH data. Each State's certified laboratories supply the containers, preservative, and trip blanks for sampling and certify that these sampling supplies are free of contaminants at the laboratory detection level for each analyte. In Rhode Island, State personnel collected the compliance samples from the community water systems until January 2008, when the responsibility was transferred to the regulated water systems. In all other New England States, personnel of the regulated water systems were responsible for collecting and submitting water samples to USEPA-certified laboratories for analysis. The USEPA Region 1 reviews and retains the acceptance limits for each certified laboratory for precision and accuracy, and the USEPA requires mandatory quality-control measures. The drinking-water program for each New England State retains sample collection sheets, custody forms, all laboratory tracking data, worksheets, and other raw data.

The USEPA and (or) State regulatory office determine locations for, and frequency of, sampling of regulated water systems. Except for New Hampshire, all New England State drinking-water programs use the sampling guidance found in "New England States Sample Collection and Preservation Guidance Manual For Drinking Water" available at <http://www.epa.gov/region1/lab/qa/pdfs/NE-States-Sample-Collection-Manual.pdf>. New Hampshire's drinking-water sampling guidelines are available at <http://des.nh.gov/organization/commissioner/pip/publications/co/documents/r-co-01-5.pdf>.

Treatment and Statistical Analysis of Water-Quality Data

Because laboratory analytical methods for many constituents improved during the study period, the LRLs

did not remain the same for most studied water-quality constituents; this difference in LRLs can affect their occurrence statistics. To remove the effect of variable LRLs for the pesticide compounds from the NAWQA samples, occurrence rates were compared using common assessment levels of 0.001 and 0.01 $\mu\text{g/L}$. The occurrence rates of the VOCs from the NAWQA samples were compared using common assessment levels of 0.02, 0.2, and 1 $\mu\text{g/L}$. Until 1996, VOC analytical results, including those reported for the CONN study, were reported by the USGS NWQL at a common LRL of 0.2 $\mu\text{g/L}$. After 1996, VOC analytical results, including those reported for the NECB and LINJ studies, were analyzed using a method (Childress and others, 1999) that reported variable LRLs that were 10 to 100 times lower than for the CONN study.

Some sections of this report combine water-quality data from the SDWA and NAWQA Programs for analysis. However, many of the 14 water-quality constituents compiled from the SDWA program had LRLs greater than the LRLs from the NAWQA program. Therefore, it was necessary to set the censoring level of the data to the lowest common reporting level when analyzing data with different reporting levels (Helsel and Hirsch, 2002; Helsel, 2005). Censored values and detected values reported below the common LRL were re-censored to the common LRL. For example, As data with reported values of <1, <2, 1.5, 4, and <5 were re-censored to <5 in order to make comparisons valid. Censored values reported above the common LRL were removed from analysis.

The Spearman correlation was used to assess the magnitude and direction of the association between two variables in a dataset (Helsel and Hirsch, 1992). The water-quality data presented in this report were correlated with each other and with explanatory variables, such as land use, population density, and well depth. Where available, the water-quality data also were analyzed to determine if there were differences in concentrations between domestic and public-supply wells. In this report, a probability value (*P*-value) of less than 0.05 indicates that there is a significant difference between two groups of data. For categorical explanatory variables, the nonparametric Tukey's test was conducted on the means of the ranks to compare concentrations among groups (Helsel and Hirsch, 1992).

Explanatory Variables

Harte and others (2008) suggest that a variety of extrinsic factors (variables that can change over time) and intrinsic factors (variables that do not change over time) can affect groundwater quality. Examples of extrinsic factors studied that can change over time include land use, land cover, population density, water-quality data, and water levels. Intrinsic factors studied that do not change over time include well-construction properties (such as well depth) and the geology in the vicinity of the sampled well.

Categories of Land Use and Land Cover

For this study, the percentage of land use and land cover for each major category (agriculture, developed, and undeveloped) within an area surrounding each sampled well and measuring 500 m [1,640 feet (ft)] in radius was assessed on the basis of the 2001 National Land Cover dataset (U.S. Geological Survey, 2006). Agricultural land uses in this study area include grasslands, pasture/hay, and cultivated crop areas. Developed (or “urban”) land uses include areas classified as open space, low intensity, medium intensity, and high intensity. The term “intensity” refers to the percent of impervious surfaces (such as roads or parking lots) within an area. Low intensity developed lands have 20 to less than 50 percent impervious surfaces, medium intensity developed lands have 50 to 79 percent impervious surfaces, and high intensity developed lands have greater than 79 percent impervious surfaces. Undeveloped lands have less than 20 percent impervious surfaces and include open water; barren and shrub lands; deciduous, evergreen, and mixed forests; woody wetlands; and emergent herbaceous wetlands.

Undeveloped lands were the dominant land use within 500-m radius area surrounding most of the wells (fig. 3A). The

medians of the percentage values of undeveloped lands within 500-m radius for public-supply and domestic wells in New England are 70 and 79 percent, respectively; and for the New Jersey and New York (NJ-NY) domestic wells, the median is 75 percent (fig. 3A). The medians of the percentage values of developed lands within 500-m radius for the public-supply and domestic wells in New England are 18 and 11 percent, respectively; and for the NJ-NY domestic wells, the median is 17 percent (fig. 3B). The medians of the percentage values of agricultural lands within 500-m radius for the public-supply and domestic wells in New England are 6.6 and 7.5 percent, respectively; and for or the NJ-NY domestic wells, the median is 1.4 percent (fig. 3C).

On the basis of the distribution of percentages for the three major land uses within the 500-m radius of the sampled wells, each well was assigned to one of four categories: (1) agricultural land use (greater than 15 percent agricultural lands and 5 percent or less of developed lands), (2) developed land use (greater than 25 percent of developed (or urbanized) lands and 15 percent or less of agricultural lands), (3) undeveloped land use (85 percent or greater undeveloped lands) and (4) mixed land use (no dominant land use) (table 5). Forty-two percent of all the sampled wells were in the mixed category,

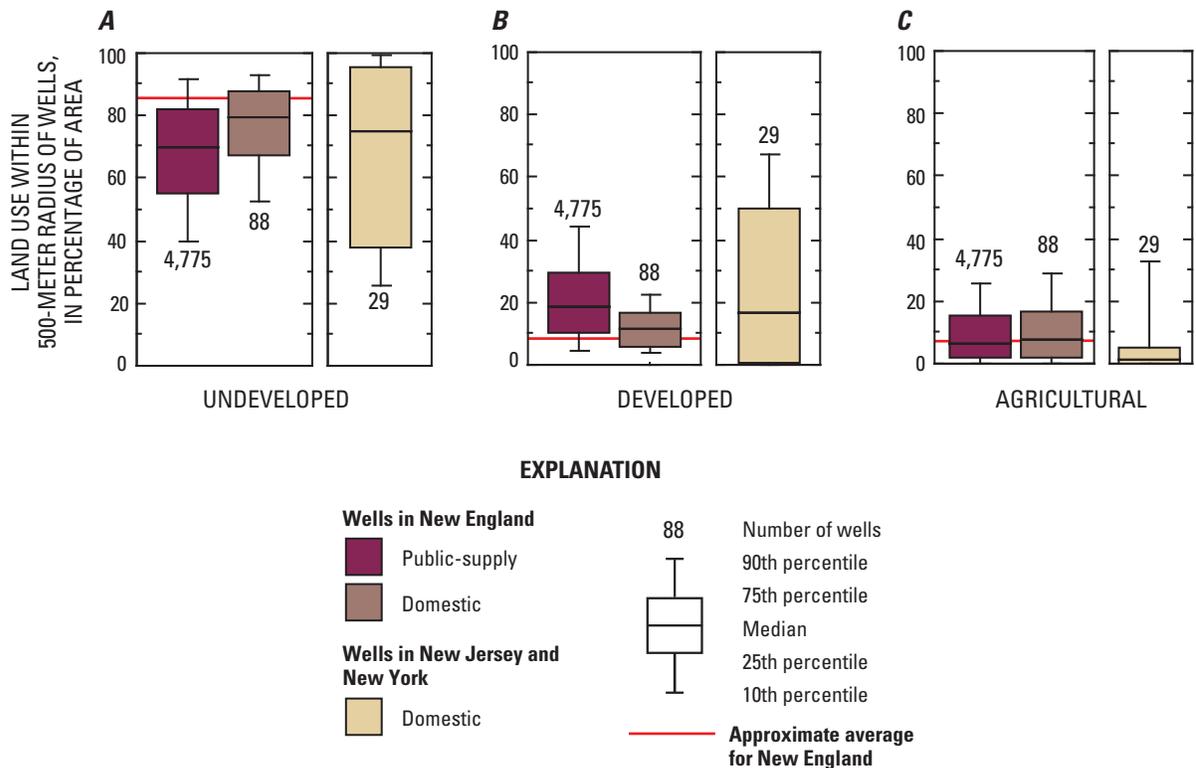


Figure 3. Distributions of A, undeveloped, B, developed, and C, agricultural land uses within 500-meter radius of the public-supply and domestic wells, by percentage of area, in New England crystalline rock aquifers for the year 2001. See table 5 for the distribution of sampled wells on the basis of categories of land use.

Table 5. Distribution of domestic and public-supply wells in New England crystalline rock aquifers, by major categories of land use, population density, and well-construction properties.

[USEPA SDWA, public-supply wells sampled for the U.S. Environmental Protection Agency Safe Drinking Water Act Program in New England; USGS NE, domestic wells sampled for the U.S. Geological Survey National Water-Quality Assessment (NAWQA) Program in New England; USGS NJ-NY, domestic wells sampled for the USGS NAWQA program in New Jersey and New York; PS, public-supply; dom, domestic supply; Agriculture, agricultural lands are greater than 15 percent and urban (or developed) lands are less than or equal to 5 percent; Developed, urban lands are greater than 25 percent and agricultural lands are less than or equal to 15 percent; Mixed, neither agricultural, developed, or undeveloped lands are dominant; Undeveloped, undeveloped lands are greater than 85 percent; \leq less than or equal to; $>$, greater than; km², square kilometers; N, number of wells. Population densities were determined for the year 2000]

Data source	Water use	Total N	Agriculture			Developed			Undeveloped			Mixed			N with population density (within 500-meter radius)			N with:		
			N	Per-centage of total	Per-centage of total	N	Per-centage of total	Per-centage of total	N	Per-centage of total	Per-centage of total	N	Per-centage of total	Per-centage of total	≤ 50 per-sons per km ² , N	> 50 per-sons per km ² , N	Well depth ≤ 300 ft and cas-ing length ≤ 50 ft, N	Well depth ≤ 300 ft and cas-ing length > 50 ft, N	Well depth > 300 ft and cas-ing length ≤ 50 ft, N	Well depth > 300 ft and cas-ing length > 50 ft, N
USEPA SDWA	PS	4,775	543	11	1,230	26	968	20	2,033	43	2,402	2,373	189	170	274	289				
USGS NE	dom	88	14	16	6	7	29	33	39	44	52	36	34	16	28	9				
USGS NJ-NY	dom	29	3	10	10	34.5	10	34.5	6	21	3	26	11	18	0	0				
Total for study		4,892	560	11	1,246	25	1,007	21	2,078	42	2,457	2,435	234	204	302	295				

21 percent were in the undeveloped category, 25 percent were in the developed category, and 11 percent were in the agricultural category (table 5). Small areas of agricultural and residential lands are scattered throughout the New England region (Harte and others, 2008); the high proportion of the sampled wells in the mixed land-use category reflects this feature.

Categories of Population Density

The average population density in 2000 for New England was 85 persons per square kilometer (persons/km²) (U.S. Bureau of the Census, 2001). The population densities in 2000 within a 500-m radius area surrounding the public-supply wells were mostly (10th to 90th percentile) in the range of 7 to 224 persons/km²; the median population density was 49 persons/km² (fig. 4). The population densities in 2000 within a 500-m radius area surrounding the domestic wells in New England were mostly in the range of 7 to 170 persons/km²; the median population density was 34 persons/km² (fig. 4).

The average population density in 2000 for New Jersey was 373 persons/km² (U.S. Bureau of the Census, 2001). Twenty-six of the 29 NJ-NY domestic wells are clustered in a small area of crystalline rock in the higher elevation areas (the “Highlands”) of northern New Jersey; the remaining 3 domestic wells are located across the State border in southeastern New York (fig. 1). The population densities in 2000 within a 500-m radius area surrounding the NJ-NY domestic wells were mostly in the range of 14 to 398 persons/km²; the median population density was 117 persons/km² (fig. 4).

Two population density categories were created to allow for nearly equal distribution of wells based on a demarcation point of 50 persons/km² (table 5). However, since the 29 NJ-NY domestic wells are in areas of significantly higher population densities than the wells in New England, 26 of these wells are in the higher population density category; the remaining 3 wells are in the lower population density category (table 5).

Categories of Well Depth and Casing Length

All wells in this report were generally constructed to similar specifications, using predominantly 6-inch (0.15-m) diameter steel casing (table 6). Casings are typically installed through the unconsolidated glacial sediments and driven into the underlying bedrock for a short distance. Groundwater enters the wells through fractures that intersect the open boreholes. The public-supply wells are generally deeper in total depth (median is 300 ft) than the domestic wells (median is 235 ft); and the bottom of the well casings (casing length) are at deeper depths (median is 50 ft) than the domestic wells (median is 40 ft) (table 6). Since there is little capacity for groundwater storage in crystalline rock, public-supply wells may be installed at deeper depths than domestic wells to increase borehole storage capacity or to intercept additional water-bearing fractures to increase well yield.

A total of 1,035 public-supply and domestic wells have information on both well depth and casing length. For these wells, the median well depth was 300 ft and the median casing length was 50 ft. On the basis of these median values, each well was assigned to one of 4 categories: (1) well depth

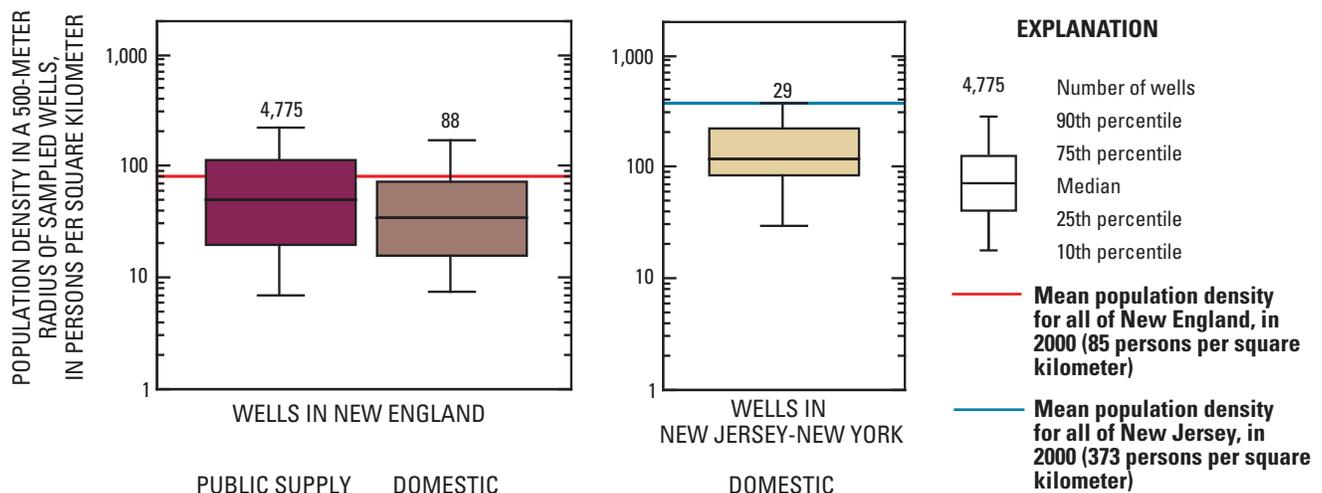


Figure 4. Distribution of population densities, by persons per square kilometer, in a 500-meter radius of the public-supply and domestic wells in New England crystalline rock aquifers for the year 2000. See table 5 for the distribution of sampled wells on the basis of categories of population density.

Table 6. Summary statistics for selected well-construction properties of the domestic and public-supply wells in New England crystalline rock aquifers, 1995–2007.

[N, number of wells; Min, minimum; Max, maximum; USGS NAWQA, domestic bedrock wells sampled for the U.S. Geological Survey National Water-Quality Assessment (NAWQA) Program in New England, New Jersey and New York; USEPA SDWA, public-supply bedrock wells sampled for the U.S. Environmental Protection Agency Safe Drinking Water Act Program in New England]

Data source	N	Min	Percentiles							Max
			5th	10th	25th	50th	75th	90th	95th	
Well casing diameter, in inches										
USGS NAWQA	117	6	6	6	6	6	6	6	6	8
USEPA SDWA	114	2	6	6	6	6	6	6	8	12
Well depth, in feet										
USGS NAWQA	117	41	103	128	180	235	320	500	555	705
USEPA SDWA	2,213	12	100	125	200	300	465	630	750	1,350
Depth to bottom of well casing, in feet										
USGS NAWQA	116	8	18	20	21.5	40	62.5	97	127	165
USEPA SDWA	922	3	19	20	32	50	82	134	161	600
Water level, in feet below land surface										
USGS NAWQA ¹	103	0	1.16	2.7	8.17	20.92	36.18	55.15	60	95.5
USEPA SDWA	143	0	3	5	13	24	50	90	150	425

¹Groundwater naturally flowed out of top of well casing in two of the domestic wells.

≤300 ft and casing length ≤50 (23 percent); (2) well depth ≤300 ft and casing length >50 ft (20 percent); (3) well depth >300 ft and casing length ≤50 ft (28 percent); and (4), well depth >300 ft and casing length >50 ft (28 percent; table 5). In this study, the shallow wells (≤300 ft) with short casing lengths (≤50 ft) are more likely to intersect water-bearing fractures at shallower depths than the deeper wells (>300 ft) with longer casing lengths (>50 ft).

Major Lithology Categories and Lithology Groups

Bedrock lithology and other bedrock geologic features are known to be among the important factors that affect the chemical quality, residence time, and direction of flow of groundwater in New England crystalline rock (Robinson, 1997; Robinson and others, 2002; Montgomery and others, 2002; Robinson and Kapo, 2003), and these geologic features are a critical component of the framework design (Harte and others, 2008). The lithology and geochemistry of bedrock in the study area is complex and extremely variable. More than 1,200 individual bedrock geologic units (sometimes referred to as “bedrock formations”) have been mapped collectively on state bedrock geologic maps (Robinson and Kapo, 2003). These geologic units have been mapped by a time-stratigraphic strategy and by rock type (dominant mineralogy and fabric). Rock weathering studies have shown that carbonate and sulfide minerals in the rocks are highly reactive in water

and can have a disproportionately large effect on groundwater quality (Goldich, 1938; White and Brantley, 1995). Thus, Robinson and Kapo (2003) re-classified these bedrock geologic units into 37 lithogeochemical groups for the New England region based on the bedrock unit’s minerals and texture; presence of carbonate, graphite, and sulfide minerals; depositional setting (such as restricted deposition within fault-bounded sedimentary basins of Mississippian or younger age); and for some of the granitic units, mineralogy and magma chemistry. For this study, the 37 lithogeochemical groups were further simplified into three major lithology categories—felsic igneous rocks, mafic igneous and metamorphic rocks, and metasedimentary rocks—and nine lithology groups with broadly generalized geochemical and mineralogical characteristics (table 7).

The felsic igneous rocks category, consisting primarily of granitic and related plutonic rocks, covers about 25 percent of the study area (fig. 5A; table 7). The granitic and related plutonic rocks were subdivided into three lithology groups on the basis of major element chemistry and mineralogy: alkali granite (I_a), metaluminous granite (I_m), and peraluminous granite (I_p). The alkali granite group (I_a) of rocks contains a higher concentration of alkalis (calcium, sodium, and potassium) than needed to produce feldspars, resulting in minerals composed of alkali-rich iron-magnesium (Fe-Mg) silicates, such as biotite, sodic amphiboles, nepheline, pyroxene, and biotite. Syenite, monzosyenite, and monxonite rocks also are members of the I_a group (table 7). I_a rocks

Table 7. Generalized description of the major lithology categories and lithology groups in the New England crystalline rock aquifers used in this report.

[The major lithology categories and lithology groups are illustrated in figures 5A–B. Text is modified from Robinson and Kapo, 2003]

Major lithology categories and their characteristics	Lithology group identifier	Lithology group name	Predominant rock types and tectonostratigraphic setting	Percentage of aquifer area in New England, by group	Percentage of aquifer area in New Jersey and New York, by group
Granite and related plutonic rocks including tonalite, monzodiorite, granodiorite, monzonite, granite, and alkali-feldspar granite in discrete intrusive bodies. They generally contain from 20 to 60 percent quartz and varying proportions of alkali and plagioclase feldspars with other accessory minerals. Subdivided on the basis of major element chemistry and mineralogy.	I _a	Felsic igneous rocks		24.9	25
		Alkali granite	Alkali-feldspar granite, quartz syenite, monzonite, granodiorite, and syenite enriched in alkali (calcium, sodium, and potassium) and incompatible elements. Peralkaline granitoid rocks have a molar proportion of aluminum oxide (Al ₂ O ₃) less than that of sodium oxide (Na ₂ O) and potassium oxide (K ₂ O) combined.	1.3	3
	I _m	Metaluminous granite	Primarily metaluminous granitoid rocks not in other granite categories. Includes Precambrian basement granites and small areas of rhyolite, felsite, and fine-grained felsic volcanic rocks, some interbedded with mafic volcanics. Metaluminous granitoid rocks have a molar proportion of Al ₂ O ₃ less than that of Na ₂ O, K ₂ O, and calcium oxide (Ca ₂ O) combined.	20.0	22
	I _p	Peraluminous granite	Peraluminous granitic rocks containing primary muscovite, biotite, and accessory minerals such as garnet. Generally have high concentrations of uranium, thorium, and rare earth elements. Peraluminous granitoid rocks have a molar proportion of Al ₂ O ₃ greater than that of Na ₂ O, K ₂ O, and Ca ₂ O combined.	3.6	0
Mafic igneous rocks and their metamorphic equivalents. May include locally felsic volcanics and (or) metaclastic rocks.	M _m	Mafic igneous and metamorphic rocks Mafic rocks	Mafic volcanics, basalt, greenstone, gabbro, diorite, monzodiorite, diabase, amphibolite, mafic gneiss, and serpentine.	8.5	8
Layered pelitic, semipelitic, and calcareous metasedimentary rocks. May include locally noncalcareous rocks, sulfidic rocks, and metavolcanics. Fractures frequently parallel to compositional layering and metamorphic foliation that range from shallow to steep orientation.	M _{c-nm}	Metasedimentary rocks Calcareous metasedimentary rocks, New Hampshire-Maine geologic province	Ordovician to Siluro-Devonian, layered, clastic metasedimentary rocks derived mostly from moderately calcareous sedimentary protoliths. Occurs as a tectonostratigraphic belt in the New Hampshire-Maine geologic province (Robinson and Kapo, 2003).	66.2	67
	M _{c-wg}	Calcareous metasedimentary rocks, Waits River-Gile Mountain geologic province	Ordovician to Siluro-Devonian, layered, clastic metasedimentary rocks formed from interbedded calcareous pelite, siltstone, and sandstone protoliths. Occurs primarily as a tectonostratigraphic belt in the Waits River-Gile Mountain geologic province (Robinson and Kapo, 2003).	6.8	0
	M _p	Pelitic rocks	Micaceous, muscovite-rich metasedimentary rocks, generally strongly foliated and layered. Includes sulfidic schists and interbedded semipelitic rocks.	40.9	0
	M _{ot}	Metasedimentary rocks, other	Minor amounts of layered and intermixed metasedimentary rocks not in other categories; gneiss is the dominant metasedimentary rock in the New Jersey and New York part of the study area.	4.4	67
	M _{mb}	Narragansett basin metasedimentary rocks	Variably metamorphosed 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.	1.3	0

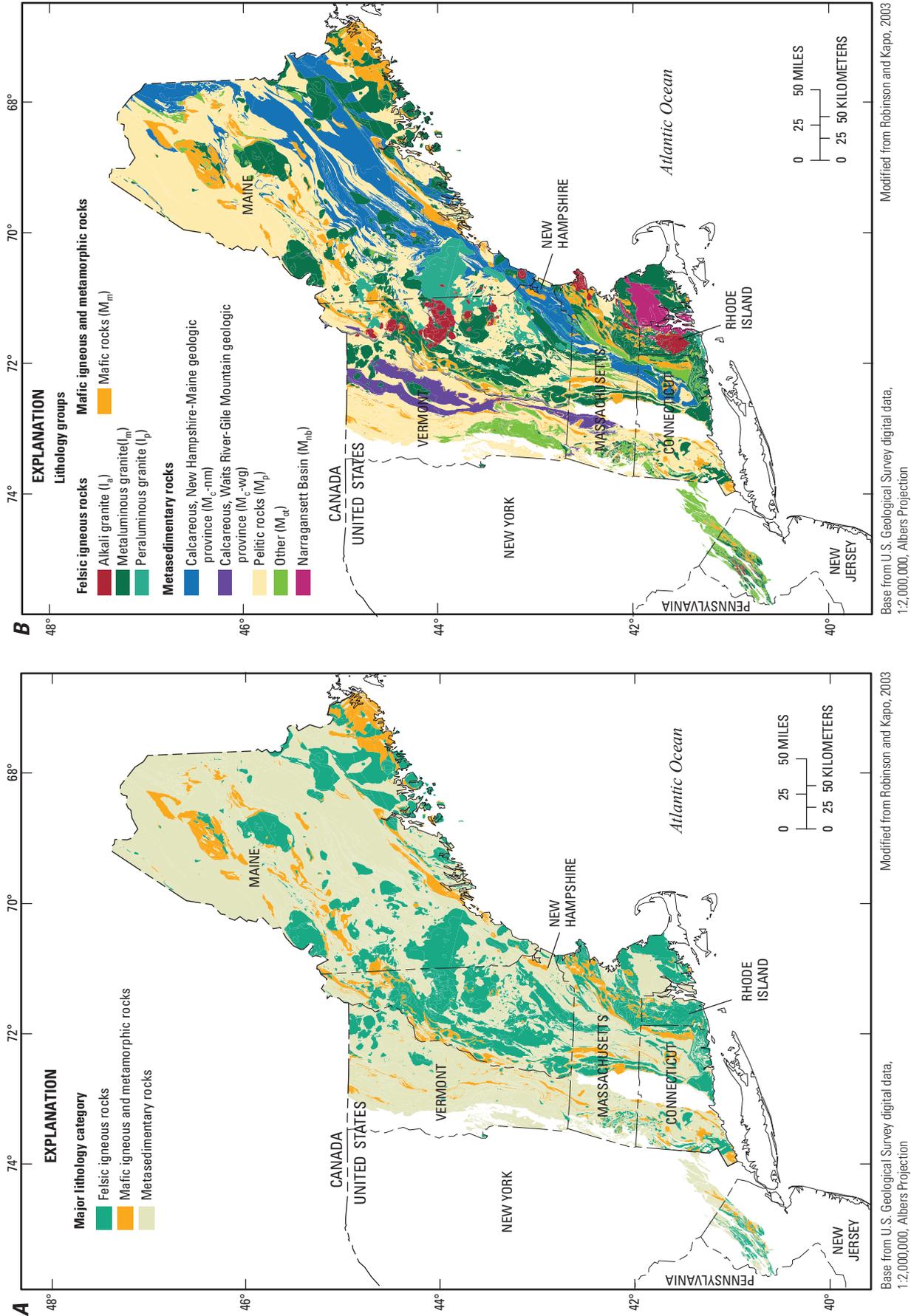


Figure 5. General distribution of A, major lithology categories and B, of lithology groups of New England crystalline rock aquifers in New England, New Jersey, and New York. See table 7 for the full description of the major lithology categories and lithology groups.

compose less than 3 percent of NECR aquifers, primarily in the White Mountains region of New Hampshire and central Rhode Island (fig. 5B). The metaluminous granite group (I_m) of rocks has a near equal balance of alkalis and aluminum to generate feldspar with biotite, hornblende, and epidote as typical accessory minerals. I_m rocks compose about 20 percent of NECR aquifers throughout the study area in New England and in New Jersey and New York (fig. 5B). The peraluminous granite group (I_p) of rocks has more aluminum than can be incorporated in feldspars, and major and accessory minerals in these rocks include muscovite (with or without biotite), garnet, topaz, and Al-silicates (such as andalusite, kyanite, or sillimanite) (table 7). I_p rocks compose about 3.6 percent of NECR aquifers. The largest area of I_p rocks is in west-central Maine near the New Hampshire border (fig. 5B).

Mafic igneous and metamorphic (M_m) rocks are generally rich in magnesium and ferrous iron and low in silica (generally <45 percent). Basalt, mafic volcanics, greenstone, gabbro, diorite, monzodiorite, diabase, amphibolite, mafic gneiss, and serpentine rocks are members of the M_m lithology group. M_m rocks compose about 8.5 percent of NECR aquifers, mostly in narrow northeast-trending belts and isolated intrusive bodies northeast in the study area (table 7; figs. 5A–B).

Metasedimentary rocks, the most dominant lithology category in the study area, compose about 66 percent of NECR aquifers (table 7; fig. 5A). The largest lithology group in this category is composed of pelitic (M_p) rocks. Some of the more common M_p rocks include slate, phyllite, and schist, sometimes interlayered with lesser amounts of other types of rock (table 7). M_p rocks compose nearly 41 percent of NECR aquifers, mostly in northern New England and westernmost Connecticut and Massachusetts (fig. 5B). The second largest group of metasedimentary rocks includes the clastic metamorphic rocks derived predominantly from moderately calcareous sedimentary protoliths. In this study, these calcareous metasedimentary rocks were further separated into two distinct geologic provinces (or tectonostratigraphic zones): the New Hampshire-Maine geologic province (M_c -nm group) and the Waits River-Gile Mountain geologic province (M_c -wg group). The M_c -nm lithology group lies in a north-northeast trending belt of rocks within eastern New England, primarily in New Hampshire and Maine (fig. 5B). The M_c -wg lithology group is predominately in west-central Massachusetts and eastern Vermont near the New Hampshire border in a south-north belt of rocks (fig. 5B). Combined, the M_c -nm and M_c -wg lithology groups compose 19.6 percent of NECR aquifers (table 7).

The “other” metasedimentary rocks (M_o) lithology group composes 4.4 percent of NECR aquifers and consists of metamorphosed metasedimentary rocks that do not fit into the other metasedimentary rock lithology groups (table 7). M_o rocks, consisting primarily of oligoclase- and feldspar-gneiss, dominate the area (67 percent) of crystalline rock in the LINJ part of the study area (fig. 5B). The Narragansett Basin metasedimentary (M_{nb}) rocks, in eastern Rhode Island and southeastern Massachusetts, compose 1.3 percent of NECR aquifers (fig. 5B). The M_{nb} lithology group consists of layered

sedimentary rocks that have been partially metamorphosed and, thus, are considered part of NECR aquifers.

Quality of Water in New England Crystalline Rock Aquifers

The physiochemical properties and chemical data on domestic and public-supply wells in NECR aquifers are discussed in this section. A statistical summary for selected physiochemical properties of and inorganic constituents in water samples collected by the USGS NAWQA Program from 88 domestic wells in New England is provided in appendix 1, and from 29 domestic wells in New Jersey and New York is provided in appendix 2. A statistical summary for 2 physiochemical properties and 12 water-quality constituents in water samples collected for the USEPA SDWA Program from 4,775 public-supply wells in New England is provided in appendix 3. A statistical summary for 4 physiochemical properties and 24 water-quality constituents from all wells studied is presented in table 8.

Dissolved Gases and Apparent Age of Groundwater

Dissolved, atmospheric-gas samples were collected from 56 domestic wells for the NECB NAWQA study to aid in the interpretation of the CFC-isotope method for age-dating groundwater (Plummer and others, 1993; Plummer and Busenberg, 2000). Gas concentrations in mg/L ranged from <0.001 to 15.5 for methane (CH_4), 17.6 to 29.8 for nitrogen (gas; N_2), 0.2 to 135 for carbon dioxide (CO_2), and 0.53 to 0.9 for argon (Ar) (appendix 1). Much of the groundwater from NECR aquifers is young (less than 50 years since date of recharge). The apparent residence time (age) of groundwater (calculated as the sample date minus the estimated year of recharge) in samples from 55 domestic wells ranged from 3 to more than 51 years, with a median value of 25 years (appendix 1).

Two samples had unusually high CH_4 concentrations (8.9 and 15.5 mg/L). Methane is highly flammable in confined spaces, and high concentrations of CH_4 dissolved in bedrock groundwater have been documented in isolated areas in New Hampshire and Massachusetts (David Wunsch, New Hampshire State Geologist, written commun., 2004; Pierce and others, 2007). Degnan and others (2008) investigated in detail, using borehole-geophysical logs and other tools, the surrounding geology of the domestic well (in Wolfboro, N.H.) in this study that had the highest CH_4 concentration (15.5 mg/L). Results from the geophysical logs indicated that the geologic units exposed within the borehole of this well consist largely of foliated tonalite that is cut by abundant dikes of granite and pegmatite (Degnan and others, 2008).

Table 8. Summary statistics for selected physiochemical properties and water-quality constituents in water samples collected from domestic and public-supply wells in New England crystalline rock aquifers, 1995–2007.

[field/lab, field or laboratory; $\mu\text{S}/\text{cm}$ at 25°C, microsiemens per centimeter at 25 degrees Celsius; na, not applicable; <, less than; Min, minimum; Max, maximum; mg/L, milligrams per liter; $\mu\text{g}/\text{L}$, micrograms per liter; Gross alpha, gross alpha-particle radioactivity; pCi/L, picocuries per liter; Combined radium is $^{226}\text{radium}$ plus $^{228}\text{radium}$; M/BE, methyl *tert*-butyl ether. The common LRL is the most common laboratory reporting level for each constituent]

Properties and water-quality constituents	Units	Number of samples	Common LRL	Percent- age of samples above LRL	Concentration					
					Min	Percentile				Max
						10th	25th	50th	75th	
Oxygen, dissolved (as O ₂)	mg/L	115	na	100	0.2	0.3	1.9	4.8	8	10.5
pH, field/lab	Standard units	2,019	na	100	5.1	7.1	7.6	8	8.2	11
Specific conductance, field/lab	$\mu\text{S}/\text{cm}$ at 25°C	821	na	100	20	170	240	382	609	5,260
Total dissolved solids (TDS)	mg/L	117	10	100	29	89	126	200	323	876
Calcium (Ca)	mg/L	117	na	100	2.7	13.6	19.8	31	53.4	98.5
Magnesium (Mg)	mg/L	117	na	100	0.4	2.52	3.95	7.25	13.2	31
Sodium (as Na)	mg/L	2,521	0.05	100	<0.05	4.42	7	24.4	51	958
Alkalinity, filtered, field/lab (as CaCO ₃)	mg/L	116	na	100	9	44.3	72	106.5	177.9	606
Bicarbonate, filtered, field (as HCO ₃)	mg/L	88	na	100	9	56	79	114	183	606
Chloride (as Cl)	mg/L	1,867	2.5	95	<2.5	6	17	49.5	117	1,800
Fluoride (as F)	mg/L	2,167	0.2	70	<0.2	<0.2	0.3	0.8	1.7	17.9
Sulfate (as SO ₄)	mg/L	117	na	100	0.31	9	13.42	20.22	26	68.48
Nitrate (as NO ₃)	mg/L	4,781	0.5	25.2	<0.5	<0.5	<0.5	0.5	1.6	18.4
Barium (as Ba)	$\mu\text{g}/\text{L}$	87	1	85	<1	1.7	4.5	12.14	48	113.8
Chromium (as Cr)	$\mu\text{g}/\text{L}$	87	1	22	<1	<1	<1	<1	1.57	4
Copper (as Cu)	$\mu\text{g}/\text{L}$	87	1	59.8	<1	<1	1.77	7.3	18.6	416
Iron (as Fe)	$\mu\text{g}/\text{L}$	1,632	50	65.2	<50	<50	77	250	905	100,000
Lead (as Pb)	$\mu\text{g}/\text{L}$	87	1	16	<1	<1	<1	<1	2.1	12.9
Manganese (as Mn)	$\mu\text{g}/\text{L}$	1,759	20	58.4	<20	<20	30	89	226	3,420
Molybdenum (as Mo)	$\mu\text{g}/\text{L}$	87	1	42.5	<1	<1	<1	2.1	3.8	18.8
Nickel (as Ni)	$\mu\text{g}/\text{L}$	87	1	35	<1	<1	<1	1.52	2.54	11.6
Zinc (as Zn)	$\mu\text{g}/\text{L}$	86	1	55	<1	<1	1.18	3.34	6.74	463
Arsenic (as As)	$\mu\text{g}/\text{L}$	2,054	5	23.5	<5	<5	<5	<5	13	2,400
Boron (as B)	$\mu\text{g}/\text{L}$	79	12	45.6	<12	<12	<12	18.5	31.3	132.7
M/BE	$\mu\text{g}/\text{L}$	1,299	1	10	<1	<1	<1	<1	1	190
Gross alpha	pCi/L	893	3	47.7	<3	<3	<3	7.1	17.3	2,560
Combined radium	pCi/L	562	1	33.9	<1	<1	<1	1.3	2.7	16.0
²²² Radon gas	pCi/L	943	100	98.4	<100	1,200	2,600	5,300	11,400	215,200
Uranium (as U)	$\mu\text{g}/\text{L}$	556	1	75.2	<1	<1	2.3	10.6	42	3,640

Physiochemical Properties

Dissolved oxygen (DO), pH, specific conductance, alkalinity, turbidity, and water temperature are physiochemical properties of water that can affect the mobility of trace elements and other contaminants in groundwater. These properties vary in crystalline rock aquifers depending on precipitation chemistry, properties and chemical characteristics of soil and of aquifer materials, fracture flow (such as whether water being pumped originates from discharge or recharge zones), residence time of groundwater, and inputs from anthropogenic contaminants.

Dissolved oxygen concentrations in 115 domestic well samples were mostly in the range of 0.2 to 8 mg/L; the median concentration was 1.9 mg/L (table 8). Dissolved oxygen in groundwater originates primarily from the atmosphere at the time of recharge and is highly reactive with other compounds dissolved in water. Therefore, DO is consumed through reaction with organic material and minerals over time. Younger groundwater typically contains more DO and CO₂ and has lower pH values than older groundwater. The concentrations of DO and CO₂ in 53 to 55 samples for the NECB study were strongly and inversely correlated with apparent residence time (appendix 4), indicating that DO and CO₂ concentrations decreased with increasing residence time of groundwater. The strong inverse correlations among apparent residence time with DO and CO₂ show that these two gases are reliable indicators of young recharge waters and that, over time, DO and CO₂ are probably consumed during water-rock weathering. For example, weathering of plagioclase feldspar by dissolved atmospheric CO₂ produces hydrogen (H) and bicarbonate (HCO₃) ions, which over time progressively increase pH and alkalinity (Hem, 1985).

Groundwater pH is a measure of the hydrogen ion activity in water and is an important control on the solubility of many trace elements. Highly acidic (low pH) or highly alkaline (high pH) waters can be corrosive to pipes and may have an unpleasant taste. The USEPA recommends a pH range of 6.5 to 8.5 for drinking water (U.S. Environmental Protection Agency, 2009). The spatial distribution of pH values in water samples collected from the studied wells is shown in figure 6. Measurements of pH in water samples from 2,019 domestic and public-supply wells were mostly in the range of 6.5 to 8.2; the median value was 7.6 (table 8; fig. 7A). However, 9 percent of the pH values for all wells studied were below 6.5 and nearly 4 percent were greater than 8.5 (table 9). In addition, pH values were significantly higher in the public-supply and domestic wells in New England than in the NJ-NY domestic wells (fig. 7A). The significantly lower pH values and higher DO concentrations in the water samples from the NJ-NY domestic wells (figs. 7A–B) indicate apparent residence times that probably are younger than those for water samples from the domestic wells in New England.

Alkalinity, a measurement of the ability of water to neutralize acids, is an important consideration in the operation of water-treatment systems. Field and (or) laboratory

alkalinity concentrations in 116 domestic well samples were mostly in the range of 27 to 178 mg/L as calcium carbonate (CaCO₃); the median value was 72 mg/L as CaCO₃ (table 8). Older bedrock groundwater typically contains more alkalinity and have higher pH values than younger groundwater. The pH values and alkalinity concentrations in 55 samples for the NECB study were strongly and positive correlated with apparent residence time (appendix 4), indicating that groundwaters with high pH and high alkalinity concentrations are generally associated with older, chemically evolved groundwater.

Specific conductance, a measure of the ability of water to conduct an electric current, is an indicator of the amount of dissolved ions in water. Dissolved ions make up a large fraction of the total dissolved solids in natural waters; specific conductance and total dissolved solids (TDS) were closely related in the domestic wells studied (linear R^2 equal to 0.97, $n = 117$). Measurements of specific conductance in water samples from 821 domestic and public-supply wells were mostly in the range of 120 to 609 microsiemens per centimeter ($\mu\text{S}/\text{cm}$) at 25° Celsius; the median measurement was 240 $\mu\text{S}/\text{cm}$ (table 8). The relative amount of dissolved solids from natural sources in groundwater from NECR aquifers generally reflects the ability of minerals in native soils and aquifer materials to dissolve in water. Anthropogenic sources that can affect concentrations of dissolved solids include deicing salts on roads and leachate from onsite septic systems. Total dissolved solids has a U.S. Environmental Protection Agency secondary maximum contaminant level (SMCL) that relates primarily to aesthetic problems in drinking water, such as taste, hardness, mineral precipitation, and corrosiveness. Only 5 of the 117 domestic well samples (4.3 percent) had TDS concentrations equal to or greater than the USEPA SMCL of 500 mg/L (table 9). Three of the 5 samples with TDS concentrations exceeding the SMCL were from the NECB NAWQA study, and two were from the LINJ NAWQA study. Overall, specific conductance, TDS, and alkalinity concentrations in groundwater from NECR aquifers are among the lowest values when compared to those from other principal aquifers studied (DeSimone, 2009).

Nutrients

The widespread application of chemical fertilizers, manure, and sewage sludge to some agricultural fields to improve soil fertility and crop yields is a common practice in the United States (U.S. Geological Survey, 1999; Ruddy and others, 2006). One of the most significant changes in land use in New England and New Jersey since the 1960s has been the conversion of rural agricultural and forested lands to developed (residential and commercial) land uses (Ruddy and others, 2006; Guillard, 2008). As urban and suburban development replaces rural areas, developed lands and turf grass farming is replacing cropland as one of the largest fertilized areas in New England (Guillard, 2008). From 2002 to 2004 in Connecticut, Massachusetts, New Hampshire,

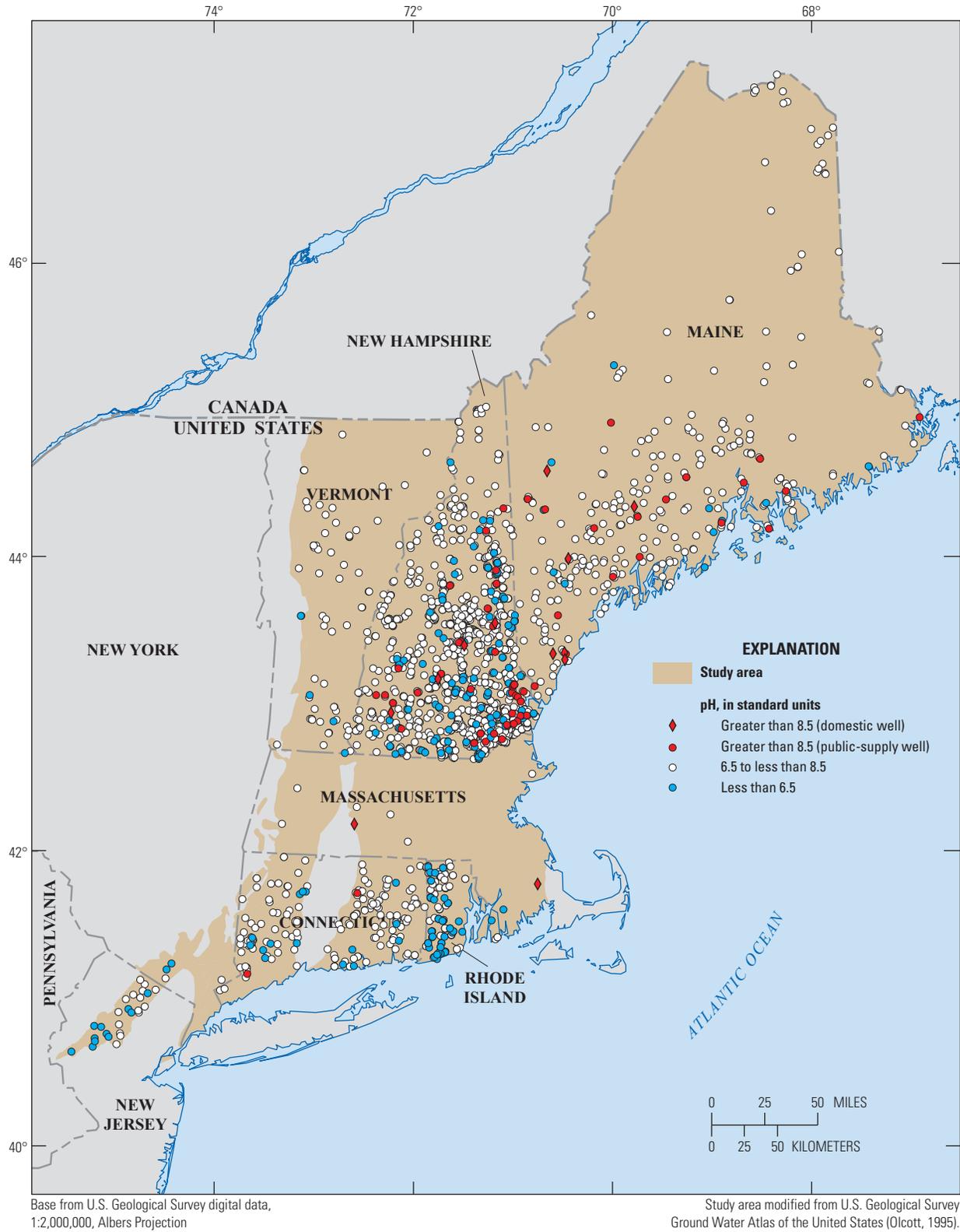


Figure 6. Spatial distribution of pH values in water samples collected from domestic and public-supply wells in New England crystalline rock aquifers, 1995–2007.

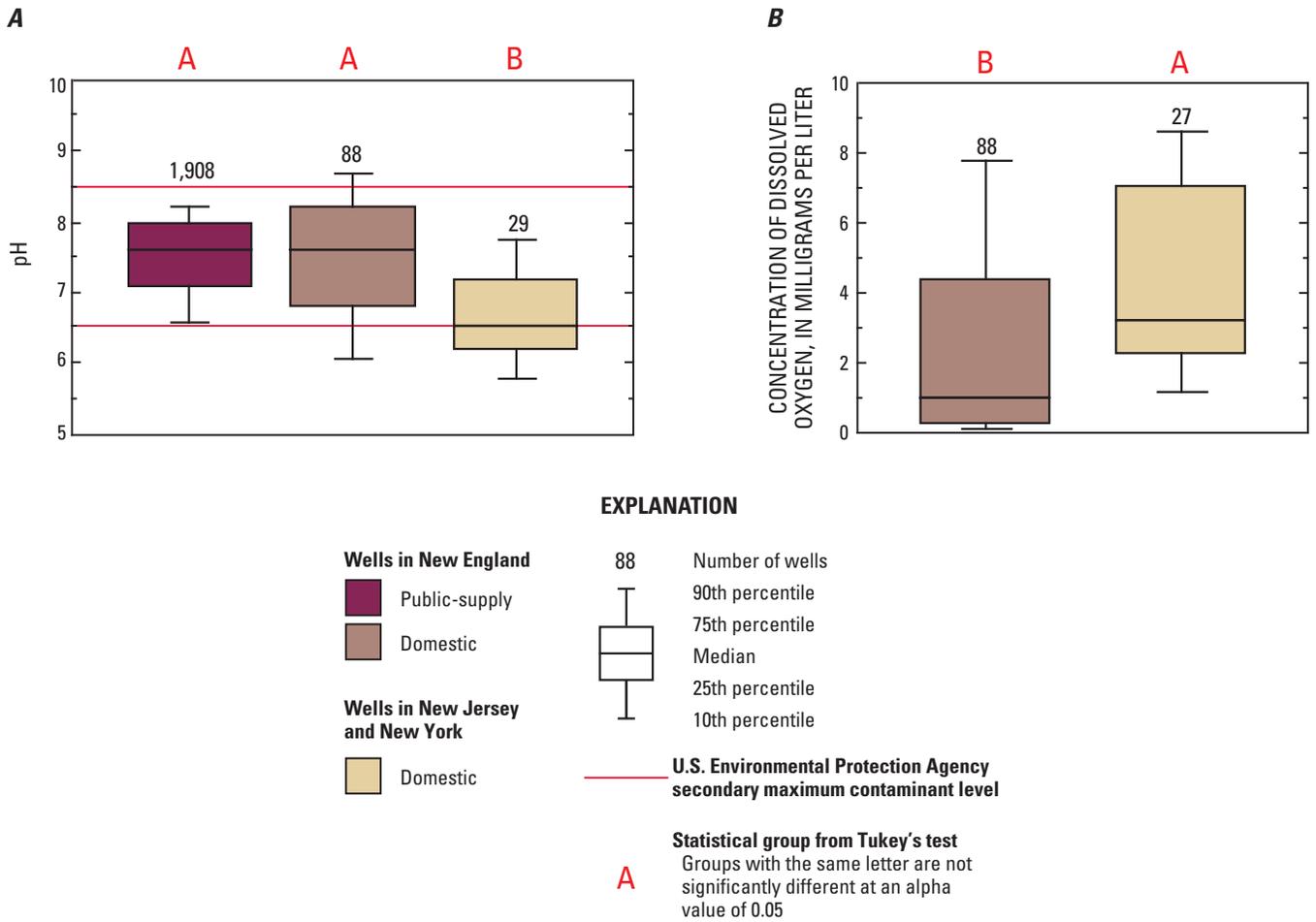


Figure 7. Distribution of *A*, pH values and *B*, concentrations of dissolved oxygen in water samples collected from public-supply and domestic wells in New England crystalline rock aquifers, 1995–2007.

Rhode Island, and New Jersey, the amount of nitrogen (N)-based fertilizers applied to farmland decreased while the amount of N fertilizers applied to nonfarmland increased, reflecting the trend of converting farmland to developed land (table 10). Atmospheric deposition of N is another major source of N to New England waters (U.S. Geological Survey, 1999; Boyer and others, 2002; Moore and others, 2004; Elliott and others, 2007). Owing in part to industrial and automotive emissions, rates of N deposition in New England are among the highest in the United States (National Atmospheric Deposition Program, 2000; Ruddy and others, 2006). Using data provided by Ollinger and others (1993), Moore and others (2004) showed that atmospheric deposition of total N in New England ranged from 320 to 1,030 kilograms per square kilometer per year (kg/km²/yr). Recent trends in atmospheric deposition of total N indicate that the amount of N inputs from atmospheric deposition decreased from 2002 to 2004 in all six

New England States, but increased in New Jersey (table 10). Other sources of N and P compounds in groundwater include septic-disposal systems (especially in rural areas where septic systems are common), domestic animal wastes (manure), and infiltration of runoff from streets and parking lots. Locally, bedrock blasting activities may cause short-term N contamination in nearby wells by the partial combustion of explosives comprising of ammonium nitrate fuel oil (ANFO) (Kernan, 2010).

In 88 domestic wells in New England, total P concentrations ranged from <0.01 to 0.22 mg/L and orthophosphate (PO₄) concentrations ranged from <0.01 to 0.22 mg/L (appendix 1). In the 29 NJ-NY domestic wells, the maximum total P and PO₄ concentrations both were 0.06 mg/L as P (appendix 2). Orthophosphate is the most common form of P in groundwater but is mostly immobile in groundwater because it tends to adsorb onto soils and aquifer materials.

Table 9. Concentrations of selected water-quality constituents in water samples collected from domestic wells for the U.S. Geological Survey National Water-Quality Assessment Program and public-supply wells for the U.S. Environmental Protection Agency Safe Drinking Water Act Program in New England crystalline rock aquifers, 1995–2007, with exceedances of human health benchmarks and non-health guidelines.

[HHB, human-health benchmark; NHG, non-health guideline; MCLs, U.S. Environmental Protection Agency (USEPA) maximum contaminant levels; SMCLs, USEPA secondary maximum contaminant levels; LHAs, USEPA lifetime health advisory levels using USEPA toxicity data and methods; TDS, total dissolved solids; mg/L, milligrams per liter; µg/L, micrograms per liter; pCi/L, picocuries per liter; N, number of samples; --, not applicable; USGS NAWQA, domestic wells sampled for the U.S. Geological Survey National Water-Quality Assessment Program in New England, New Jersey, and New York; USEPA SDWA, public-supply wells sampled for the USEPA Safe Drinking Water Act Program in New England; M/BE, methyl *tert*-butyl ether; Combined radium is ²²⁶radium plus ²²⁸radium; DWEL, non-enforceable USEPA Drinking Water Equivalency Level (guidance level); only for individuals on sodium-restricted diets). Action level is a concentration that, if exceeded, triggers treatment or other requirements in USEPA regulations for public water supplies]

Properties and water-quality constituents	Units	Human-health benchmark (HHB)		Non-health guideline (NHG)		Percentages of water samples exceeding human-health benchmark or non-health guideline											
		Value	Type	Value	Type	USGS NAWQA domestic wells				USEPA SDWA public-supply wells				All wells in this study			
						N	HHB (percent)	NHG (percent)	N	HHB (percent)	NHG (percent)	N	HHB (percent)	NHG (percent)	N	HHB (percent)	NHG (percent)
Physical properties																	
Low pH	pH units	--	--	<6.5	SMCL	117	--	23.1	1,902	--	8.2	2,019	--	9.04			
High pH	pH units	--	--	>8.5	SMCL	117	--	10.3	1,902	--	3.3	2,019	--	4.04			
TDS	mg/L	--	--	500	SMCL	117	--	4.27	--	--	--	117	--	4.27			
Major ions and nutrients																	
Nitrate	mg/L	10	MCL	--	--	117	0	--	4,664	0.11	--	4,781	0.1	--			
Chloride	mg/L	--	--	250	SMCL	117	--	1.71	1,750	--	3.37	1,867	--	3.27			
Fluoride	mg/L	4	MCL	2	SMCL	117	1.71	3.42	2,050	1.37	7.76	2,167	1.4	7.5			
Sodium	mg/L	--	--	20	DWEL	117	--	17.1	2,404	--	32.2	2,521	--	31.5			
Trace elements																	
Aluminum	µg/L	--	--	50 to 200	SMCL	86	--	3.5 to 2.33	--	--	--	86	--	3.5 to 2.33			
Antimony	µg/L	6	MCL	--	--	87	0	--	--	--	--	87	0	--			
Arsenic	µg/L	10	MCL	--	--	117	10.3	--	1,937	13.5	--	2,054	13.3	--			
Barium	µg/L	2,000	MCL	--	--	87	0	--	--	--	--	87	0	--			
Beryllium	µg/L	4	MCL	--	--	87	0.01	--	--	--	--	87	0.01	--			
Boron	µg/L	1,000	LHA	--	--	79	0	--	--	--	--	79	0	--			
Cadmium	µg/L	5	MCL	--	--	87	0	--	--	--	--	87	0	--			
Chromium	µg/L	100	MCL	--	--	87	0	--	--	--	--	87	0	--			
Copper	µg/L	1,300	Action level	1,000	SMCL	58	0	0	--	--	--	87	0	0			
Total iron	µg/L	--	--	300	SMCL	117	--	6.8	1,516	--	24	1,632	--	22			
Lead	µg/L	15	Action level	--	--	87	0	--	--	--	--	87	0	--			
Manganese	µg/L	300	LHA ¹	50	SMCL	117	3.42	17	1,642	7.60	39	1,759	7.3	38			

Table 10. Sources and quantities of nitrogen inputs in New England States and in New Jersey, 2002 and 2004.[km², square kilometers; kg/km², kilograms per square kilometer; UNC, unconfined lots; CON, confined lots. Data from Ruddy and others, 2006]

State	Area (km ²)	Fertilizer				Manure		Atmospheric deposition	
		2002		2004		2002		2002	2004
		Farm (kg/km ²)	Nonfarm (kg/km ²)	Farm (kg/km ²)	Nonfarm (kg/km ²)	UNC (kg/km ²)	CON (kg/km ²)	kg/km ²	kg/km ²
Connecticut	12,853	692.1	269.3	460.6	359.4	61.7	210.4	493.4	444.0
Maine	84,173	219.7	23.8	278.4	26.3	20.4	45.6	330.0	228.6
Massachusetts	20,999	435.1	225.6	369.5	323.7	59.4	116.6	485.5	403.3
New Hampshire	24,003	85.7	76.3	76.2	86.8	37.8	72.8	430.8	363.8
Rhode Island	2,800	409.4	333.3	310.5	379.8	59.0	98.0	477.5	387.9
Vermont	24,900	206.8	14.6	283.9	38.6	127.2	548.3	572.9	485.3
New Jersey	19,517	978.0	429.0	708.0	493.0	72.0	115.0	470.0	671.0

Nitrogen is the only nutrient for which there are enforceable USEPA drinking-water standards. The USEPA MCLs in community water systems is 1 mg/L as N for nitrite (NO₂), 10 mg/L as N for nitrate (NO₃), and 30 mg/L as N for ammonia (NH₃) (U.S. Environmental Protection Agency, 2009). None of the water samples from the 117 NAWQA domestic wells had NO₂ concentrations that exceeded the MCL, and only five samples contained measureable NO₂ concentrations above the laboratory reporting level (LRL) of 0.01 mg/L as N. The maximum NO₂ concentration was 0.08 mg/L as N (appendixes 1–2).

While NH₃ is soluble in water, NH₃ is more likely to adsorb onto soils and aquifer materials. Ammonia was detected (>0.02 mg/L as N) in about 11 percent of the 88 domestic wells in New England (appendix 1) and in about 21 percent of the 29 NJ-NY domestic wells (appendix 2). The largest NH₃ concentration in any of the domestic wells studied was 0.22 mg/L as N. The largest NH₃ plus organic N concentration in any of the domestic wells studied was 0.3 mg/L as N (appendixes 1–2). The relatively low concentrations of NO₂, NH₃, and NH₃ plus organic N in the domestic well samples indicate that they are the least dominant forms of dissolved N in NECR aquifers.

Nitrate concentrations in this study were reported as NO₂ plus NO₃ as N, but because NO₂ accounts for less than 1 percent of the reported NO₂ plus NO₃ as N concentrations, the remainder of this report refers to those summed concentrations as NO₃ concentrations. Nitrate is highly soluble and mobile; it can leach through permeable soils and migrate to underlying aquifers. Most of the NO₃ that reaches groundwater has evolved chemically from organic N and NH₃ applied on the land surface in the form of fertilizers and manure and as a byproduct of leachate from septic-disposal systems. In the northeastern United States, the volume of N compounds derived from atmospheric sources (precipitation and particulate matter) is significant, especially to the region's largest

rivers (Moore and others, 2004), but it is not known how much of the NO₃ in NECR groundwater is ultimately derived from atmospheric sources.

Nitrate concentrations in 4,781 untreated water samples from the domestic and public-supply wells were mostly in the range of <0.5 to 1.6 mg/L, with a maximum concentration of 18.4 mg/L (table 8). Only 5 water samples from 4,664 public-supply wells (<1 percent) had NO₃ concentrations that exceeded the MCL (table 9). None of the water samples from the 117 domestic wells had NO₃ concentrations that exceeded the MCL (table 9). By comparison, DeSimone (2009) reported that 4.4 percent of 2,132 domestic wells from all aquifers sampled nationally for the NAWQA Program had a NO₃ concentration greater than the MCL. However, the median NO₃ concentration (1.04 mg/L; appendix 2) in the 29 NJ-NY domestic well samples was at least 20 times higher than the median concentration (<0.05 mg/L; appendix 1) in the 88 domestic well samples from New England and nearly twice the median concentration (0.55 mg/L) that DeSimone (2009) reported for the domestic wells sampled from all aquifers nationally for the NAWQA Program.

In the NECR aquifers, the higher NO₃ concentrations in the sampled wells appear to coincide with areas of higher population density, as illustrated by the spatial distribution of NO₃ concentrations in water samples from the domestic and public-supply wells in figure 8. The percentage of samples (21.3 percent) with NO₃ concentrations >1 mg/L from public-supply wells where population density was high (>50 persons/km²) was significantly (and statistically) greater than the percentage of samples (12.3 percent) in public-supply wells where population density was low (≤50 persons/km²) (fig. 9). The percentage of samples (33.9 percent) with NO₃ concentrations >1 mg/L from domestic wells where population density was high also was significantly greater than the percentage of samples (10.9 percent) from domestic wells where population density was low (fig. 9). Interestingly, although

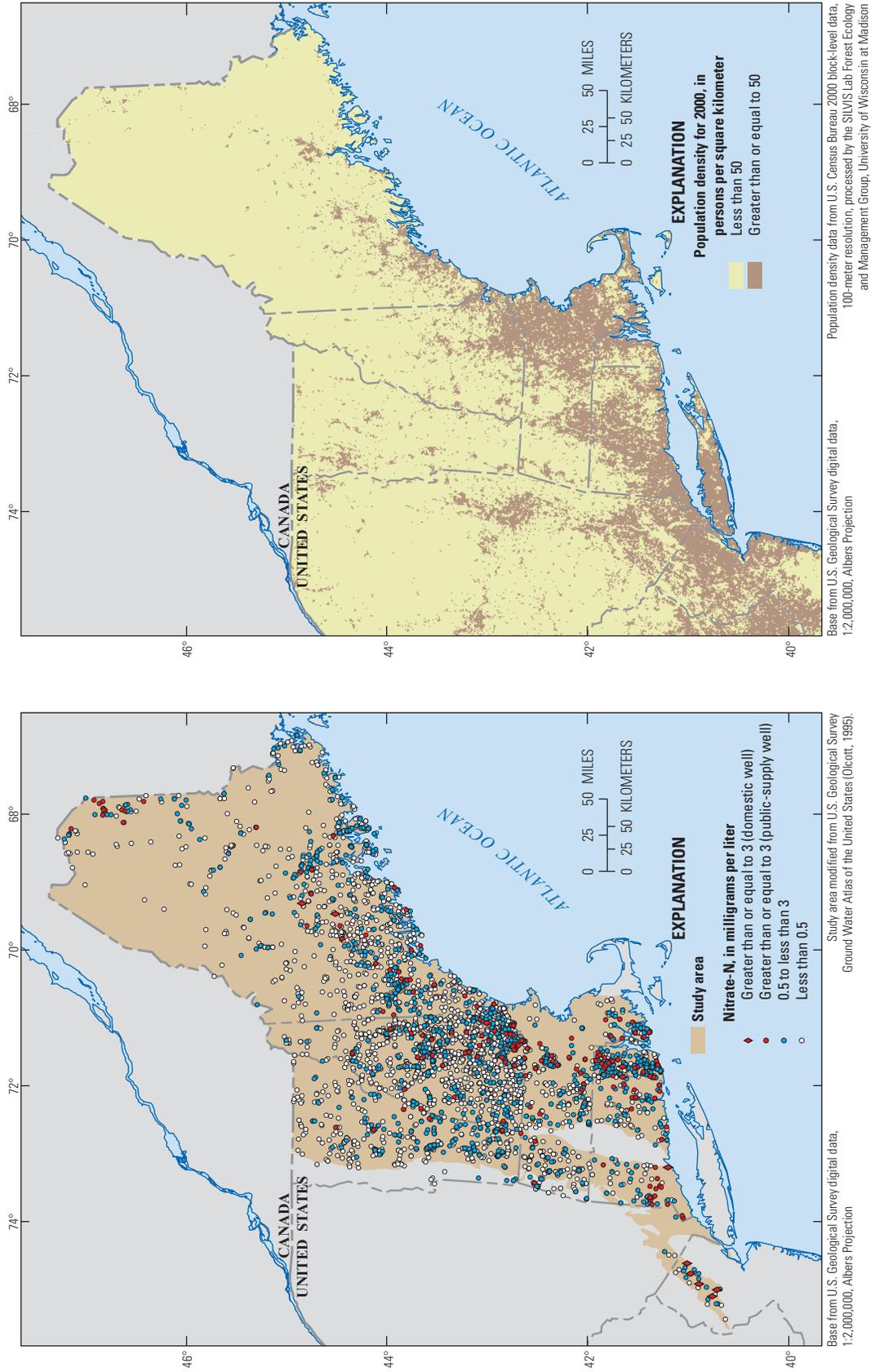
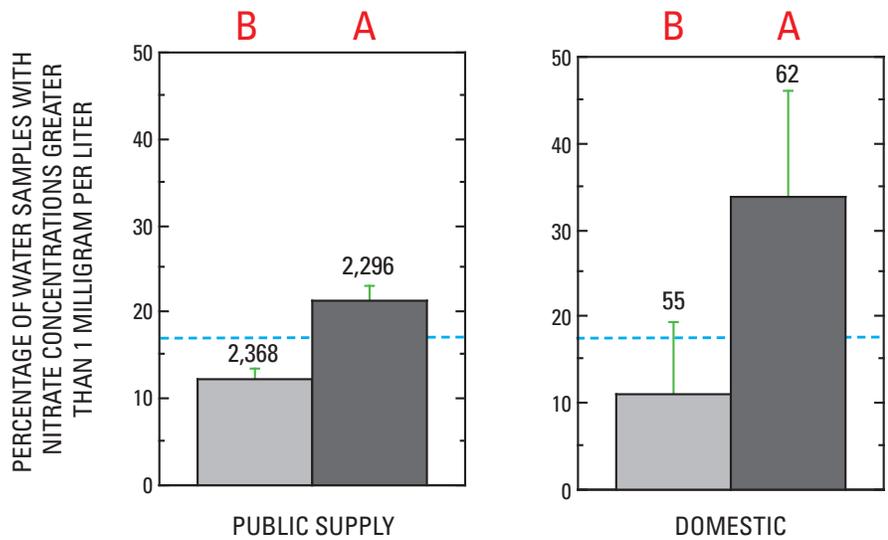


Figure 8. Spatial distributions of *A*, concentrations of nitrate in water samples from domestic and public-supply wells in New England crystalline rock aquifers, 1995–2007, and *B*, population density in New England and parts of New Jersey and New York for the year 2000.



EXPLANATION

- Population density within a 500-meter radius of sampled wells in 2000**
 - Fewer than or equal to 50 persons per square kilometer
 - More than 50 persons per square kilometer
- A** Statistical group from Tukey's test
Groups with the same letter are not significantly different at an alpha value of 0.05
- 2,368** Number of water samples
- T** Error bar representing the 95-percent confidence interval of the mean (binomial distribution)
- Percentage of all wells in this study (16.9 percent)

Figure 9. Distribution of percentages of water samples with concentrations of nitrate greater than 1 milligram per liter collected from public-supply and domestic wells in New England crystalline rock aquifers, by categories of population density, 1995–2007.

NO₃ concentrations >1 mg/L occurred more frequently in domestic well samples in areas where the dominant land use is developed lands, NO₃ concentrations >1 mg/L occurred more frequently in public-supply well samples in areas where the dominant land use is agricultural (fig. 10). However the NO₃ occurrence rates were not significantly different for the public-supply well samples among the four land-use categories. Only the domestic well samples in the undeveloped land-use category had a significantly lower occurrence rate of NO₃ concentrations >1 mg/L than those from areas where the dominant land use was agricultural, developed, or mixed (fig. 10). The percentage of samples (20 percent) with NO₃ concentrations >1 mg/L from shallow wells (total well depths ≤300 ft and casing lengths ≤50 ft) was significantly (and statistically) greater than the percentage of samples (6 percent) from deep wells (total well depths >300 ft and casing lengths >50 ft) (fig. 11), indicating that higher NO₃ concentrations are associated with shallower groundwater.

The percentages of water samples from public-supply and domestic wells with concentrations of NO₃ greater than 0.5 mg/L (the common LRL), greater than 3 mg/L, and greater than 6 mg/L are shown in figure 12. The bar charts in figure 12 show that with increasing concentrations of NO₃, there is a

greater percentage of water samples from the domestic wells that equaled or exceeded the stated concentrations of NO₃ than the water samples from the public-supply wells. For example, 5 times as many water samples from the domestic wells (2.5 percent) had NO₃ concentrations greater than 6 mg/L than did water samples from the public-supply wells (0.5 percent; fig. 12C). Three times as many had NO₃ concentrations greater than 3 mg/L, and 1.3 times as many had NO₃ concentrations greater than 0.5 mg/L (figs. 12A–B). One possible explanation for the higher NO₃ concentrations in domestic well samples is that homeowners may have less flexibility in siting wells within their property boundaries than do public utilities. Domestic wells may be close to neighboring homes that have septic systems, and they may be sited on managed lawns where fertilizers are applied. Elevated NO₃ concentrations in groundwater underlying some residential areas may also be due to previous land-use practices. About half of the water samples in New Jersey and New York were from domestic wells drilled on land previously used for agriculture (Leon J. Kauffman, U.S. Geological Survey, oral commun., 2009). The domestic well sample in New England with the highest NO₃ concentration (8.96 mg/L) was from a home on a working farm that has been in use for decades (Robinson and others,

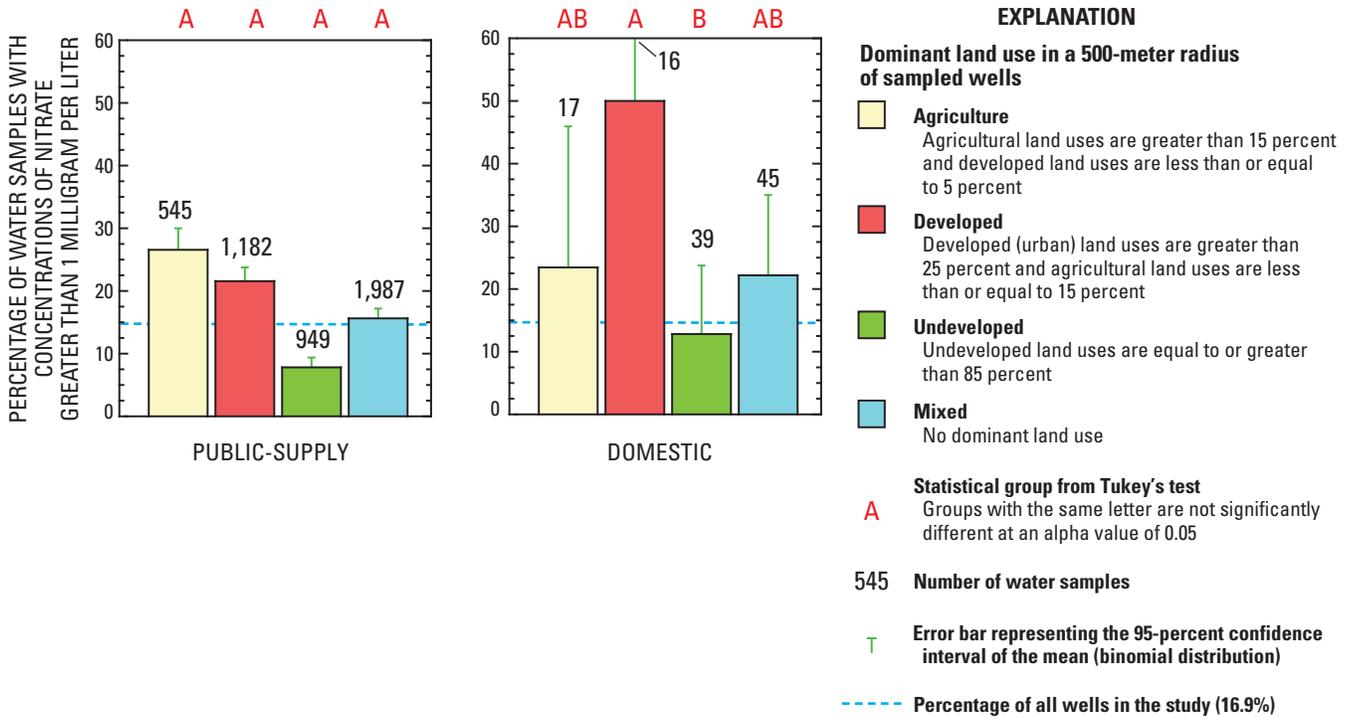


Figure 10. Distribution of percentages of water samples with concentrations of nitrate greater than 1 milligram per liter collected from public-supply and domestic wells in New England crystalline rock aquifers, by major category of land use within a 500-meter radius of the sampled wells, 1995–2007.

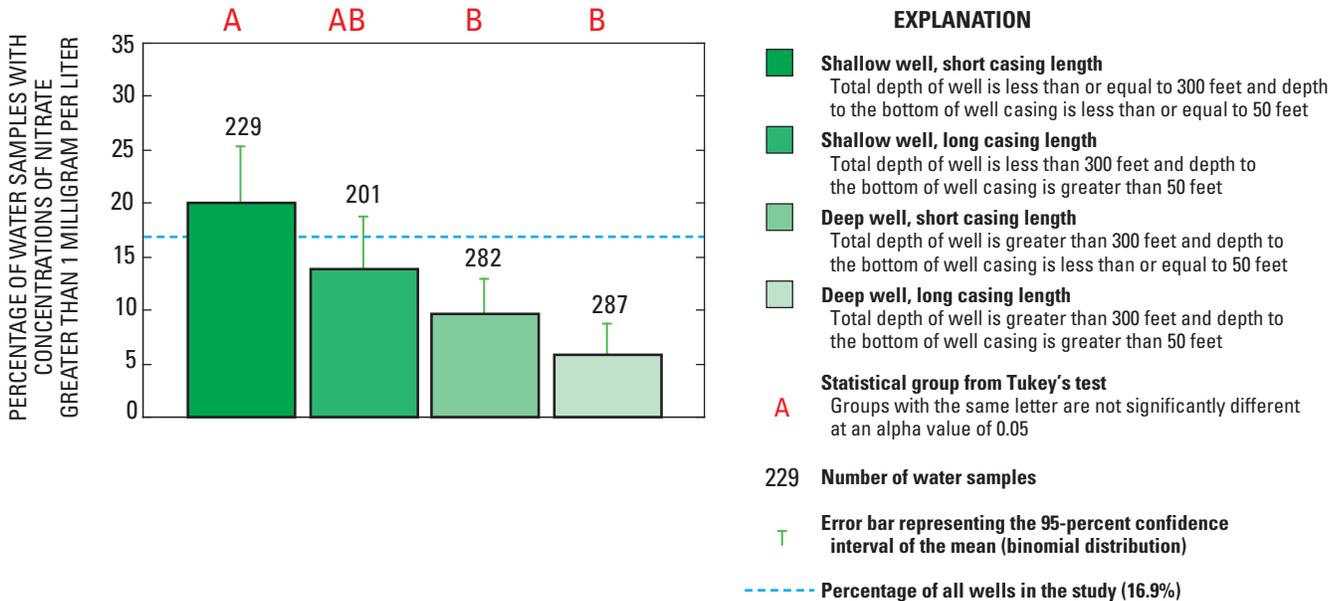


Figure 11. Distribution of percentages of water samples with concentrations of nitrate greater than 1 milligram per liter collected from public-supply and domestic wells in New England crystalline rock aquifers, by categories of well depth and casing length, 1995–2007. See table 5 for the distribution of sampled wells on the basis of categories of well depth and casing length.

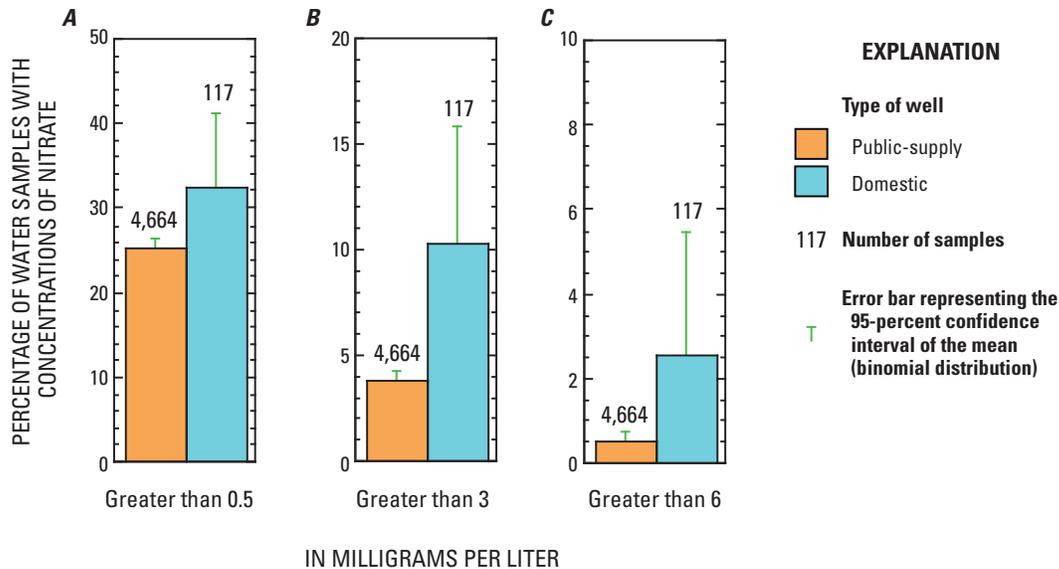


Figure 12. Distribution of percentages of water samples with concentrations of nitrate greater than A, 0.5, B, 3, and C, 6 milligrams per liter collected from public-supply and domestic wells in New England crystalline rock aquifers, 1995–2007.

2004). The public-supply wells also are generally greater in total depth and have longer well casings than the domestic wells (table 6). These conditions may explain why NO_3 concentrations are generally lower in groundwater from public-supply wells than from domestic wells.

Nitrate concentrations in the water samples were strongly correlated with other variables, such as apparent residence time (appendix 4), specific conductance concentrations, DO concentrations, pH, and CO_2 gas concentrations (appendix 5). These correlations indicate that the largest NO_3 concentrations in NECR aquifers are associated with young, oxic, shallow groundwater that is in close proximity to the source of NO_3 (such as local use of fertilizers or nearby septic systems). Under these conditions, NO_3 -enriched groundwater would have little time to undergo denitrification processes.

Major Ions

Under natural conditions, major dissolved ions in NECR aquifers are controlled by aquifer mineralogy and the residence time of groundwater in the system. Natural waters are commonly categorized by water type based on the relative percentage of major ions in the sample. The presence of any particular major ion in groundwater generally may not pose a specific serious risk to human health, but understanding the type of water produced from an aquifer can be valuable in understanding some of the processes that affect the water-quality conditions in groundwater.

Water types of samples collected from the domestic wells for the NAWQA Program are illustrated in the trilinear

diagram in figure 13, which highlights the variability in the major ion chemistry of groundwater from NECR aquifers. Calcium (Ca) was the most abundant cation, and bicarbonate (HCO_3) was the most abundant anion, in most of the domestic well samples. Water samples from domestic wells in New England were primarily calcium-bicarbonate (Ca-HCO_3) water type with some calcium-chloride (Ca-Cl), sodium-chloride (Na-Cl), sodium-bicarbonate (Na-HCO_3), and sodium-sulfate (Na-SO_4) types (fig. 14). Water samples from the NJ-NY domestic wells were Ca-Cl or Ca-HCO_3 water types (fig. 14).

Initially, the interaction of precipitation and aquifer materials dissolves readily weathered minerals, such as calcite, which releases Ca, consumes hydrogen (H), and increases alkalinity. The Ca-HCO_3 type water samples generally indicate young, recently recharged groundwater in NECR aquifers (Rogers, 1989; Lipfert and others, 2006). As groundwater evolves with time, less reactive minerals such as feldspars and micas can dissolve. The Na-HCO_3 type water samples can indicate longer residence times where silicate hydrolysis allows for the dissolution of Na-feldspar, or cation exchange, or a combination of both (Rogers, 1989; Toran and Saunders, 1999; Bowser and Jones, 2002; Lipfert and others, 2006).

Calcium and magnesium (Mg) are the primary cations contributing to hardness, a property of water that has been used to describe the extent to which soap lathers readily in water and the tendency for deposition of scale on solid surfaces when the water is heated (Hem, 1985). In 117 domestic well samples, Ca concentrations ranged from 2.7 to 98.5 mg/L and Mg concentrations ranged from 0.4 to 31 mg/L (table 8). Waters with a hardness of less than 60 mg/L as

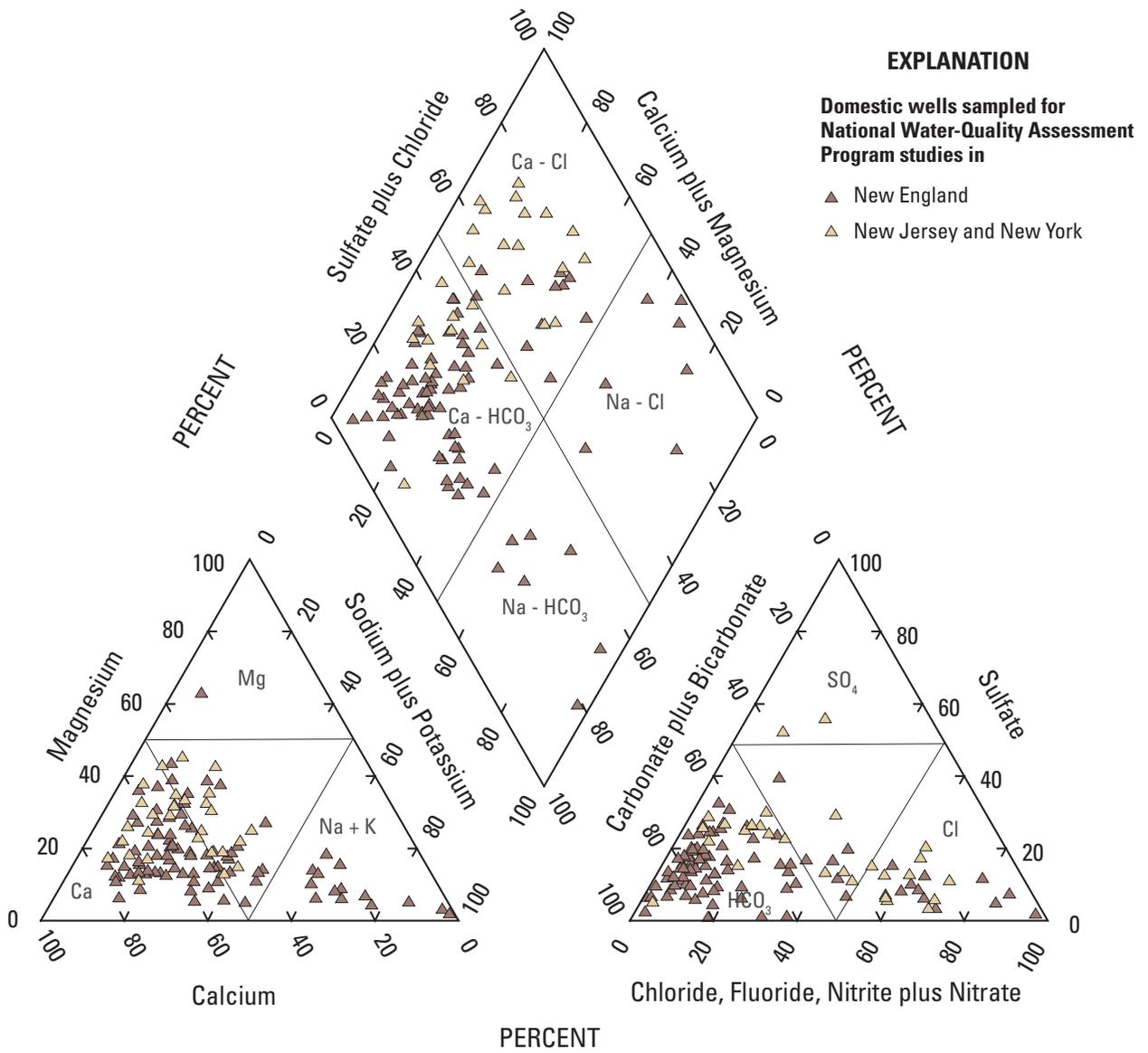


Figure 13. Trilinear diagram showing relations among major ions in water samples collected from domestic wells in New England crystalline rock aquifers, 1995–2000. (Ca, calcium; Mg, magnesium; Na+K, sodium plus potassium; HCO₃, bicarbonate; Cl, chloride; SO₄, sulfate)

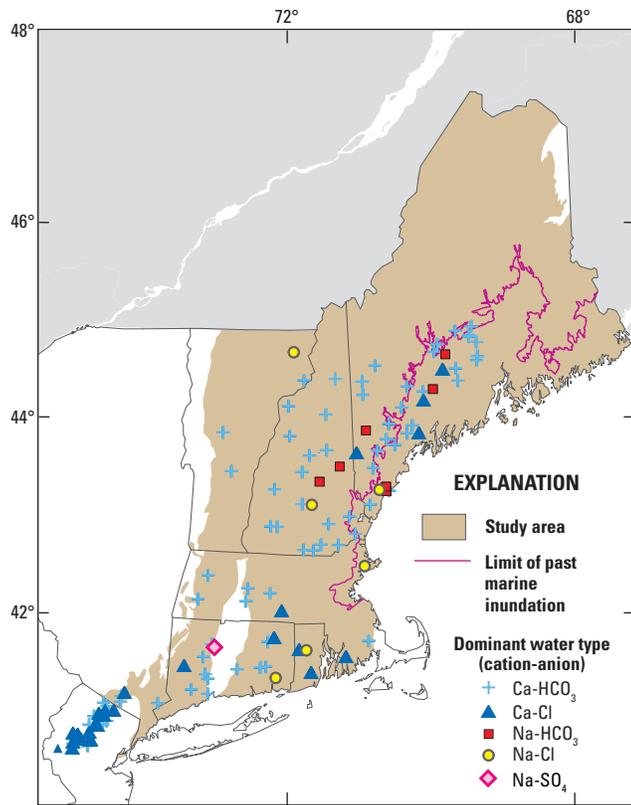


Figure 14. Dominant water types in water samples collected from domestic wells in New England crystalline rock aquifers, 1995–2000. (Ca-HCO₃, calcium-bicarbonate; Ca-Cl, calcium-chloride; Na-HCO₃, sodium-bicarbonate; Na-Cl, sodium-chloride; Na-SO₄, sodium-sulfate)

CaCO₃ are considered “soft,” and waters with more than 120 mg/L as CaCO₃ are considered “hard” (Hem, 1985). Hard or very hard (greater than 180 mg/L as CaCO₃) waters, when used for drinking water, often require treatment by use of a water softener, a process in which dissolved Ca and Mg ions are exchanged with Na ions in the water. In 87 water samples from the domestic wells, hardness values ranged from 12.6 to 280 mg/L as CaCO₃ (appendix 1). About 21 percent of these water samples were in the hard to very hard range. In general, NECR aquifers have lower hardness values when compared to other principal aquifers studied nationally (DeSimone, 2009).

The major anion sulfate (SO₄) has an SMCL that relates primarily to taste and odor. Sulfate concentrations in 117 domestic well samples ranged from 0.3 to 68.5 mg/L, with a median concentration of 13.4 mg/L (table 8)—well below the USEPA SMCL of 250 mg/L. Sulfate was the dominant anion in one of the domestic well samples for the CONN study (fig. 14).

Sodium and Chloride

Sodium and Cl concentrations varied greatly among water samples from the public-supply and domestic wells (table 8). In water samples from 2,521 public-supply and domestic wells, Na concentrations were mostly in the range of 4.4 to 51 mg/L, with a median concentration of 12.3 mg/L. In water samples from 1,867 public-supply and domestic wells, Cl concentrations were mostly in the range of 3 to 117 mg/L, with a median concentration of 17 mg/L (table 8). The maximum Na (958 mg/L) and Cl (1,800 mg/L) concentrations were from the same water sample in a public-supply well in New Hampshire (appendix 3). The spatial distribution of Cl concentrations in water samples collected from the domestic and public-supply wells is shown in figure 15. The USEPA does not have regulatory human health benchmarks for Na and Cl, but the agency has established a non-enforceable Drinking Water Equivalency Level (DWEL, or guidance level) for persons on Na-restricted diets of 20 mg/L and a SMCL for Cl of 250 mg/L because of taste. Sodium concentrations exceeded the DWEL of 20 mg/L in 31.5 percent of all wells studied, and Cl concentrations equaled or exceeded the SMCL in about 3.3 percent of all wells studied (table 9). Concentrations of Na and Cl were significantly greater in water samples from the public-supply wells than from the domestic wells, but were not significantly different when the samples were evaluated on the basis of well-construction categories or geologic lithology groups.

Natural sources of Na and (or) Cl to NECR aquifers include remnant seawater that inundated coastal Maine and New Hampshire during the post-glacial (Quaternary) period (Tepper, 1980), modern-day seawater intrusion along coastal areas (Barlow, 2003), connate brines trapped during rock deposition, and atmospheric transport of seawater aerosols during ocean storms. Figure 14 shows the demarcation line that represents the maximum extent of marine inundation during the post-glacial period. Alkali plagioclase feldspars, such as albite and oligoclase, are common in granitic and metamorphic rocks. They contain Na and are more susceptible to chemical breakdown than potassium (K)-feldspars (Rogers, 1989; Hem, 1985). In addition, most metamorphic and igneous rocks in the Earth’s crust have crystallized in the presence of fluids containing Na and K, forming fluid inclusions and connate waters; these are another source of geogenic Na to NECR aquifers. Anthropogenic sources of Na and Cl include road salt and discharges from water softeners. The dominance of the Cl anion in some domestic well water types may indicate the influence of anthropogenic sources (fig. 14).

On a regional scale, concentrations of Na and Cl in water samples from the sampled wells were significantly different when grouped into categories of land use (fig. 16) and population density (fig. 17). Water samples from wells in areas dominated by developed land and in areas of high population density (≥ 50 persons/km²) had the highest concentrations of Na and Cl, whereas the water samples from wells in areas dominated by undeveloped land and in areas of low population

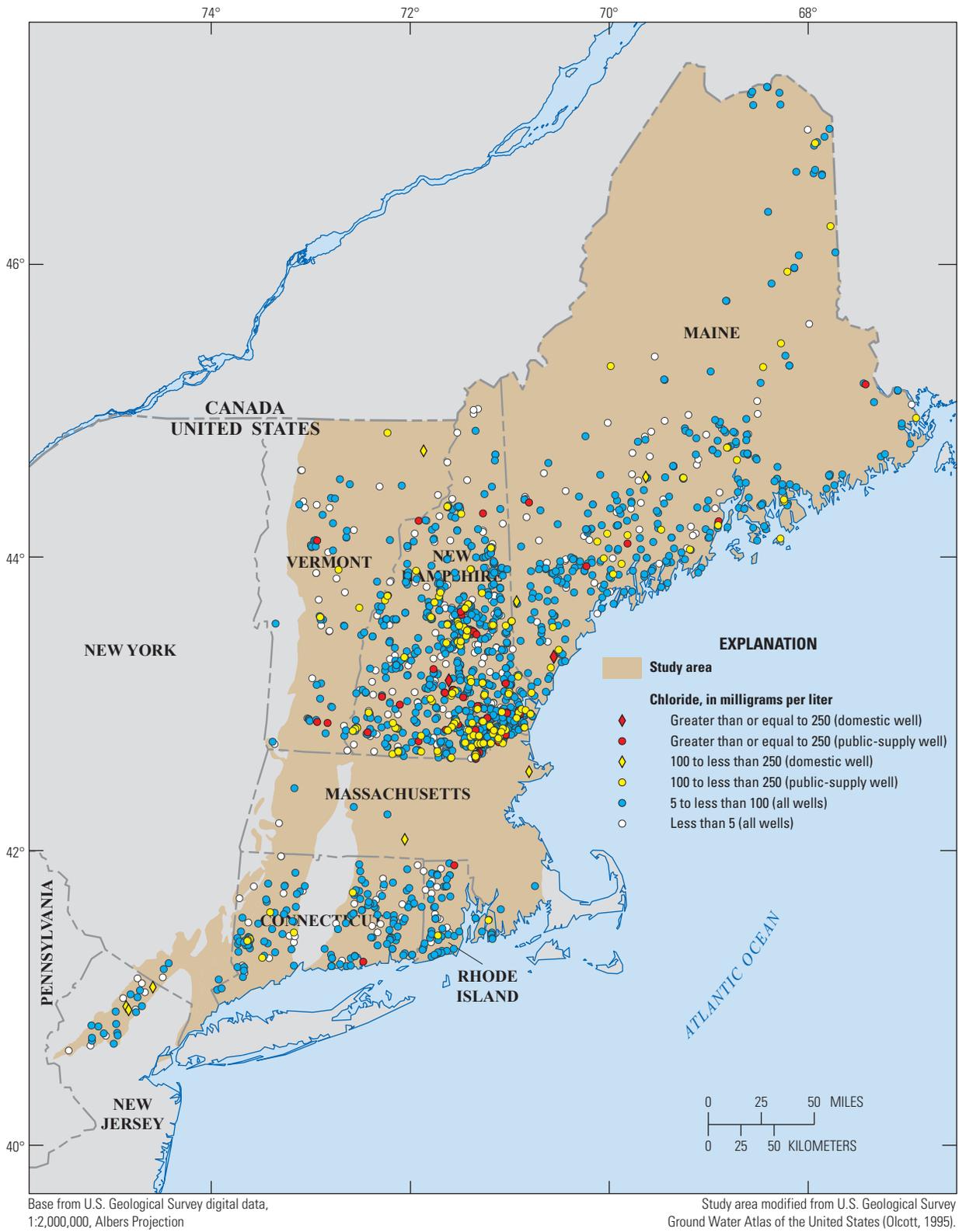
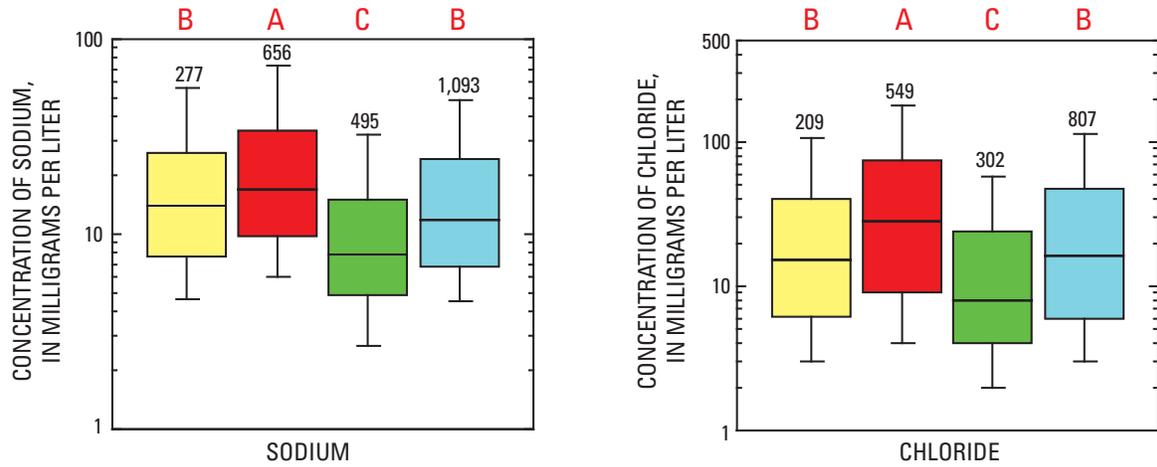


Figure 15. Spatial distribution of chloride concentrations in water samples collected from domestic and public-supply wells in New England crystalline rock aquifers, 1995–2007.



EXPLANATION

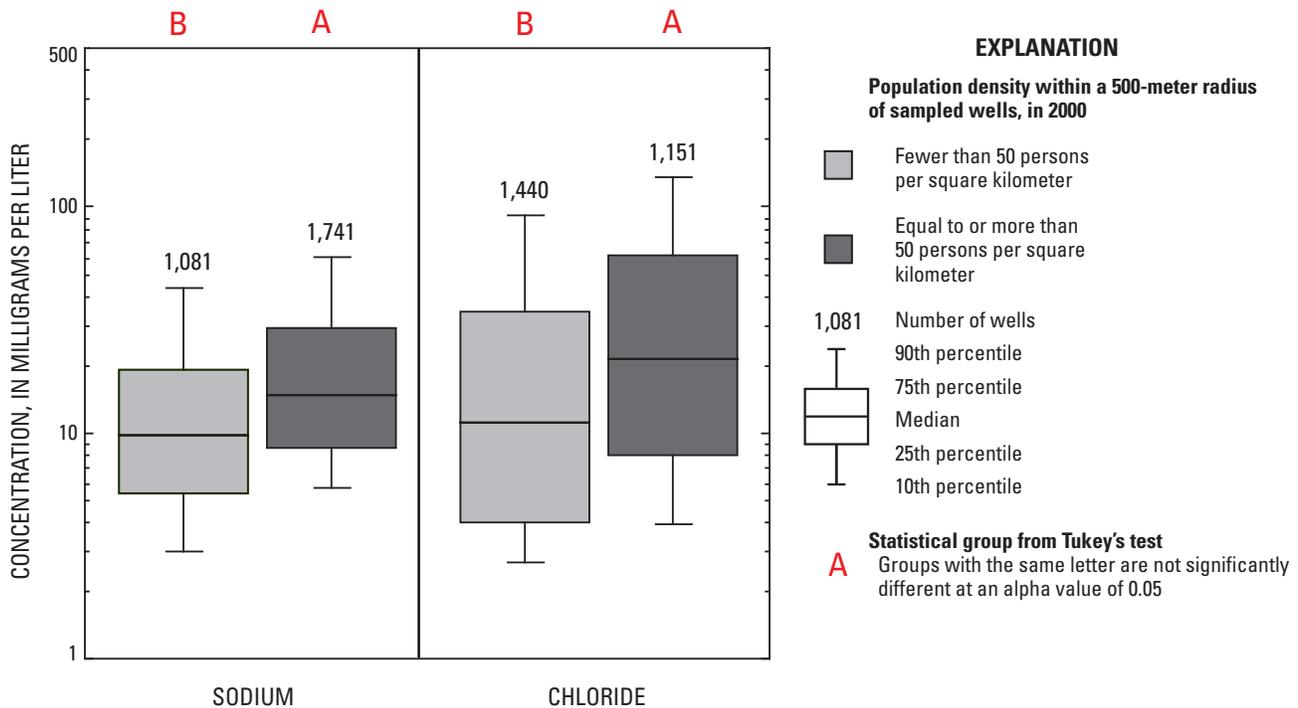
Dominant use of land within a 500-meter radius of sampled wells, in 2001

- **Agriculture**
Agricultural land uses are greater than 15 percent and developed land uses are less than or equal to 5 percent
- **Developed**
Developed (urban) land uses are greater than 25 percent and agricultural land uses are less than or equal to 15 percent
- **Undeveloped**
Undeveloped land uses are equal to or greater than 85 percent
- **Mixed**
No dominant land use

- 277 Number of wells
- 90th percentile
- 75th percentile
- Median
- 25th percentile
- 10th percentile

Statistical group from Tukey's test
Groups with the same letter are not significantly different at an alpha value of 0.05

Figure 16. Distribution of sodium and chloride concentrations in water samples collected from public-supply and domestic wells in New England crystalline rock aquifers, by categories of land use, 1995–2007.



EXPLANATION

Population density within a 500-meter radius of sampled wells, in 2000

- Fewer than 50 persons per square kilometer
- Equal to or more than 50 persons per square kilometer
- 1,081 Number of wells
- 90th percentile
- 75th percentile
- Median
- 25th percentile
- 10th percentile

Statistical group from Tukey's test
Groups with the same letter are not significantly different at an alpha value of 0.05

Figure 17. Distribution of sodium and chloride concentrations in water samples collected from public-supply and domestic wells in New England crystalline rock aquifers, by categories of population density, 1995–2007.

density (<50 persons/km²) had the lowest concentrations (figs. 16–17). Chloride concentrations correlated with a wide variety of water-quality constituents and land-use variables (appendix 5). The positive correlations of Na and Cl concentrations with each other and with the percentage of developed lands and population density surrounding the wells probably reflect the influence of applied road salt to New England and New Jersey roadways and to other paved surfaces during the winter months (Mullaney and others, 2009).

The widespread rise of NaCl in surface water and groundwater in northern areas of the United States, where road salt is applied to paved roadways as a deicing agent, is a growing concern over the future quality of drinking water and the potential negative effect on human health (New Hampshire Department of Environmental Services, 1996). Road salt, which consists primarily of mined NaCl and trace amounts of other constituents, has been identified as a primary source of Cl in streams and groundwater (Mullaney and others, 2009). Roadways in the northeastern parts of the United States receive up to 24,000 kg/km²/yr of road salt, the greatest amount in the nation (Panno and others, 2005). Road salt can enter drinking-water supplies by migrating through soil into groundwater or by runoff and drainage directly into surface water. Susceptibility of freshwaters to increased NaCl depends on many factors: intensity and duration of salting, overburden type and thickness, climate, road density, topography, and volume and dilution of water. Additional factors in fractured bedrock may be the extent and direction (horizontal versus vertical) to which the fractures are connected to the land surface (Harte and others, 2008).

Ratios of chloride to bromide (Cl:Br) in water have been used to deduce the likely sources that contribute NaCl to groundwater (Davis and others, 1998; Stober and Bucher, 1999; Snow and others, 1990). NaCl, or “salt,” in its pure form has a molar ratio of sodium to chlorine (Na:Cl) equal to 1. Cl:Br mass ratios in water samples from the domestic wells relative to Cl concentrations, molar ratios of Na:Cl, and pH are shown in figure 18. Water samples with Cl concentrations less than 6 mg/L and Cl:Br mass ratios below 200 probably reflect local precipitation sources and water-rock weathering (fig. 18A). The Ca-HCO₃ type water samples have a wide range of Cl:Br mass ratios, and Cl:Br mass ratios increase as Cl concentrations increase (fig. 18A). The Ca-HCO₃ type water samples also have a wide range of Na:Cl molar ratios (fig. 18B) and variable pH (fig. 18C). Therefore, a mixture of recently recharged groundwaters (diluted precipitation) that are affected by variable degrees of road salt dissolution and water-rock weathering may dominate the Ca-HCO₃ water types.

Waters affected by road salt have Cl:Br mass ratios more than 1,000 (Davis and others, 1998; Stober and Bucher, 1999). The Ca-Cl and Na-Cl type water samples generally have Cl:Br mass ratios greater than 1,000, Cl concentrations greater than 30 mg/L, Na:Cl molar ratios less than 1, and variable pH (figs. 18A–C). These data indicate a mixture of groundwaters with differing alkali and halogen characteristics and with

anthropogenic contaminants, such as road salt and discharges from water softeners. Two samples of Na-Cl type water have Cl:Br mass ratios in the seawater/connate water range of 200 to 400, high pH (>8), and Na:Cl molar ratios approximately equal to 1 (figs. 18A–C), indicating that seawater aerosols from ocean storms might be a possible source of NaCl in these samples.

A few samples of Na-HCO₃ type water with high pH (>8) and Cl:Br mass ratios in the seawater/connate water range (fig. 18A) were found in areas similar to those described by Tepper (1980) and in areas where bedrock groundwater may still contain remnant seawater (Snow and others, 1990; Ayotte and others, 2003) (fig. 14). These water samples also may reflect ion exchange of Ca for Na where Na-enriched aquifer materials are in equilibrium with calcite, as indicated by Na:Cl molar ratios greater than 1 (fig. 18B).

Fluoride

Fluoride (F) concentrations in water samples from 2,167 domestic and public-supply wells were mostly in the range of <0.2 to 1.7 mg/L, with a median concentration of 0.3 mg/L (table 8). The maximum F concentration was 17.9 mg/L (table 8). The spatial distribution of F concentrations in the domestic and public-supply wells is illustrated in figure 19.

Fluoride is the only major anion that has an enforceable drinking-water standard. The USEPA SMCL and MCL for F in drinking water are 2 and 4 mg/L, respectively. Fluoride has both beneficial and detrimental effects on human health. At excessive exposure to F in drinking water (greater than 2.0 mg/L) or in combination with exposure to F from other sources, adverse effects, ranging from mild dental fluorosis to crippling skeletal fluorosis, can occur as the level and period of exposure increases (World Health Organization, 2004). Water samples from 1.4 percent of 2,167 domestic and public-supply wells had F concentrations that were equal to or greater than the MCL, and 7.5 percent of the samples had F concentrations equal to or greater than the SMCL (table 9).

Fluoride concentrations in this study were significantly (and statistically) different when the water samples were evaluated on the basis of well-construction categories, water use, and location of wells within a lithology group. Fluoride concentrations were significantly greater in samples from the public-supply wells than in samples from the domestic wells. Fluoride concentrations also were significantly greater in water samples from deep wells with long casing lengths (well depths ≥ 300 ft and casing lengths ≥ 50 ft) than in any of the other three well-construction categories studied. In general, the public-supply wells are completed at deeper depths and have longer casing lengths than the domestic wells and might be one explanation for the differences in F concentrations between these two groups of wells.

Fluoride concentrations also were significantly greater in water samples from wells completed in felsic igneous rocks than from wells completed in mafic igneous and metamorphic rocks or metasedimentary rocks (fig. 20A). Wells in the

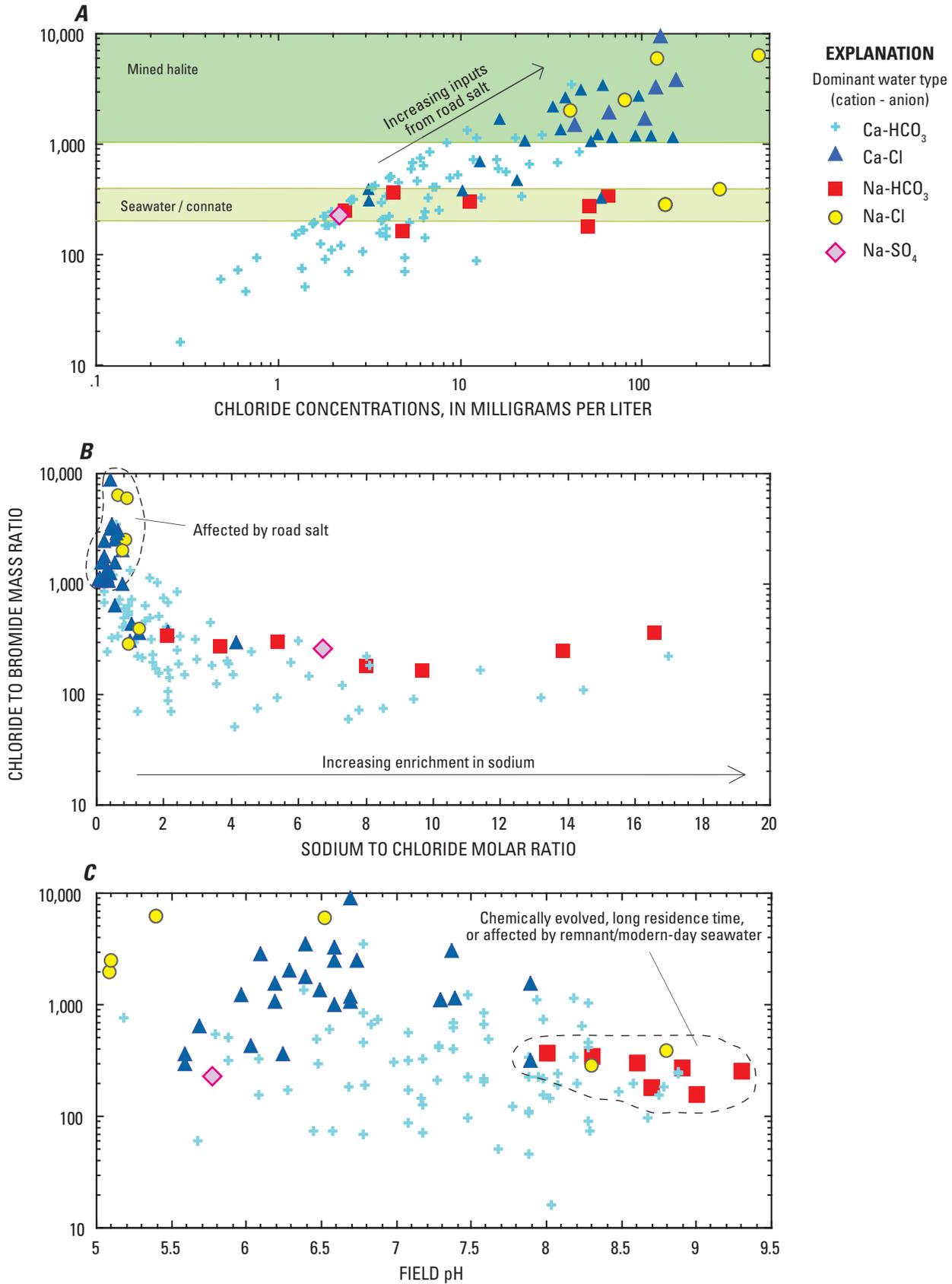


Figure 18. Chloride to bromide mass ratios in relation to *A*, chloride concentrations, *B*, sodium to chloride molar ratios, and *C*, pH in water samples collected from domestic wells in New England crystalline rock aquifers, 1995–2000. Sodium to chloride ratios greater than 20 are not shown. (Ca-HCO₃, calcium-bicarbonate type water; Ca-Cl, calcium-chloride type water; Na-HCO₃, sodium-bicarbonate type water; Na-Cl, sodium-chloride type water; Na-SO₄, sodium-sulfate type water)

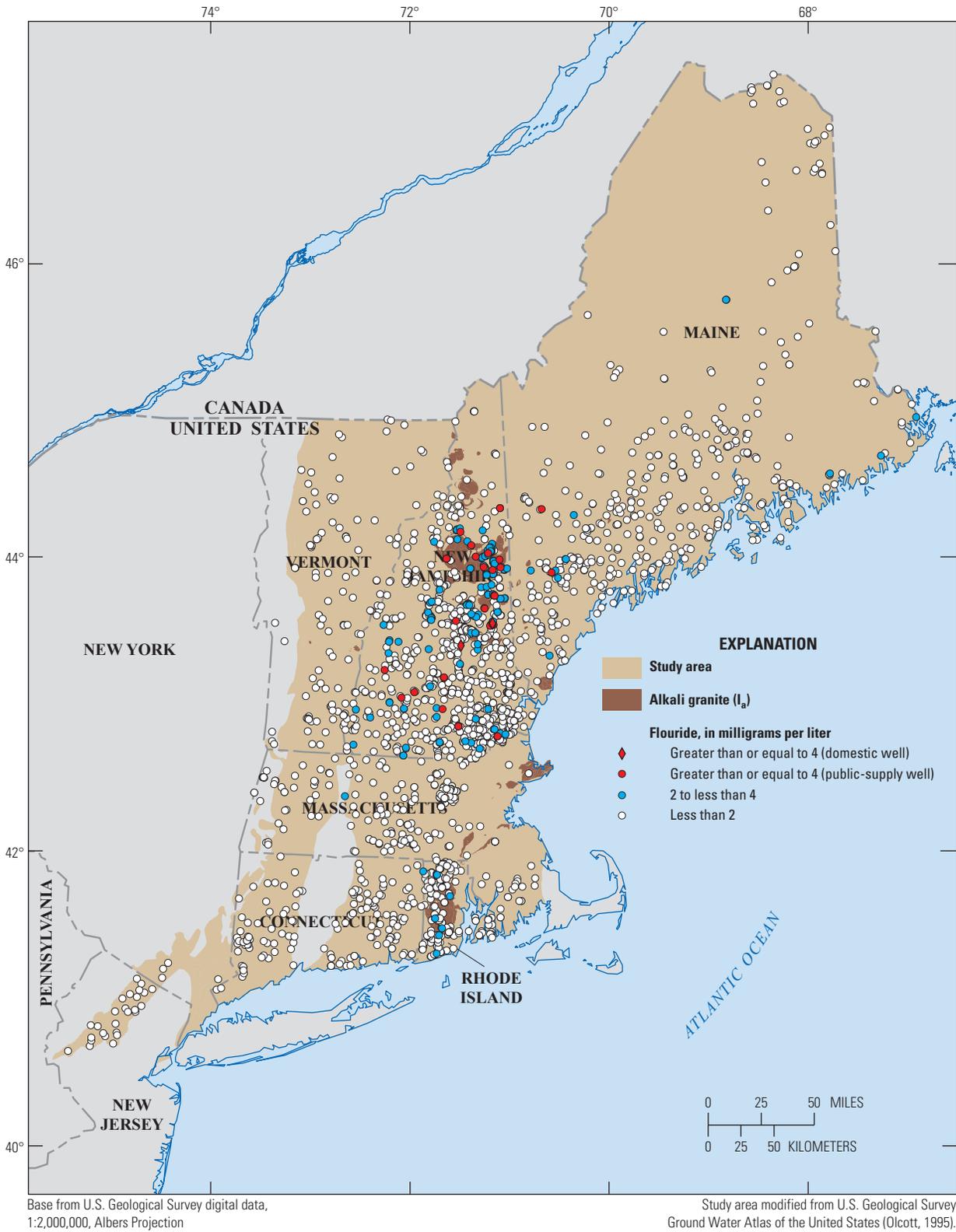


Figure 19. Spatial distribution of fluoride concentrations in water samples collected from domestic and public-supply wells in New England crystalline rock aquifers, 1995–2007. The alkali granite (I_a) lithology group is described in detail in table 7.

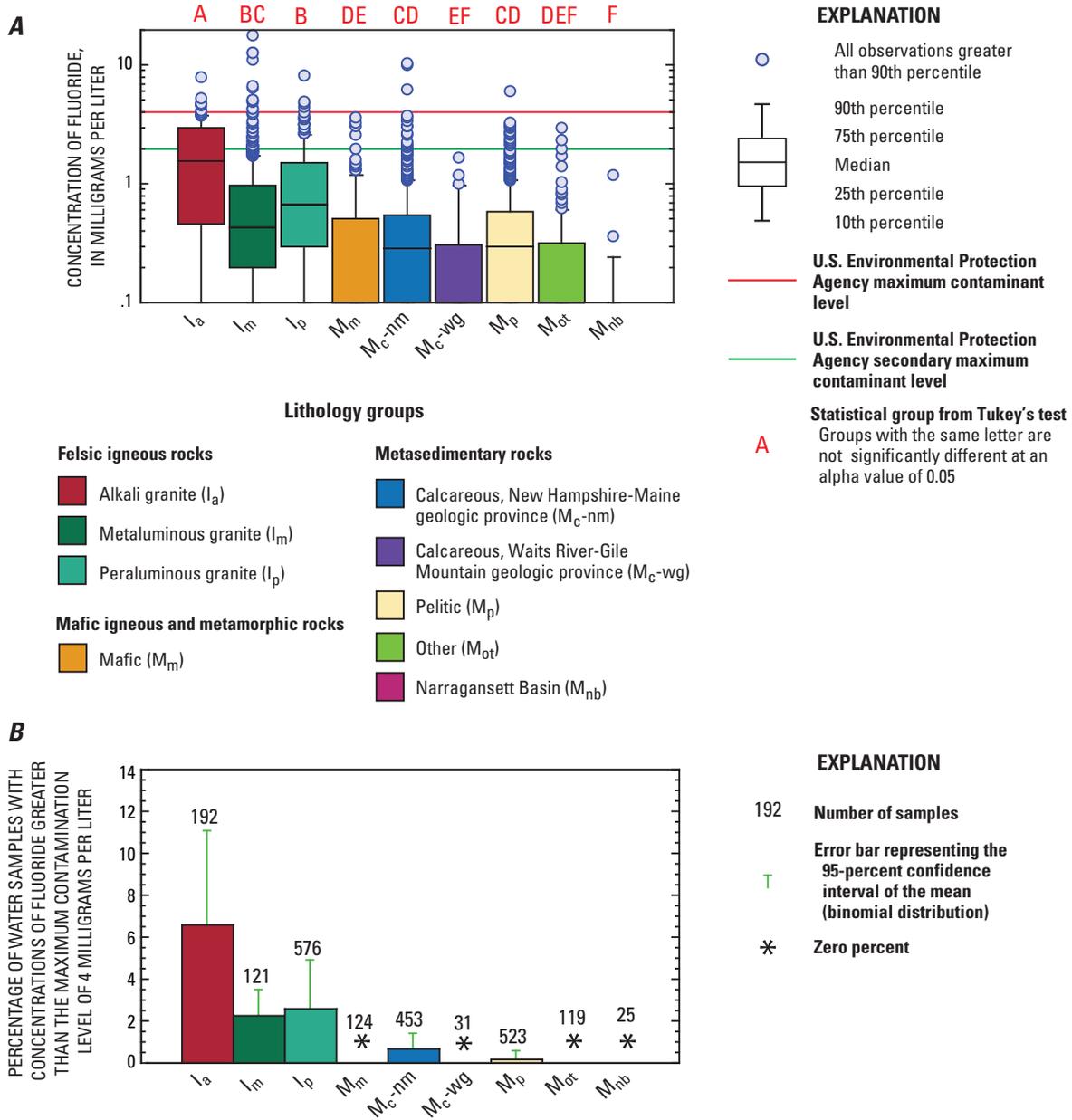


Figure 20. Distribution of *A*, concentrations of fluoride in water samples collected from public-supply and domestic wells in New England crystalline rock aquifers and *B*, percentages of these samples with concentrations of fluoride greater than the U.S. Environmental Protection Agency maximum contaminant level of 4 milligrams per liter, by lithology group, 1995–2007. The lithology groups are described in detail in table 7 and illustrated in figure 5B.

alkali granite (I_a) lithology group had the largest percentage of samples with F concentrations greater than the MCL (6.6 percent), followed by wells in the peraluminous granite (I_p) group at 2.6 percent, and by wells in the metaluminous granite (I_m) group at 2.3 percent (fig. 20B). All other studied lithology groups had less than 1 percent of water samples with F concentrations exceeding the MCL (fig. 20B). In a recent study of crystalline rock aquifers in New Hampshire, Moore (2004) found that 3 percent of samples from 527 domestic bedrock wells completed in felsic igneous rocks exceeded the MCL for F, while none of the samples from 71 domestic bedrock wells completed in calcareous metasedimentary rocks exceeded the MCL.

Most fluoride-bearing minerals, such as fluorite, apatite, mica, and hornblende are relatively insoluble in water (Murray, 1986). Fluorite (CaF_2), a common F mineral of low solubility, occurs in both igneous and sedimentary rocks. Hitchcock (1878) reported that large crystals of CaF_2 are found in the White Mountains of New Hampshire, an area that is primarily classified in this study as belonging to the I_a lithology group (fig. 19). From the data collected for this study, the highest four concentrations of F (11.1 to 17.9 mg/L) were from water samples in wells completed in the Winnepesaukee Tonalite Formation in New Hampshire (appendix 6). Winnepesaukee Tonalite, a geologic bedrock unit in the I_m lithology group, varies from diorite to granodiorite and granite and contains biotite as the major fluorine-bearing mafic mineral.

Edmunds and Smedley (1996) and Frengstad and others (2001) note that F concentrations can increase in groundwaters in which cation exchange occurs. In this study, four of the seven Na-HCO_3 water-type samples, where cation exchange of Ca for Na has likely occurred, have F concentrations greater than 1 mg/L. Interestingly, the samples from two domestic wells in New Hampshire with unusually high CH_4 concentrations also had high F concentrations (>6 mg/L) and were Na-HCO_3 type water, even though the wells are not in the area affected by the postglacial marine inundation where cation exchange may be significant (fig. 14).

Fluoride concentrations in samples from the domestic wells correlated positively with field pH and Na and correlated inversely with CO_2 gas, DO, NO_3 , and Ca (appendix 7). Fluoride concentrations in samples from the public-supply wells correlated positively with pH, well depth, and Na, and also correlated positively with U concentrations in streambed-sediment samples collected in New England for the National Uranium Resources Evaluation (NURE) Program (appendix 7). These correlations and the spatial pattern of F concentrations shown in figure 19 indicate that high F concentrations in NECR aquifers are related to F-bearing rock minerals in felsic igneous rocks and to chemically evolved, high pH groundwaters with low concentrations of Ca. Studies from other countries have shown that high F concentrations occur under similar conditions (Frengstad and others, 2001; Chae and others, 2006; Mondal and others, 2009; Rafique and others, 2009).

Trace Elements

With the exception for Fe and Mn, trace elements described in this section include metals and semimetallic elements that typically are found in fresh waters at concentrations less than 1 $\mu\text{g/L}$. All trace elements originate primarily from rock weathering, and their concentrations in groundwater reflect their presence and abundance in aquifer materials, geochemical (reduction-oxidation potential) conditions, pH, residence time, and ability to precipitate from or dissolve in water (Hem, 1985). Many trace elements occur in groundwater at multiple oxidation states and, depending on geochemical conditions and pH, have different solubility characteristics. Some trace elements can be derived from anthropogenic sources, such as those present as trace contaminants in pesticides, fertilizers and road salt. Materials used for construction of wells, pumps, spigots, and water distribution lines may have components that contain leachable amounts of Cu, Zn, or Pb. Mining activities, waste disposal, and leachate migration from landfills and septic systems also can contribute or affect concentrations of trace elements in groundwater.

The trace elements cobalt, silver, and thallium were not measureable at concentrations greater than their respective LRLs in any of the water samples collected from the domestic wells (appendixes 1–2). The trace elements antimony (Sb), beryllium (Be), cadmium (Cd), selenium (Se), and vanadium (V) were measured at concentrations greater than 1 $\mu\text{g/L}$ in less than 10 percent of the water samples from the domestic wells (appendixes 1–2). The trace elements Al, As, barium (Ba), boron (B), Cu, chromium (Cr), Fe, Pb, lithium (Li), Mn, molybdenum (Mo), nickel (Ni), strontium (Sr), U, and Zn were measured at concentrations greater than 1 $\mu\text{g/L}$ in 10 percent or more of the samples from the domestic wells (appendixes 1–2). Values for correlations of the concentrations of trace elements in water samples from the domestic wells with physiochemical properties and chemical constituents, by use of Spearman correlation, are provided in table 11. The following sections discuss in more detail some of the trace-element constituents analyzed in the water samples from the domestic and public-supply wells.

Iron and Manganese

Iron and Mn concentrations were highly variable in water samples from this study. Iron concentrations in water samples from 1,632 domestic and public-supply wells were mostly in the range of <50 to 905 $\mu\text{g/L}$, with a median concentration of 77 $\mu\text{g/L}$ (table 8). Manganese concentrations in water samples from 1,759 domestic and public-supply wells were mostly in the range of <20 to 226 $\mu\text{g/L}$, with a median concentration of 30 $\mu\text{g/L}$ (table 8). The maximum Fe (100,000 $\mu\text{g/L}$) and Mn (3,420 $\mu\text{g/L}$) concentrations, in samples collected from public-supply wells, show that their concentrations can be considerable in NECR aquifers (table 8). The spatial distribution of Mn concentrations in water samples collected from the domestic and public-supply wells is illustrated in figure 21.

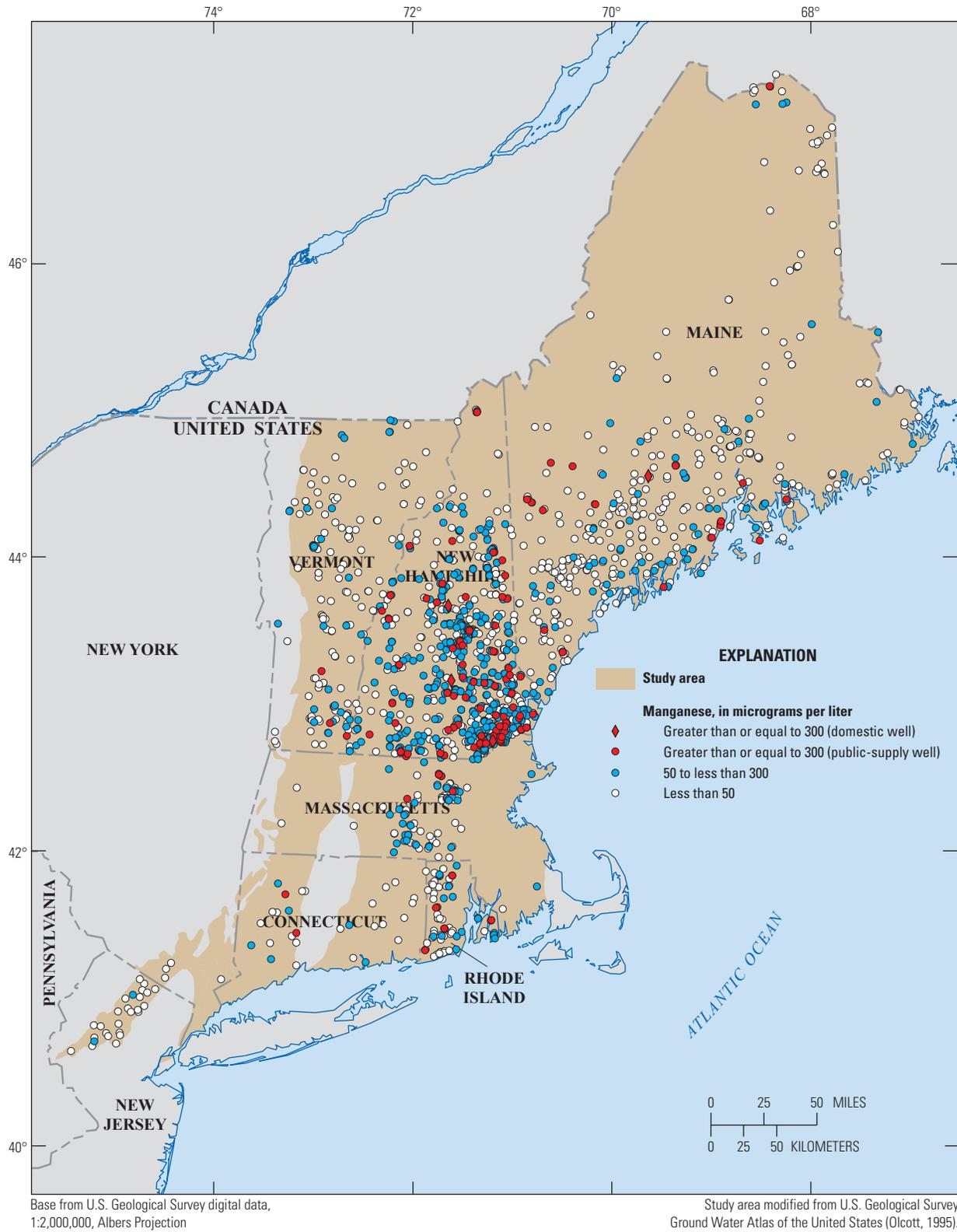


Figure 21. Spatial distribution of manganese concentrations in water samples collected from domestic and public-supply wells in New England crystalline rock aquifers, 1995–2007.

Iron and Mn are trace elements essential for human health, but Mn may have adverse neurological effects at high doses (Agency for Toxic Substances and Disease Registry, 2008); therefore, USEPA has issued a lifetime health advisory (LHA) of 300 $\mu\text{g/L}$ for Mn. Manganese concentrations were equal to or greater than the LHA in 7.3 percent of the water samples from the domestic and public-supply wells (table 9). The recommended SMCLs for Fe (300 $\mu\text{g/L}$) and Mn (50 $\mu\text{g/L}$) were established primarily to avoid aesthetic nuisances, such as staining of laundry and of plumbing fixtures. Iron concentrations were equal to or greater than the SMCL in 22 percent of the water samples, and Mn concentrations were equal to or greater than the SMCL in 38 percent of the water samples from domestic and public-supply wells (table 9).

Iron and Mn concentrations in this study were not significantly different when the samples were evaluated on the basis of land use, population density, or well-construction categories. However, concentrations of Fe and Mn were significantly different among some of the geologic lithology groups. In comparing Fe and Mn concentrations among the nine lithology groups, water samples from wells in the M_{nb} lithology group ranked the highest, while water samples from wells in the M_c -wg lithology group ranked the lowest. There were no significant differences in Fe and Mn concentrations among the remaining seven lithology groups studied.

Iron and Mn concentrations were significantly greater in the public-supply well samples than in the domestic well samples. Iron concentrations were greater than the SMCL (300 $\mu\text{g/L}$) in 24 percent of the public-supply well samples, whereas only 6.8 percent of the domestic well samples had Fe concentrations greater than the SMCL (table 9). Manganese concentrations were greater than the SMCL (50 $\mu\text{g/L}$) in 39 percent of the public-supply well samples, whereas only 17 percent of the domestic well samples had Mn concentrations greater than the SMCL (table 9). It is possible that this difference in Fe and Mn concentrations between the public-supply and domestic wells could be related to the difference in sample processing (domestic well samples were filtered, whereas the public-supply well samples were unfiltered). The difference in pumping rates for the public-supply and domestic wells is another possible explanation for the differences in Fe and Mn concentrations between the two data programs. Larger and more sustained pumping rates in the public-supply wells may result in greater mixing of groundwater from different fractures or induce water from other sources (such as overlying glacial aquifers or surface water), which in turn, changes geochemical conditions and (or) groundwater-flow patterns in ways that enhances the solubility and mobility of Fe and Mn to pumped groundwater.

Iron and Mn solubility increases as DO decreases. As such, DO concentrations in the water samples from the domestic wells correlated inversely with concentrations of Fe and Mn (table 11). While Fe and Mn concentrations in the domestic well samples were not correlated with pH, they were strongly and positively correlated with each other (table 11) and with apparent residence time (appendix 4). Iron and Mn

concentrations in the public-supply well samples were also strongly and positively correlated with each other ($\rho = 0.54$, p -value = <0.0001 , $n = 1,373$), suggesting that Fe and Mn commonly co-occur in NECR aquifers and some of the largest concentrations may be associated with older groundwaters.

Aluminum, Barium, and Strontium

Concentrations of Al greater than 1 $\mu\text{g/L}$ were measured in 57 percent of 86 domestic well samples, although there may be a positive bias due to contamination in some of the blank samples (table 3). High concentrations of Al in drinking water can result in undesirable color and turbidity (World Health Organization, 2004), and the USEPA recommends that concentrations not exceed 50 to 200 $\mu\text{g/L}$. Concentrations of Al greater than 50 $\mu\text{g/L}$ occurred in 3 of the domestic well samples. Aluminum concentrations in water samples from the domestic wells correlated positively with DO concentrations and correlated inversely with pH (table 11). Aluminum-rich clays and colloids produced by rock weathering of aluminosilicate minerals, such as feldspars, micas, and other related minerals, are relatively insoluble in groundwater, but high Al concentrations can occur under very low pH conditions (Hem, 1985). The three highest Al concentrations (140 to 360 $\mu\text{g/L}$) were measured in water samples under very low pH (<5.7) and oxic conditions ($\text{DO} >2.8$ mg/L), and were from wells completed in felsic igneous rocks.

Barium and Sr are alkaline-earth elements that vary widely in their abundance and behavior in groundwater (Hem, 1985). Concentrations of Ba greater than 1 $\mu\text{g/L}$ were measured in 85 percent of 87 domestic well samples (table 8). Concentrations of Sr greater than 1 $\mu\text{g/L}$ were detected in all 58 domestic well samples (appendix 1). The maximum Ba concentration (113.8 $\mu\text{g/L}$) was well below the MCL of 2,000 $\mu\text{g/L}$ and the maximum Sr concentration (1,660 $\mu\text{g/L}$) was below the LHA of 4,000 $\mu\text{g/L}$ (table 9). DeSimone (2009) reported that the highest Sr concentrations in domestic wells nationally occurred more frequently in the southwestern and south-central United States. Barium concentrations in the domestic well samples correlated positively with Sr, K, and Mg concentrations, and with ^{224}Ra , ^{226}Ra , and ^{228}Ra activities (table 11). A study of a NECR aquifer in western Vermont also has shown an association between Ba and Ra concentrations (North, 2005). Strontium concentrations in the domestic well samples correlated positively with Ca and Mg (table 12). Strontium in groundwater can occur at higher concentrations in calcareous and calc-pelite rocks than in other rock lithologies because Sr geochemistry is similar to that of Ca, whereas Ba geochemistry is similar to that of K and Ra and occurs at similar concentrations among lithology groups.

Boron, Lithium, and Molybdenum

Boron concentrations in 79 domestic well samples ranged from <12 to 132.7 $\mu\text{g/L}$ (table 8); none of the samples exceeded the LHA of 1,000 $\mu\text{g/L}$ (table 9). Boron in groundwater may originate from anthropogenic sources, such as

Table 12. Arsenic occurrence in groundwater at concentrations greater than the U.S. Environmental Protection Agency Maximum Contaminant Level, by previous studies.

[N, number of water samples; µg/L, micrograms per liter; --, no data; USEPA SDWA, U.S. Environmental Protection Agency Safe Drinking-Water Act Program; USGS NAWQA, U.S. Geological Survey National Water-Quality Assessment Program; Unk, unknown. The Maximum Contaminant Level (MCL) for arsenic in publicly-supplied drinking water is 10 µg/L]

Source of data	Area studied	Arsenic samples			
		Domestic wells		Public-supply wells	
		N	Percent greater than 10 µg/L	N	Percent greater than 10 µg/L
Wells used in this study					
USEPA SDWA	New England	--	--	1,937	13.5
USGS NAWQA	New England, New Jersey, and New York	117	10	--	--
Wells from other crystalline rock aquifer studies in New England					
National Institutes of Health	Maine, New Hampshire, and Vermont	1,321	13.6	--	--
Ayotte and others, 2003	New Hampshire	645	11	--	--
Lipfert and others, 2006	Mid-coastal Maine	35	69	--	--
Moore, 2004	New Hampshire	191	21	--	--
Montgomery and others, 2003	Southeastern New Hampshire	353	19	--	--
Qiang and others, 2009	Greater Augusta, Maine	790	31	--	--
Peters and Blum, 2003	South-central New Hampshire	146	52	--	--
Peters and others, 1999	New Hampshire	218	13	506	2
Nationwide groundwater studies of all aquifers					
Focazio and others, 2000	United States	--	--	Unk	7.6
DeSimone, 2009	United States	1,774	6.8	--	--

¹From Debra Silverman and Dalsu Baris, National Institute of Health, written commun., 2009.

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sewage disposal (DeSimone, 2009). Boron concentrations in water samples from the domestic wells correlated positively with NO_3 (table 11), suggesting that leachate from onsite septic systems is a possible source of B in the domestic well samples.

Lithium concentrations in 54 domestic well samples were mostly in the range of 1 to 19.8 $\mu\text{g/L}$, with a maximum concentration of 1,320 $\mu\text{g/L}$ (appendix 1). Lithium concentrations in the water samples correlated positively with Br, Cl, Na, and F and inversely with DO (table 11), suggesting that Li in NECR aquifers is associated with road salt, connate waters, or chemically evolved groundwater. The domestic well sample in this study (in New Hampshire) with the unusual Li concentration of 1,320 $\mu\text{g/L}$ also had high concentrations of F (17.9 mg/L) and CH_4 (15.5 mg/L) and had high pH (8.7).

Molybdenum concentrations in 87 domestic well samples were mostly in the range of <1 to 3.8 $\mu\text{g/L}$, with a maximum concentration of 18.8 (table 8). None of the samples exceeded the LHA of 40 $\mu\text{g/L}$ (table 9). Molybdenum concentrations in the water samples correlated inversely with concentrations of DO and correlated positively with pH (table 11), indicating that Mo solubility increases as DO decreases and pH increases. Molybdenum concentrations also were strongly and positively correlated with apparent residence time (appendix 4), suggesting that higher Mo concentrations are associated with older NECR groundwaters.

Beryllium and Chromium

Three water samples from 57 domestic wells had measureable Be (>1 $\mu\text{g/L}$), and one of these samples had a concentration (7.54 $\mu\text{g/L}$) that exceeded the USEPA MCL of 4 $\mu\text{g/L}$ (appendix 1; table 9). Beryllium's solubility is enhanced in acidic waters. The three water samples with measureable concentrations of Be had low pH (<5.7) and were collected from wells completed in the I_a and I_p granite lithology groups (appendix 6). One of the most important minerals containing Be is beryl, a silicate of Al and Be that is found most commonly in pegmatites (Hem, 1985).

Chromium concentrations in 87 domestic well samples ranged from <1 to 4.1 $\mu\text{g/L}$ (table 8); none of the samples exceeded the MCL of 100 $\mu\text{g/L}$ (table 9). However, 17 of the 19 water samples with measureable Cr (>1 $\mu\text{g/L}$) were collected from NJ-NY domestic wells (appendix 2); the remaining two samples were collected from the New England domestic wells (appendix 1). Chromium concentrations in the water samples correlated positively with concentrations of DO and inversely with pH (table 11), indicating that chromium mobility is enhanced in low-pH, oxic groundwaters. Water samples from the NJ-NY domestic wells had significantly lower pH values and higher DO concentrations than the New England domestic wells (fig. 7), which might explain the difference in Cr occurrence rates between the NJ-NY wells and the New England wells.

Copper, Lead, Nickel, and Zinc

At a common LRL of 1 $\mu\text{g/L}$, 60 percent of water samples from 86 to 87 domestic wells had measurable Cu, 16 percent had measurable Pb, 35 percent had measureable Ni, and 55 percent had measurable Zn (table 8). The largest concentrations for the 4 trace elements were all in water samples collected for the NECB study. The maximum Pb concentration (12.9 $\mu\text{g/L}$) was from a domestic well in Rhode Island; the maximum Ni concentration (11.6 $\mu\text{g/L}$) was from a domestic well in Maine; and the maximum Cu (416 $\mu\text{g/L}$) and Zn concentrations (463 $\mu\text{g/L}$) were from the same domestic well in New Hampshire. Several of the associated blank samples had measureable amounts of Cu, Pb, and Zn (table 3), so there may be a positive bias in the total number of samples with detections above the LRL for these trace metals.

Copper, Pb, and Zn solubility in water increases as DO increases and pH decreases. As such, DO concentrations in the water samples from the domestic wells correlated positively with concentrations of Cu, Pb, and Zn; and pH correlated inversely with concentrations of Cu, Pb, and Zn (table 11). pH also correlated inversely with Ni concentrations. All four trace elements (except for Ni with Pb) correlated positively with each other (table 11) and inversely with apparent residence time (appendix 4), indicating that they generally occur in NECR aquifers under oxic and low-pH conditions—for example, younger groundwater.

Arsenic

Arsenic concentrations in 2,054 water samples collected from the domestic and public-supply wells were mostly in the range of <5 to 13 $\mu\text{g/L}$, with a median value of <5 $\mu\text{g/L}$ (table 8). The largest As concentration in a domestic well sample (in Maine) was 50.9 $\mu\text{g/L}$, and the largest As concentration in a public-supply well sample (in Maine) was 2,400 $\mu\text{g/L}$. The spatial distribution of As concentrations in these samples is shown in figure 22. Many of the higher concentrations (As ≥ 10 $\mu\text{g/L}$) coincide with areas classified as calcareous metasedimentary rocks in eastern New Hampshire and Maine (M_c -nm lithology group). Similar spatial distribution patterns of As concentrations in eastern New England has been reported on by previous studies (Ayotte and others, 1999, 2003).

Of the 2,054 water samples analyzed for arsenic in this study, 13.3 percent had concentrations equal to or greater than the MCL of 10 $\mu\text{g/L}$ (table 9); this finding is comparable to that of an earlier study (1995–2003) on arsenic in NECR aquifers at a regional scale (Ayotte and others, 2006). In the earlier study, As concentrations equaled or exceeded the MCL in 12 percent of water samples collected from 2,470 domestic and public-supply bedrock wells in New England. Using data from these wells, Ayotte and others (2006) modeled the probability that bedrock aquifers in New England would yield groundwater with As concentrations greater than 5 $\mu\text{g/L}$. Many of those public-supply wells analyzed by Ayotte and others (2006) also were selected for this study, therefore, similar results were expected.

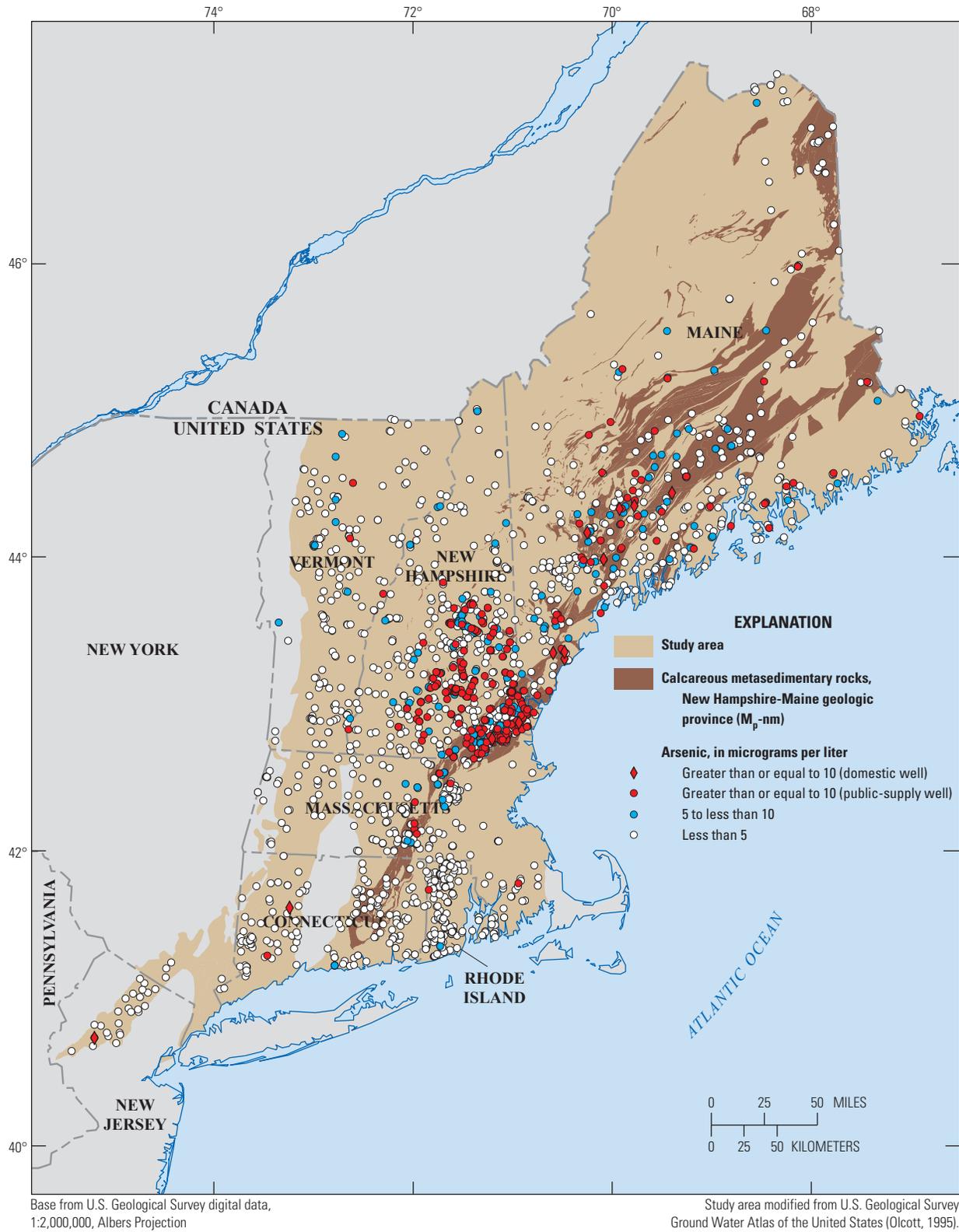


Figure 22. Spatial distributions of arsenic concentrations in water samples collected from domestic and public-supply wells in New England crystalline rock aquifers, 1995–2007. The calcareous metasedimentary rocks, New Hampshire-Maine geologic province (M_c-nm) lithology group is described in detail in table 7.

The As exceedance rate (13.3 percent) for this study also is nearly identical to a recent (2003–2006) bladder cancer study in Maine, New Hampshire, and Vermont, where As concentrations equaled or exceeded the MCL in 13.6 percent of water samples collected from 1,321 domestic bedrock wells (Debra Silverman and Dalsu Baris, National Institutes of Health, National Cancer Institute, written commun., 2009) (table 12). The As exceedance rate (13.3 percent) for this study was nearly double the national rate of 7.6 percent reported for public-supply systems in the United States (Focazio and others, 2000) and the national rate of 6.8 percent for domestic wells sampled from all aquifers (in which the NAWQA samples from this study are included) for the NAWQA Program (DeSimone, 2009) (table 12).

Other studies of New England drinking water also have shown that wells completed in crystalline rock can contain high concentrations ($>10 \mu\text{g/L}$) of As, but at variable occurrence rates. For studies in New Hampshire, Peters and others (1999), Montgomery and others (2003), and Moore (2004) reported that As concentrations exceeded the MCL in domestic and public-supply bedrock wells at rates as low as 2 percent to rates as high as 21 percent (table 12). When studies are targeted for aquifers known to contain As-enriched groundwater, the occurrence rate above the MCL in water samples can be much higher than in larger-scale studies where samples are more randomly selected (Peters, 2008). Yang and others (2009) found that 31 percent of water samples from 790 domestic bedrock wells in the greater Augusta area (about five towns in south-central Maine) had As concentrations greater than the MCL and that the highest As concentrations were associated with Silurian pelite-sandstone and pelite-limestone bedrock units (table 12). Peters and Blum (2003) reported that 52 percent of water samples from 146 domestic wells in a fractured-silicate bedrock aquifer in central New Hampshire had As concentrations greater than the MCL and that the highest As concentrations were associated with pelitic metasedimentary rocks. Lipfert and others (2006) reported that 69 percent of water samples from 35 domestic bedrock wells in a small mid-coastal Maine watershed comprising of sulfidic schist with granitic to diorite intrusions had As concentrations greater than the MCL (table 12). As mentioned previously in the study design section, the first NECB well network consists of 28 domestic wells (fig. 1) in areas where the geologic units are dominated by calcareous metasedimentary rocks in the New Hampshire-Maine (M_c -nm) geologic province. As a result, 28.6 percent of the water samples in this NAWQA well network had As concentrations equal to or greater than the MCL, a rate significantly higher than the rates for the other three NAWQA well networks (fig. 23).

Arsenic concentrations in this study were not significantly different when the samples were evaluated on the basis of water use (domestic versus public supply), land use, or population density. At this regional scale, agricultural lands (where for some areas, As-based pesticides may have been used in the past) were not found to be a factor in the occurrence of elevated As concentrations in groundwater. Although

As residues in soils resulting from past use of arsenical pesticides is a potential anthropogenic source, Robinson and Ayotte (2006) concluded that in areas of former arsenical pesticide use, As contamination did not significantly affect the distribution of elevated As concentrations in NECR groundwater.

Arsenic concentrations in this study, however, were significantly different when the water samples were evaluated on the basis of well-construction categories. High As concentrations ($>10 \mu\text{g/L}$) occurred in nearly 20 percent of the water samples from deep wells (well depths >300 ft and casing lengths >50 ft) compared to only 6 percent from shallow wells (well depths ≤ 300 ft and casing lengths ≤ 50 ft) (fig. 24). This is not surprising, since deeper bedrock wells are more likely to tap into fractures yielding older, high pH groundwater than shallower wells—a condition that favors As mobility.

Arsenic concentrations also were significantly different when the water samples in this study were evaluated on the basis of the location of wells within a lithology group (fig. 25A). Arsenic concentrations in sampled wells from the M_c -nm, I_p , and M_p lithology groups were significantly higher and exceeded the MCL more often (12.5 to 22.8 percent) than in sampled wells from the six other studied lithology groups (fig. 25B).

Notably, both the M_c -wg and M_c -nm lithology groups comprise predominantly calcareous metasedimentary rocks; however, rocks in the Waits River-Gile Mountain (wg) geologic province have lesser amounts of As-enriched minerals than rocks in the New Hampshire-Maine (nm) geologic province. This is an example of how the different tectonostratigraphic settings of crystalline rock units of similar lithology can have differences in groundwater quality. Arsenic concentrations in sampled wells from the I_p and I_m granite lithology groups may be related to dissolution of As-bearing minerals associated with pegmatitic dikes in (or near) granite plutons (Peters and others, 1999; Ayotte and others, 2006; Peters, 2008).

Arsenic concentrations in water samples from the domestic wells correlated positively with pH values and inversely correlated with DO and NO_3 concentrations (table 11). These correlations are illustrated in figure 26, which shows the relations in domestic wells between As concentrations, pH, and NO_3 . The largest As concentrations were associated with water samples under high pH (>7.5), low dissolved oxygen or “anoxic” ($<1 \text{ mg/L}$) conditions (fig. 26A) and with negligible amounts of NO_3 (fig. 26B). Arsenic concentrations in water samples from the public-supply wells also correlated positively with pH values and inversely with NO_3 concentrations (appendix 7).

Water samples collected from public-supply wells for compliance monitoring associated with the SDWA Program are commonly analyzed for NO_3 . Since DO and pH are important factors in As mobility in groundwater, combinations of pH with concentrations of NO_3 (used here as a substitution for DO) may be a useful indicator of the possible occurrence of greater than background concentrations of As in groundwater. High As concentrations ($\geq 10 \mu\text{g/L}$) occurred in

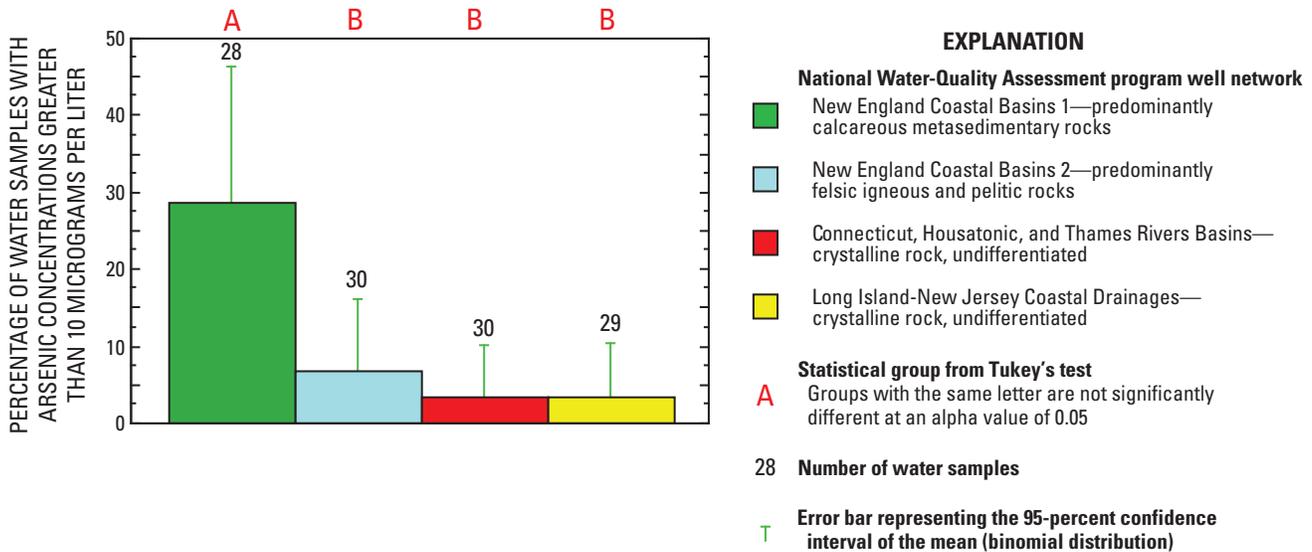


Figure 23. Distribution of percentages of water samples with concentrations of arsenic greater than 10 micrograms per liter collected from domestic wells in New England crystalline rock aquifers, by the National Water-Quality Assessment Program well network, 1995–2000. Locations of well networks are shown in figure 1.

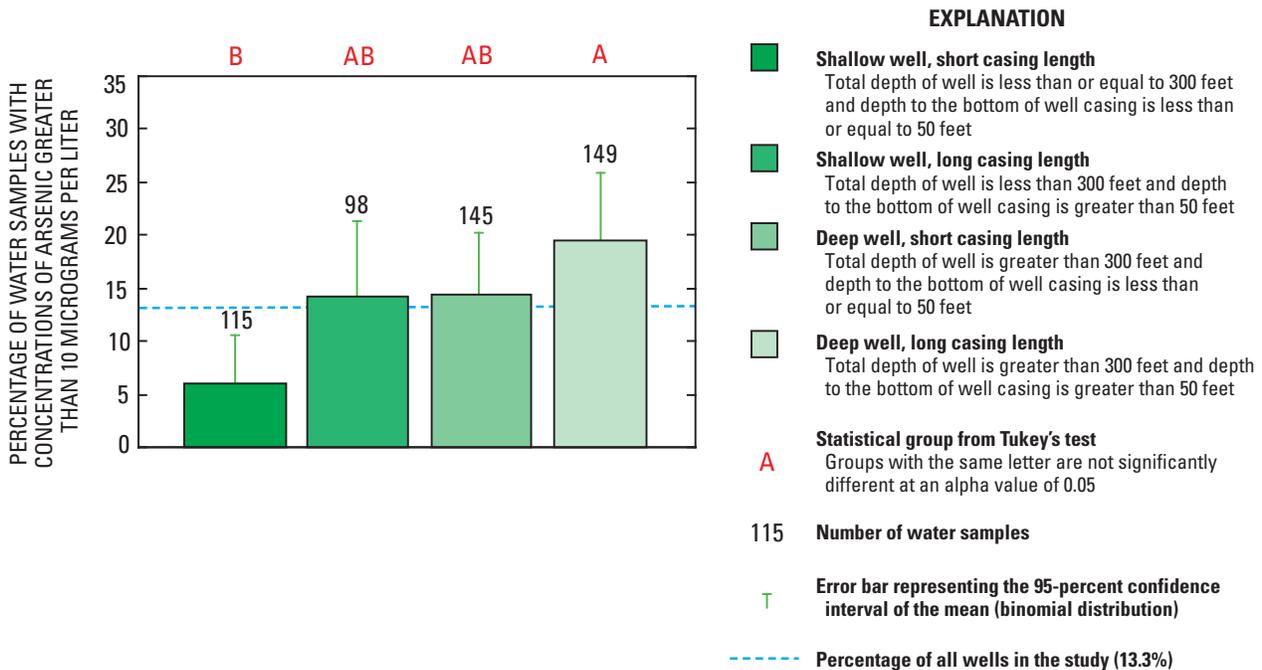
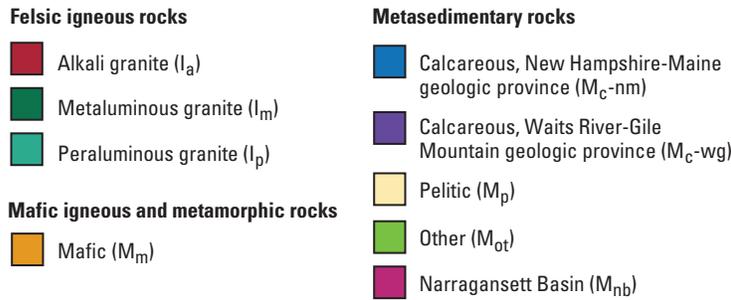
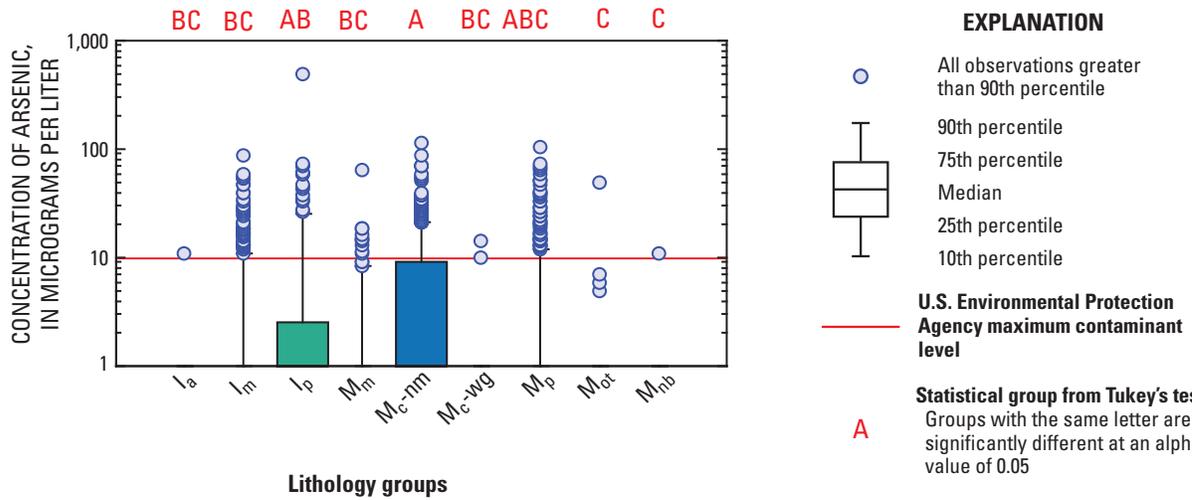


Figure 24. Distribution of percentages of water samples with concentrations of arsenic greater than 10 micrograms per liter collected from public-supply and domestic wells in New England crystalline rock aquifers, by categories of well depth and casing length, 1995–2007. See table 5 for the distribution of sampled wells on the basis of categories of well depth and casing length.

A



B

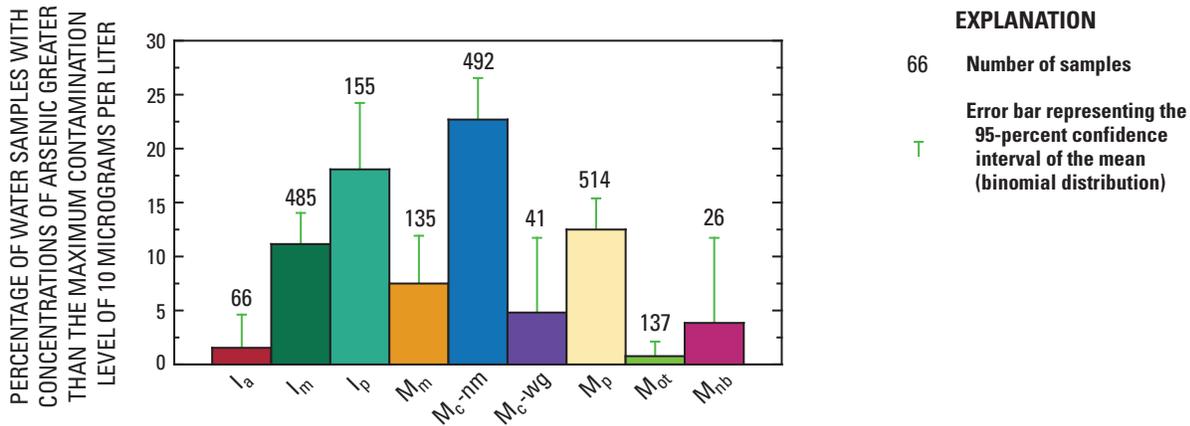


Figure 25. Distributions of *A*, concentrations of arsenic in water samples collected from public-supply and domestic wells in New England crystalline rock aquifers and *B*, percentages of these samples with concentrations of arsenic greater than the U.S. Environmental Protection Agency maximum contamination level of 10 micrograms per liter, by lithology group, 1995–2007. Water samples with concentrations of arsenic concentrations greater than 1,000 micrograms per liter are not shown in graph *A*. The lithology groups are described in detail in table 7 and illustrated in figure 5B.

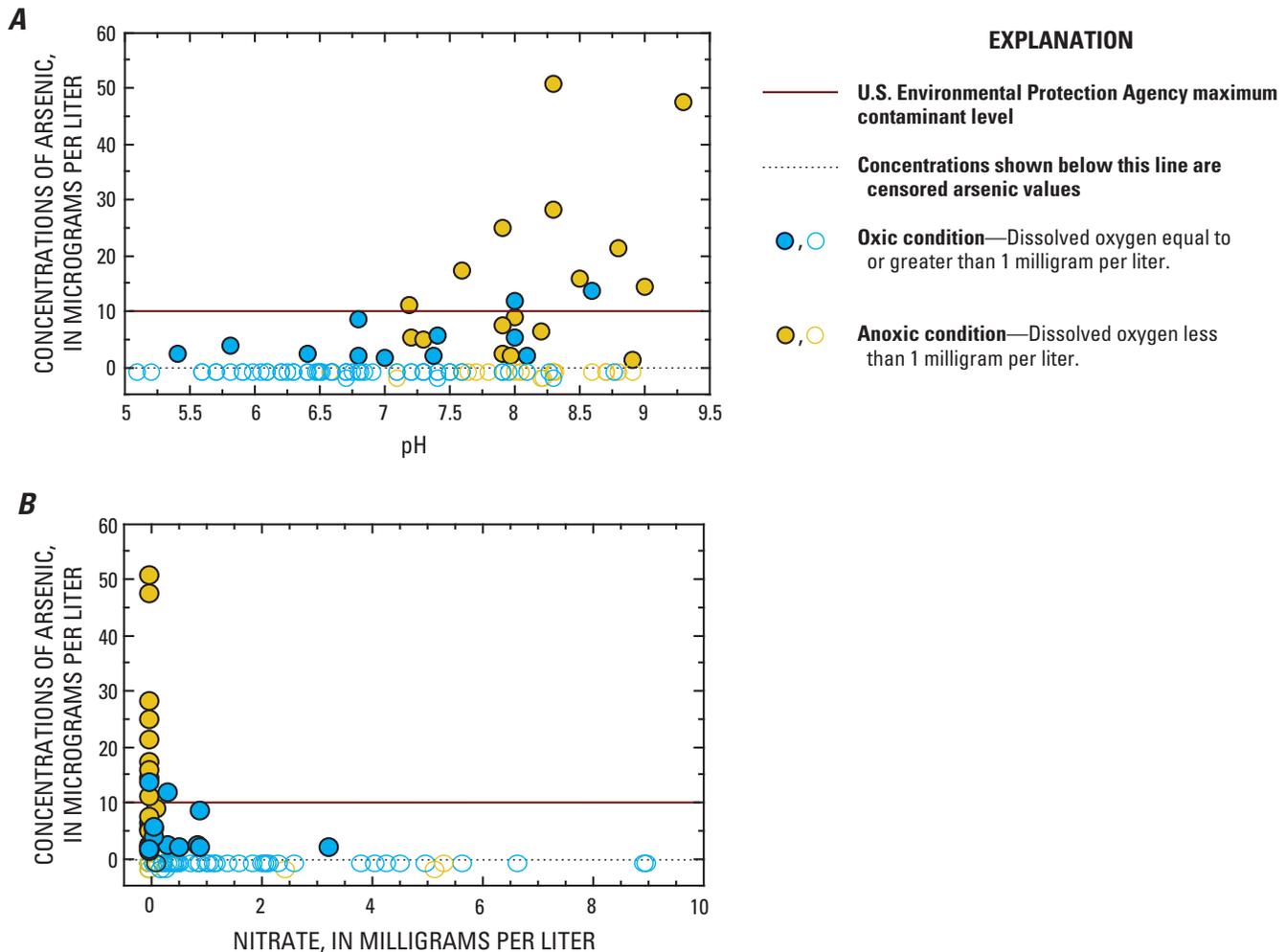


Figure 26. Relations of concentrations of arsenic in water samples collected from domestic wells in New England crystalline rock aquifers to *A*, pH, and *B*, concentrations of nitrate, 1995–2000.

21 percent of 897 sampled wells with high pH (≥ 7) and low NO_3^- (< 0.5 mg/L; fig. 27). In contrast, high As concentrations occurred in less than 3 percent of 110 sampled wells with low pH (< 7) and measureable NO_3^- (≥ 0.5 mg/L) (fig. 27). Ayotte and others (2003) also noted that high As concentrations (> 10 $\mu\text{g/L}$) occurred more frequently in groundwater with high pH (> 7.5), even among wells in the same geologic setting.

Arsenic concentrations in the water samples also correlated positively with As concentrations in streambed-sediment samples collected in New England for the NURE Program (appendix 7). Other studies found a similar relation between As in groundwater and nearby streambed sediments and concluded that rock-based As is the dominant source of the trace element in streambed sediments and groundwater in New England (Ayotte and others, 2006; Robinson and Ayotte, 2006). These correlations show the importance of both the geologic source of As and the geochemical processes

that affect As mobility in groundwater. Sources of naturally occurring As in NECR aquifers include As-bearing sulfides, As sorbed onto iron-manganese hydroxide coating fractures, and other mineral surfaces. Sorbed As is mobilized from iron oxides by reductive dissolution in waters with low DO concentrations and (or) by desorption from the oxides in high pH waters (Welch and others, 2000; Ayotte and others, 2003; Lipfert and others, 2006; Peters, 2008).

Arsenic concentrations were much greater than the MCL in some of the water samples. Thirty-two samples (1.65 percent) collected from public-supply wells and 1 sample (1.14 percent) from a domestic well had As concentrations greater than five times (50 $\mu\text{g/L}$) the MCL. The greatest As concentration in this study (2,400 $\mu\text{g/L}$) was measured in a water sample from a public-supply well in Maine and completed in a pelitic rock member of the Silurian Sangerville Formation, a geologic unit that is mostly in the M_c -nm lithology group (appendix 6). Rocks that are common

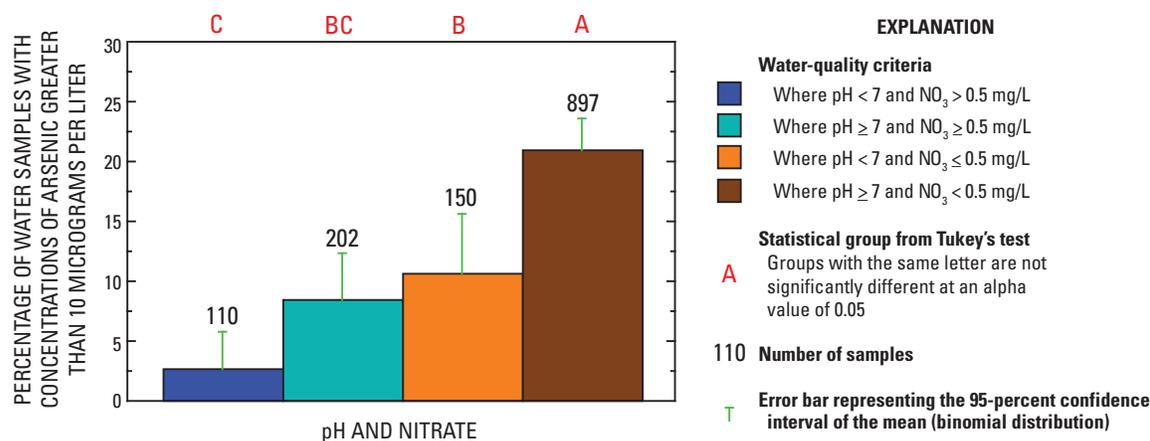


Figure 27. Distribution of percentages of water samples collected from public-supply and domestic wells in New England crystalline rock aquifers with concentrations of arsenic greater than the U.S. Environmental Protection Agency maximum contaminant level of 10 micrograms per liter, by categories of pH and nitrate concentrations, 1995–2007. (≤, less than or equal to; ≥, greater than or equal to; >, greater than; <, less than; mg/L, milligrams per liter; NO₃, nitrate)

in the Sangerville Formation include crystallized calc-silicate rocks, granofels, and pelitic schist of high metamorphic grade (Osberg and others, 1985). In a different study in mid-coastal Maine, Lipfert and others (2006) reported that one well had groundwater with a mean As concentration of 1,990 µg/L.

Nielsen and others (2010) conducted a recent assessment of all available As data from more than 11,000 domestic wells in Maine during 2005–09. The purpose of this study was to determine which Maine towns were at risk for very high concentrations of As in groundwater. Nielsen and others (2010) reported that four Maine towns (Surry, Danforth, Blue Hill, and Woolwich) had 1 percent or more of sampled domestic wells with As concentrations greater than 500 µg/L. One domestic well in the town of Danforth, Maine, had a reported As concentration of 3,100 µg/L (Nielsen and others, 2010).

Radionuclides

The occurrence and distribution of radionuclides in groundwater is controlled by the local geology and geochemistry of rock and water interactions. The most common radioactive elements, ²³⁸uranium and ²³²thorium, decay slowly and produce other radioactive elements, such as Ra and ²²²Rn, which in turn undergo radioactive decay and form their own daughter elements, with the end product being stable ²⁰⁶Pb (Ayotte and others, 2007). The factors relating to U and ²²²Rn measurements in water samples from the 117 NAWQA domestic wells in this study were analyzed in detail by Ayotte and others (2007), along with other wells sampled for the NAWQA program in the northern United States.

Gross Alpha- and Gross Beta-Particle Activity

Gross alpha-particle (gross alpha) activity is used mostly as an indicator of high levels of alpha-particle radioactivity without identifying the specific radionuclides responsible for the activity (DeSimone, 2009). In 893 water samples from domestic and public-supply wells, gross alpha activities were mostly in the range of <3 to 17.3 pCi/L, with a median value of <3 pCi/L (table 8). The spatial distribution of gross alpha activity in water samples from the domestic and public-supply wells is illustrated in figure 28. In this study, gross alpha activities were significantly higher in the domestic wells than in the public-supply wells. Gross alpha activities equaled or exceeded the MCL (15 pCi/L) in 15.5 percent of 58 water samples from domestic wells and in 11.6 percent of 835 water samples from public-supply wells in New England (table 9). Gross alpha activities were significantly higher in the I_p and I_a granite lithology groups than all other studied groups. The five highest gross alpha activities in the water samples (ranging from 280 to 2,560 pCi/L) were from four public-supply wells in New Hampshire and one domestic well in Maine (appendix 6). Three of the five wells are completed in metasedimentary rocks.

Gross beta-particle (gross beta) activity is an indicator of beta-emitting isotopes in water, and analysis of gross beta is widely used in studies of naturally occurring radioactivity in groundwater (Welch and others, 1995). Gross beta activities in 58 water samples ranged from <4 to 653 pCi/L, with a median value of <4 pCi/L (appendix 1). Five samples (about 9 percent) had gross beta activities equal to or greater than

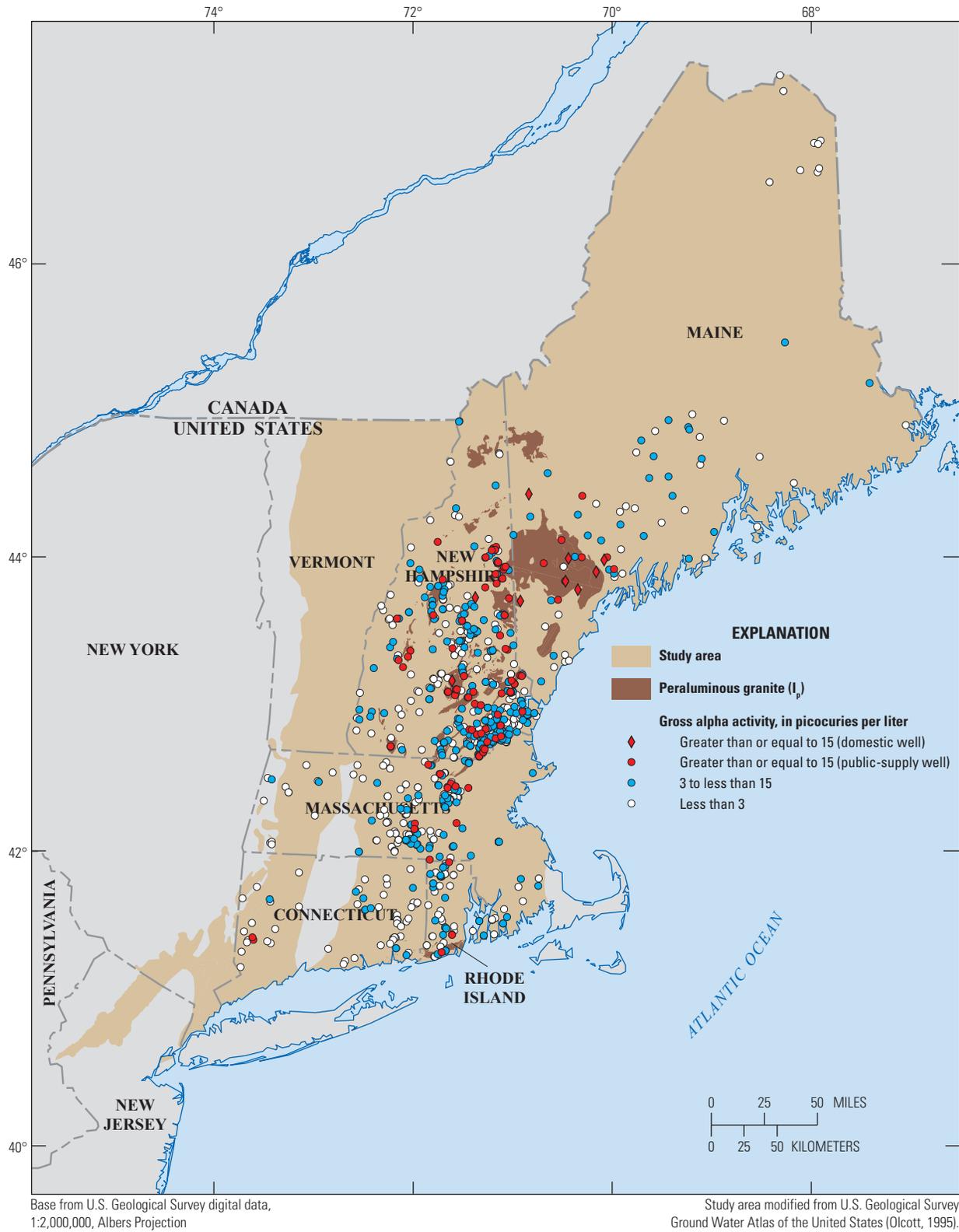


Figure 28. Spatial distribution of gross alpha-particle activities in water samples collected from domestic and public-supply wells in New England crystalline rock aquifers, 1999–2007. The peraluminous granite (I_p) is described in detail in table 7.

the MCL of 50 pCi/L (table 9). These 5 water samples (from domestic wells completed in I_p and M_p rocks) also had relatively high radon ($>5,700$ pCi/L), U (>13.3 $\mu\text{g/L}$), and gross alpha (>34.5 pCi/L) measurements. Only seven domestic wells (five of which were from this study) in all aquifers sampled nationally for the NAWQA Program had gross beta activities equal to or greater than the MCL (DeSimone, 2009).

Radium

Radium isotopes, which originate from the radioactive decay of uranium and thorium, occur as dissolved divalent cations in groundwater (Zapecza and Szabo, 1986). In water samples from 55 to 56 domestic wells, the maximum ^{224}Ra activity was 1.36 pCi/L, the maximum ^{226}Ra activity was 6.75 pCi/L, and the maximum ^{228}Ra activity was 2.1 pCi/L (appendix 1).

In water samples from 562 domestic and public-supply wells, combined radium (^{226}Ra plus ^{228}Ra) activities were mostly in the range of <1 to 2.7 pCi/L; the maximum combined radium activity was 16 pCi/L (table 8). The spatial distribution of combined radium activities in water samples from these wells is illustrated in figure 29. Activities of combined radium were equal to or greater than the MCL of 5 pCi/L in 2 samples (about 4 percent) from the domestic wells and in 16 samples (about 3 percent) from the public-supply wells (table 9). The five highest combined radium activities ranged from 12.5 to 16 pCi/L; four of these samples are from wells in metasedimentary rocks (appendix 6). Overall, however, combined radium activities did not differ significantly among the lithology groups. The combined radium activities in the public-supply well samples correlated strongly (p -values <0.0001) with activities of gross alpha ($\rho = 0.37$, $n = 422$) and radon ($\rho = 0.25$, $n = 265$) and with concentrations of U in water ($\rho = 0.27$, $n = 309$).

^{222}Rn Radon

Radon is a water-soluble, radioactive gas that originates from the decay of ^{226}Ra , part of the ^{238}U decay series. Radon activities in water samples from the studied wells were highly variable. The radon activities in 943 water samples from all studied wells were mostly in the range of 540 to 11,400 pCi/L, with a median radon activity of 2,600 pCi/L (table 8). The largest radon activity in a domestic well (in New Hampshire) was 215,200 pCi/L and the largest radon activity in a public-supply well (also in New Hampshire) was 175,000 pCi/L. Both of these wells are completed in Concord Granite, a bedrock formation which is rich in two-mica granite plutons and is part of the I_p lithology group (appendix 6). The spatial distribution of radon activities in water samples collected for the domestic and public-supply wells is illustrated in figure 30.

Radon activities exceeded the proposed MCL (300 pCi/L) in 95 percent of the 943 water samples from the domestic and public-supply wells (table 9) and the proposed AMCL of 4,000 pCi/L in 33 percent of these samples (table 9). Similarly high rates of radon occurrence in groundwater were reported

for other crystalline rock aquifer systems in the Piedmont (south and central Appalachians) and in the Rocky Mountain Front Range (Colorado) areas of the Nation (Ayotte and others, 2007; DeSimone, 2009).

In this study, radon activities were not significantly different when the water samples were evaluated based on water use, land use, population density, or well-construction categories but they differed significantly when the evaluation was based on the geologic setting of the sampled wells. Radon activities were significantly higher in the I_a , I_p , and M_{nb} lithology groups than in the other groups studied (fig. 31A). Although there are few water samples from the M_{nb} lithology group, this finding is not surprising, considering that many of the conglomerate clasts in the Narragansett Basin consist of felsic volcanic and granitic rocks. Radon activities were equal to or greater than the proposed AMCL of 4,000 pCi/L in 79 percent of water samples from the I_a lithology group, in 60 percent of water samples from the I_p lithology group, and in 20 to 30 percent of water samples from all other groups having at least 9 samples (fig. 31B).

The radon activities in the sampled domestic wells correlated positively with Pb and U concentrations in water (table 11) and radon activities in the sampled public-supply wells correlated positively with gross-alpha activities, U concentrations (in water), and with U concentrations in NURE streambed sediments (appendix 8), indicating a geologic source for radon in NECR aquifers. The radon activities in the sampled public-supply wells correlated inversely with pH, possibly suggesting that radon in NECR aquifers is associated with young groundwater, although, radon activities in 53 water samples from domestic wells were not significantly correlated with apparent residence time (appendix 4). Wood and others (2004) suggested that radon-enriched groundwater may move rapidly through fractured rock from its source (^{226}Ra) to pumped wells with little time available for radon decay. Enrichment of ^{226}Ra along the surfaces of water-bearing fractures in these rocks is a likely factor contributing to the elevated radon in fractured-rock aquifers (Wood and others, 2004).

Uranium

Uranium concentrations in 556 water samples collected from the public-supply and domestic wells were mostly in the range of <1 to 42 $\mu\text{g/L}$, with a median concentration of 2.3 $\mu\text{g/L}$ (table 8). The maximum U concentrations were 429 $\mu\text{g/L}$ in samples from 117 domestic wells and 3,640 $\mu\text{g/L}$ in samples from 439 public-supply wells. Of the 556 studied wells, 14.2 percent had U concentrations equal to or greater than the USEPA MCL of 30 $\mu\text{g/L}$ (table 9). The spatial distribution of U concentrations in water samples collected from the domestic and public-supply wells is illustrated in figure 32; many of the higher concentrations ($U \geq 30$ $\mu\text{g/L}$) occur in areas classified as part of the peraluminous granite (I_p) lithology group, although high concentrations occurred in most crystalline rock lithology groups.

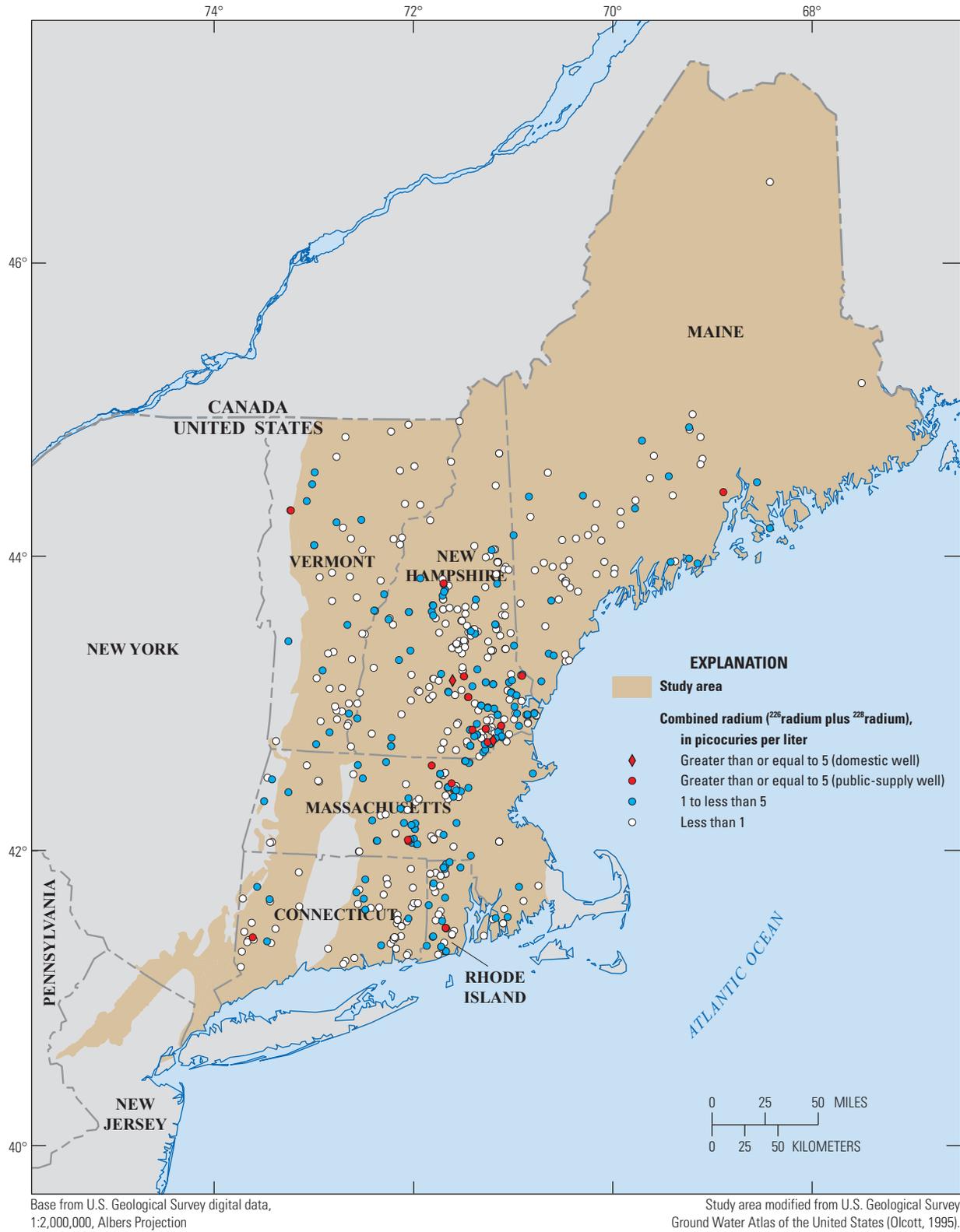


Figure 29. Spatial distribution of combined radium activities in water samples collected from domestic and public-supply wells in New England crystalline rock aquifers, 1999–2007.

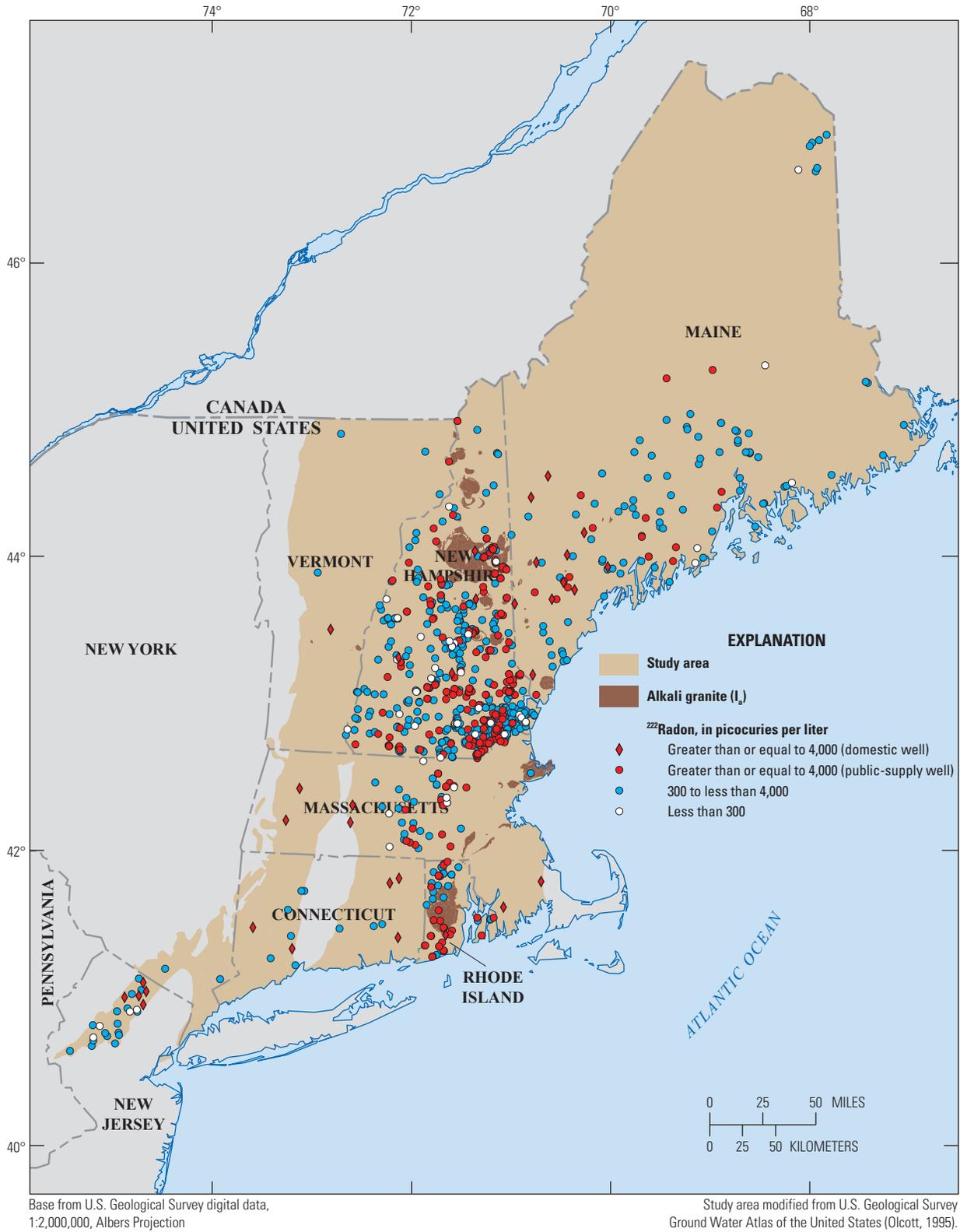
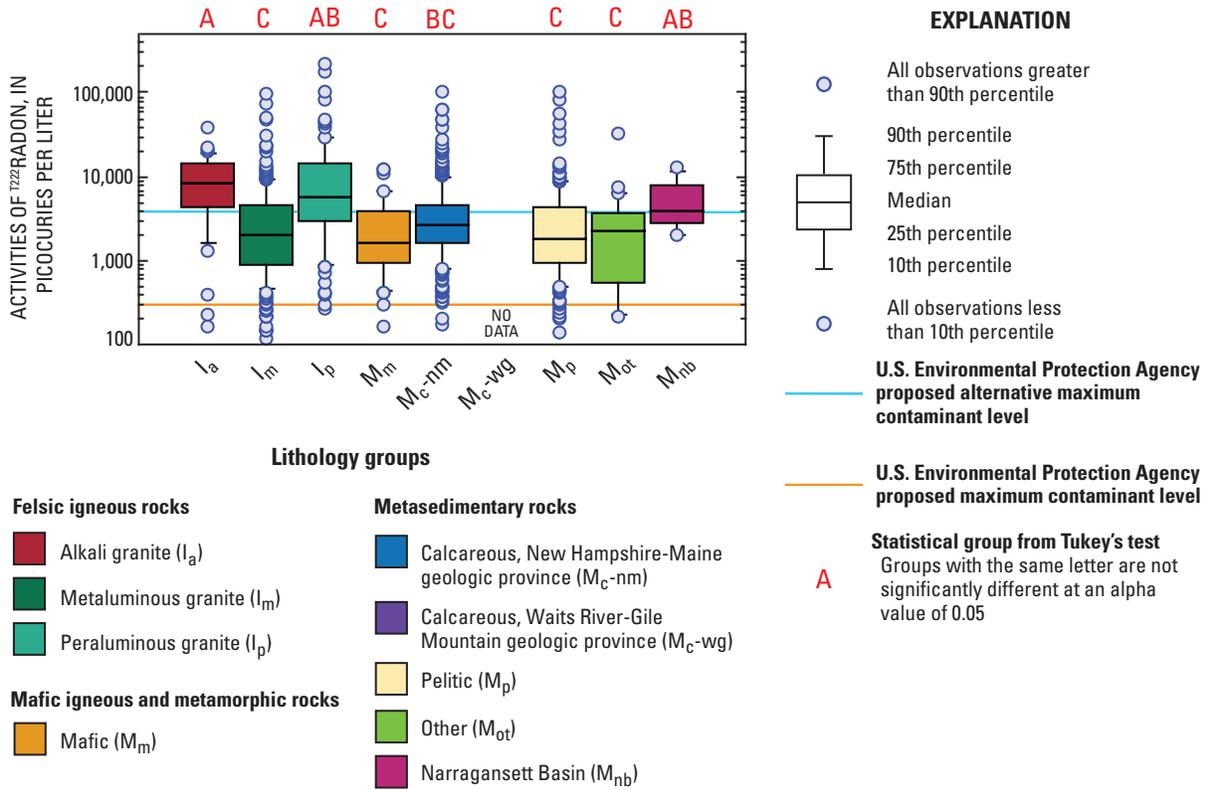


Figure 30. Spatial distribution of ²²²Rn activities in water samples collected from domestic and public-supply wells in New England crystalline rock aquifers, 1995–2007. The alkali granite (I_a) lithology group is described in detail in table 7.

A



B

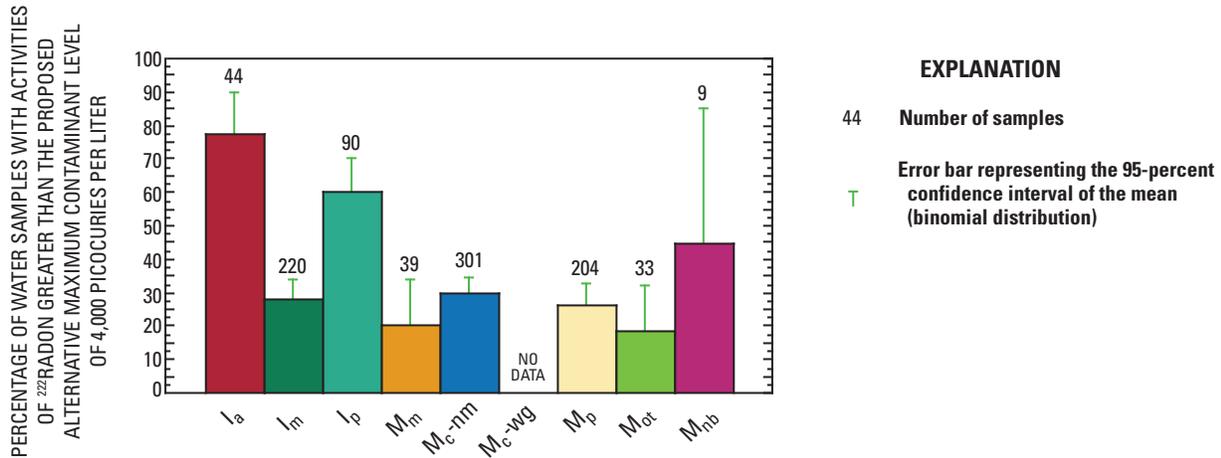


Figure 31. Distribution of *A*, activities of ²²²Rn in water samples collected from public-supply and domestic wells in New England crystalline rock aquifers, and *B*, percentages of these samples with activities of ²²²Rn greater than the proposed alternative U.S. Environmental Protection Agency maximum contaminant level of 4,000 picocuries per liter, by lithology group, 1995–2007. The lithology groups are described in detail in table 7 and illustrated in figure 5B.

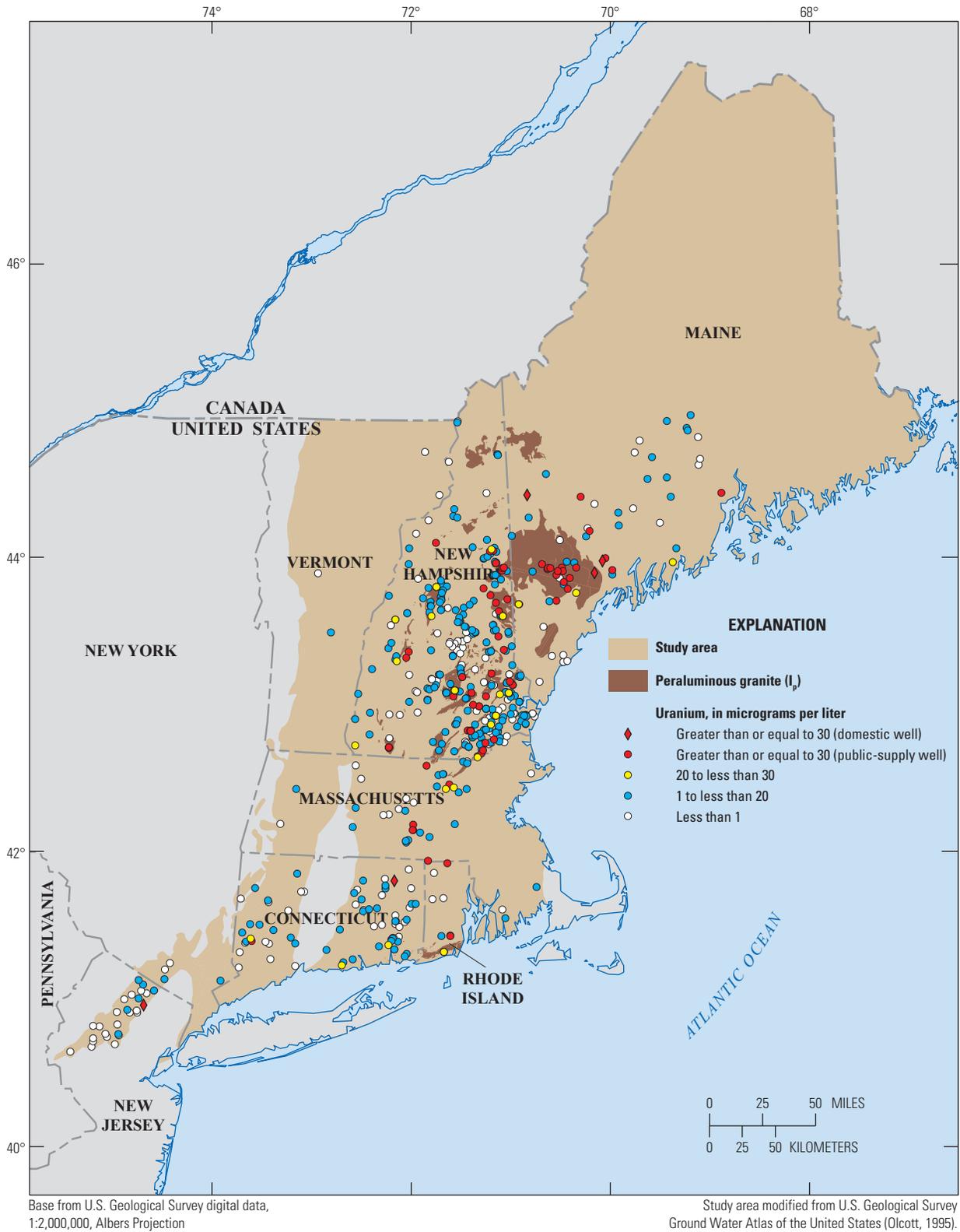


Figure 32. Spatial distribution of uranium concentrations in water samples collected from domestic and public-supply wells in New England crystalline rock aquifers, 1995–2007. The peraluminous granite (I_p) lithology group is described in detail in table 7.

Uranium concentrations were equal to or greater than the MCL in about 4.3 percent of 117 water samples from domestic wells (table 9). As reported previously, the 30 domestic wells from the second NECB well network (fig. 1) were selected from areas where the geologic units are dominated by felsic igneous rocks and pelitic rocks. However, only the U concentrations in water samples from the LINJ well network, where the bedrock consists predominantly of gneissic rocks (M_{ot} lithology group), are significantly lower than the U concentrations in water samples from wells in the other three NAWQA networks (fig. 33). DeSimone (2009) reports that 1.7 percent of water samples exceeded the MCL for U from domestic wells sampled for the NAWQA Program in all aquifers nationally.

By comparison, 16.9 percent of U concentrations in the 439 water samples from the public-supply wells equaled or exceeded the MCL (table 9). It is not known why the public-supply well samples have U concentrations greater than the MCL at a rate that is nearly four times the rate for the domestic well samples. The water-quality data obtained from the SDWA Program are a reflection of available data from the individual state SDWA databases, whereas the water-quality

data from the NAWQA Program were from randomly selected wells. Similar to conditions for Fe and Mn, larger and more sustained pumping rates in the public-supply wells, in comparison to the domestic wells, might change geochemical conditions and (or) groundwater-flow patterns in ways that enhances the solubility and mobility of U to pumped groundwater.

Uranium concentrations from all the wells studied were not significantly different when the samples were evaluated on the basis of land use, population density, or well-construction categories, but were significantly different when evaluated on the basis of the geologic setting of the sampled wells. Uranium concentrations were significantly higher in water samples from wells in the peraluminous granite (I_p) lithology group than the other studied lithology groups (fig. 34A). Although U concentrations varied greatly in the water samples, U concentrations equal to or greater than the MCL occurred most frequently in samples from the I_p (47.4 percent), I_a (20 percent), and M_c -nm (12.7 percent) lithology groups (fig. 34B). None of the water samples from the M_m lithology group had U concentrations equal to or greater than the MCL. Mafic rocks in the M_m group generally have very low uranium content (Dostal and Capedri, 1978).

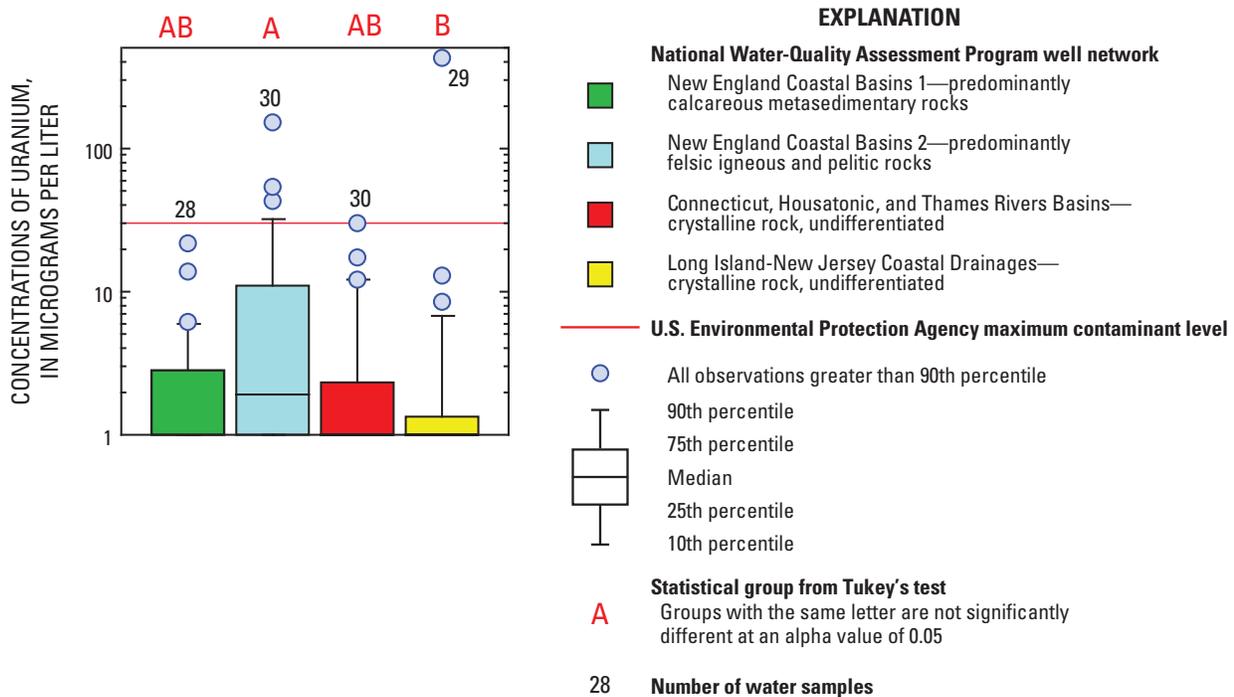


Figure 33. Distribution of concentrations of uranium in water samples collected from domestic wells in New England crystalline rock aquifers, by the National Water-Quality Assessment Program well network, 1995–2000. Locations of well networks are shown in figure 1.

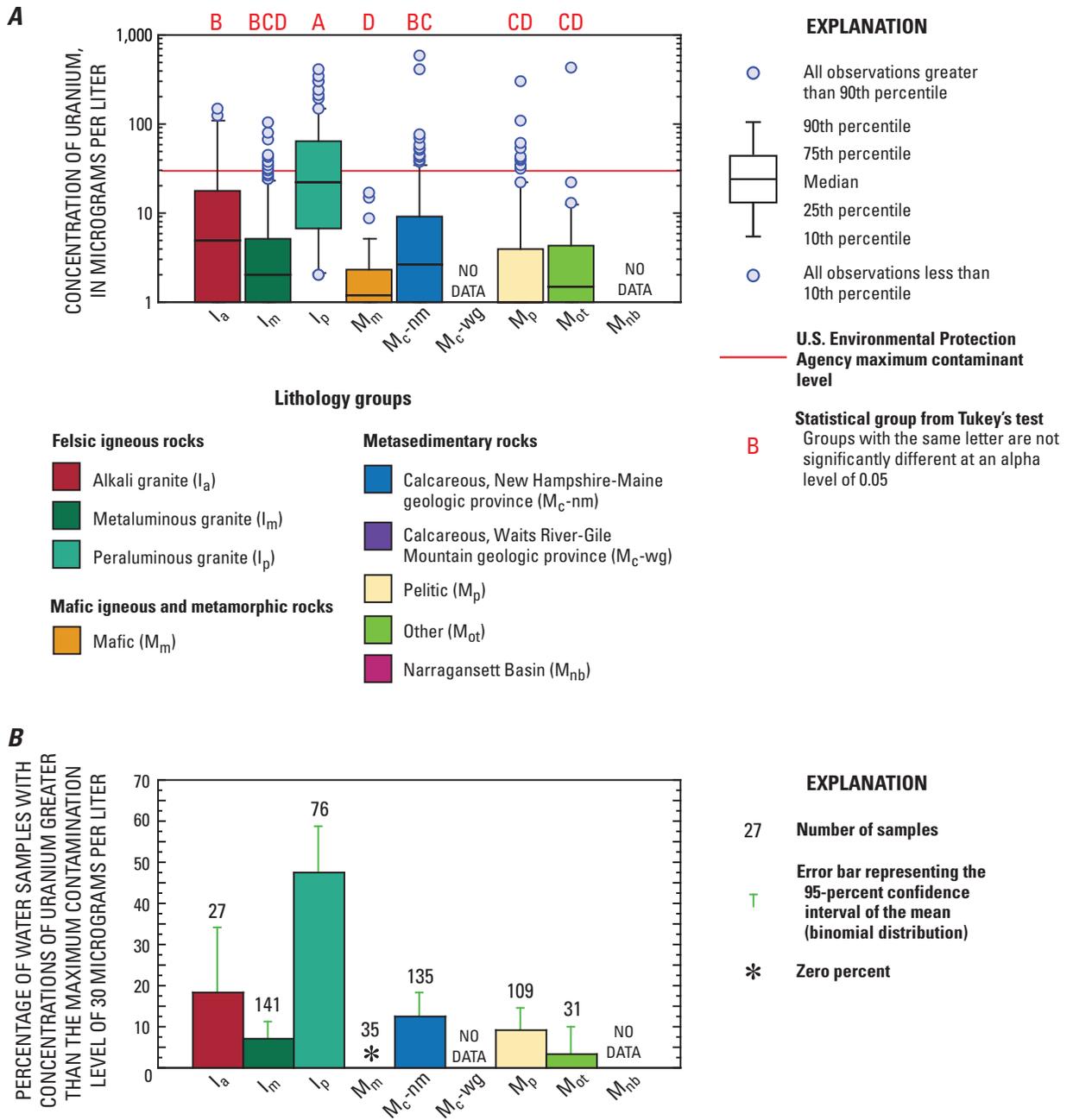


Figure 34. Distribution of *A*, concentrations of uranium in water samples collected from public-supply and domestic wells in New England crystalline rock aquifers and *B*, percentages of these samples with concentrations of uranium greater than the U.S. Environmental Protection Agency maximum contaminant level of 30 micrograms per liter, by lithology group, 1995–2007. The lithology groups are described in detail in table 7 and illustrated in figure 5B.

Water samples from one domestic well and 13 public-supply wells (2.5 percent) had U concentrations five times ($>150 \mu\text{g/L}$) greater than the MCL. The five highest U concentrations in this study ranged from 420 to 3,640 $\mu\text{g/L}$ (appendix 6). Three of these samples are from wells in metasedimentary rocks, which are not as enriched in U as in felsic igneous rocks, but which still can yield water with high U (appendix 6). Groundwater from wells with high U concentrations may be affected by a hydrogeologic connection with adjacent or nearby aquifers containing groundwater enriched in U. These high U concentrations also may be from wells that are completed in a different geologic setting than what is presented on the original, near-surface State geologic bedrock maps.

High U concentrations in groundwater from crystalline rock have been reported in previous investigations. Wathen (1986) reported that 18 percent of 111 water samples collected from drilled wells in two-mica granite (a felsic igneous rock that is part of the I_p lithology group) in New Hampshire and Maine had U concentrations greater than 100 $\mu\text{g/L}$; U concentrations in two of these wells exceeded 1,000 $\mu\text{g/L}$. Uranium occurs above background concentrations in pelitic, felsic igneous, and volcanic rocks, and specifically in (1) accessory minerals such as zircon, sphene, and apatite; (2) inter-granular U distributed and sorbed along crystal boundaries, particularly biotite; and (3) secondary U minerals precipitated along fracture surfaces and grain boundaries (Hess and others, 1985).

In this study, U concentrations in water samples from all 117 domestic wells correlated positively with HCO_3^- , Ca, Mo, and As concentrations, and inversely with Ba and Fe concentrations (table 11). Ayotte and others (2007) found that the U concentrations in the 30 water samples from the second NECB well network (fig. 1) correlated positively with concentrations of As, DO, Pb, and ^{226}Ra , and with U concentrations in NURE streambed sediments; and correlated inversely with concentrations of Mn, Fe, Ba, and ^{224}Ra . DeSimone (2009) found that the presence of DO and carbonate alkalinity were related to high U concentrations in domestic well samples from a variety of major aquifers studied nationally.

Uranium concentrations in water samples from the public-supply wells correlated positively with U concentrations in NURE streambed sediments (appendix 8), indicating a geologic source for U in groundwater. Uranium concentrations in groundwater are controlled by factors including the amount of U in the aquifer materials, the amount of DO, the oxidized state of the U ions, the availability of CO_3 and SO_4 to form complexes with U, and the nature of the contact between U-bearing minerals and water (Hem, 1985; Hess and others, 1985; Wanty and others, 1990).

Co-occurrence of Selected Radionuclides and Lead

Uranium concentrations in the water samples correlated positively with Pb concentrations and with all other radionuclide constituents in this study (table 13). Lead concentrations

in the domestic well samples correlated most strongly and positively with activities of gross alpha and radon. The many significant correlations among U, Pb, and the studied radionuclides indicate that the content of U and Ra in source rocks is probably the strongest factor relating to the occurrence of U and other radionuclides in groundwater from NECR aquifers. Ayotte and others (2007) noted that Pb and radon were strongly correlated (Spearman's $\rho = 0.52$, p -value <0.0001 , $n = 28$) in water samples from the second NECB well network (fig. 1) and hypothesized that a possible source for a small fraction of the total Pb may be radiogenic (stable) Pb.

Because significant correlations were common among the studied radionuclides, the water samples were further examined to determine which of these radiochemical constituents most commonly co-occurred at concentrations or activities that were greater than existing or proposed human health benchmarks (table 14). A total of 344 water samples collected from domestic and public-supply wells provided water-quality data on U, gross alpha, and radon. Only one of the 344 water samples (0.3 percent) had a U concentration equal to or greater than 30 $\mu\text{g/L}$ when the associated gross alpha activity was less than 15 pCi/L and the radon activity was less than 4,000 pCi/L. Similarly, gross alpha activities were equal to or greater than 15 pCi/L in only eight water samples (2.3 percent) when the associated U concentration was less than 30 $\mu\text{g/L}$ and the radon activity was less than 4,000 pCi/L. These data show that the presence of one radionuclide with a high activity or concentration generally indicates that other radionuclides would occur at high activities or concentrations. Uranium, which is measured in mass units using the ICP-MS method (Garborino and others, 2006), may be the easiest constituent to analyze when evaluating the overall radioactivity of groundwater from NECR aquifers. The I_a and the I_p lithology groups had the greatest percentages of water samples in which one or more of the three radionuclides exceeded existing or proposed human health benchmarks when compared to water samples in the other lithology groups (table 14).

Organic Compounds

The following sections discuss detections of pesticide and volatile organic compounds in groundwater from domestic wells completed in NECR aquifers and sampled for the NAWQA studies. Additional information was compiled for M/BE in samples from public-supply wells collected for the SDWA Program (table 4); the information is discussed in the section "Volatile Organic Compounds."

Pesticides

Pesticides were rarely detected in water samples from 114 domestic wells in NECR aquifers from 1995 to 2000. The water samples were analyzed for 48 pesticide compounds, 44 of which were common to all samples (appendix 9). Thirty-one water samples from the domestic wells (27 percent)

Table 13. Rho and probability values from Spearman correlations among selected radionuclides and lead in groundwater collected from domestic and public-supply wells in New England crystalline rock aquifers, 1995–2007.

[Spearman's coefficients (rho) are significantly correlated (in **bold**) when the *P*-values are less than or equal to 0.05. A negative rho value indicates an inverse relation. Rho, Spearman's rho coefficient; *p*-value, Spearman's probability value; N, number of water samples; <, less than; --, *p*-value not calculated; Gross alpha, gross alpha-particle radioactivity; Gross beta, gross beta-particle radioactivity; Combined radium is ²²⁶radium plus ²²⁸radium]

Correlation variable	Spearman's correlation variables	Spearman's Rho coefficients, <i>P</i> -values, and number of samples					
		Gross alpha	Gross beta	Uranium	²²² Radon	Combined radium	Lead
Gross alpha	Rho	1	0.571	0.776	0.465	0.355	0.414
	<i>p</i> -value	--	<0.0001	<0.0001	<0.0001	<0.0001	0.0014
	N	893	57	457	615	477	57
Gross beta	Rho	0.571	1	0.358	0.384	0.419	0.117
	<i>p</i> -value	<0.0001	--	0.0059	0.0034	0.0013	0.3821
	N	57	58	58	57	56	58
Uranium	Rho	0.776	0.358	1	0.553	0.224	0.257
	<i>p</i> -value	<0.0001	0.0059	--	<0.0001	<0.0001	0.0163
	N	457	58	556	417	365	87
²²² Radon	Rho	0.465	0.384	0.553	1	0.228	0.378
	<i>p</i> -value	<0.0001	0.0034	<0.0001	--	<0.0001	0.00046
	N	615	57	417	943	319	82
Combined radium	Rho	0.373	0.419	0.272	0.247	1	0.042
	<i>p</i> -value	<0.0001	0.0013	<0.0001	0.00005	--	0.7607
	N	422	56	309	265	564	56
Lead	Rho	0.414	0.117	0.257	0.378	0.042	1
	<i>p</i> -value	0.0014	0.3821	0.0163	0.0005	0.7607	--
	N	57	58	87	82	56	87

had one or more pesticides detected at estimated concentrations equal to or greater than 0.001 µg/L, and seven of the domestic well samples (6 percent) had one or more pesticides detected at concentrations equal to or greater than 0.01 µg/L. In comparison, Gilliom and others (2006) report that, nationally, 33 percent of all NAWQA sampled wells had one or more occurrence of pesticides. Of 48 pesticides, 6 herbicides (atrazine, EPTC, metolachlor, prometon, pronamide, and simazine), 2 pesticide degradates (deethylatrazine, p-p'-DDE), and 1 insecticide (dieldrin) were measureable at concentrations greater than 0.001 µg/L in at least 1 sample; four of these compounds (atrazine, deethylatrazine, metolachlor, and prometon) were measured at concentrations greater than 0.01 µg/L in at least one sample. Nearly all pesticide concentrations were considered estimated because they are less than or near LRLs, and no concentration exceeded human health benchmarks (appendix 9). The largest concentration of any pesticide measured

was an estimated concentration of 0.06 µg/L for metolachlor, an herbicide that is relatively soluble in water, from a NJ-NY domestic well sample (appendix 9).

Gilliom and others (2006) reported that one or more pesticides exceeded a human health benchmark in about 1 percent of 2,356 domestic wells sampled nationally for the NAWQA Program. A national retrospective analysis of pesticides in groundwater sampled during 1991–95 for the NAWQA Program showed that groundwater in major aquifers has a substantially lower frequency of occurrence of pesticides than has shallow groundwater in agricultural and urban areas (U.S. Geological Survey, 1999). This difference occurred because, in general, wells from major aquifer studies are deeper, and a greater percentage of undeveloped land surrounds the sampled wells. For the domestic wells in this study, well depths generally exceed 200 ft (table 6), and land use surrounding the wells was predominantly forested.

Table 14. Summary of 344 water samples collected from domestic and public-supply wells in New England crystalline rock aquifers with co-occurrence of uranium concentrations, gross alpha activities, and ²²²Rn activities exceeding existing or proposed human-health benchmarks, by lithology group, 1999–2007.

[µg/L, micrograms per liter; pCi/L, picocuries per liter, <, less than; ≥, equal to or greater than; N, number of water samples; I_a, alkali granite; I_p, peraluminous granite; I_m, metaluminous granite; M_c-nm, calcareous metasedimentary rocks, NH-Maine geologic province; M_p, pelitic rocks. All other groups include M_m (mafic rocks), M_c-wg (calcareous metasedimentary rocks, Waits River-Gile Mountain geologic province); M_{ot} (metasedimentary rocks, other); M_{nb} (Narragansett Basin metasedimentary rocks) lithology groups. The U.S. Environmental Protection Agency (USEPA) maximum contaminant level (MCL) for uranium is 30 µg/L; the USEPA MCL for gross alpha-particle radioactivity is 15 pCi/L; and the USEPA proposed alternative maximum contaminant level (AMCL) for ²²²Rn is 4,000 pCi/L. The lithology groups are described in table 7 and are illustrated in figure 5B]

Water-quality criteria			Lithology group																	
All wells			I _a			I _p			I _m			M _c -nm			M _p			All other groups		
Uranium, in µg/L	Gross alpha, in pCi/L	²²² Rn, in pCi/L	N	Percent	N	Percent	N	Percent	N	Percent	N	Percent	N	Percent	N	Percent	N	Percent	N	Percent
≥ 30	≥ 15	≥ 4,000	4	16.7	13	27.1	4	4.8	7	7	5	6.8	0	0	0	0	0	0	0	0
≥ 30	≥ 15	< 4,000	1	4.2	4	8.3	1	1.2	2	2	1	1.4	0	0	0	0	0	0	0	0
≥ 30	< 15	≥ 4,000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
< 30	≥ 15	≥ 4,000	5	20.8	10	20.8	3	3.6	9	9	3	4.1	2	14.3	2	14.3	2	14.3	2	14.3
≥ 30	< 15	< 4,000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
< 30	≥ 15	< 4,000	1	4.2	1	2.1	2	2.4	2	2	2	2.7	0	0	0	0	0	0	0	0
< 30	< 15	≥ 4,000	10	41.7	10	20.8	16	19	19	19	12	16.2	3	21.4	3	21.4	3	21.4	3	21.4
< 30	< 15	< 4,000	3	12.4	10	20.8	57	67.9	61	61	51	68.9	9	64.3	9	64.3	9	64.3	9	64.3
Total			24	100	48	100	84	100	100	100	74	100	14	100	14	100	14	100	14	100

Water samples collected from wells with uranium, gross alpha-particle radioactivity, and ²²²Rn water-quality information

The greatest number of pesticide compounds detected in an individual water sample was three. The most common compounds detected in the water samples were atrazine and deethylatrazine. At the assessment level of 0.001 $\mu\text{g/L}$, deethylatrazine, a degradate of atrazine (18 percent frequency detection), and atrazine (8 percent frequency detection) were the only pesticide compounds detected in more than 3 percent of the water samples collected from the domestic wells (appendix 9). Gilliom and others (2006) found that the most frequently occurring pesticide compounds in groundwater nationally were those that are highly persistent in the environment, are highly soluble in water, and had high levels of use in both agricultural and developed areas. Other studies found that detection frequencies of individual pesticides were also related to the tendency to adsorb onto aquifer materials and to the time needed for degradation (Kolpin and others, 1998; Barbash and others, 1999, 2001). Although the number and concentrations of pesticides in the domestic well samples were small, it is unclear whether similar results would be found for public-supply wells completed in crystalline rock, where pesticides are not analyzed at LRLs as low as for the NAWQA Program.

Volatile Organic Compounds

Of the 27 VOCs detected in water samples from 115 domestic wells at concentrations equal to or greater than 0.02 $\mu\text{g/L}$, 11 were fuel hydrocarbons or oxygenates, 9 were solvents, 3 were trihalomethanes (THMs), 2 were refrigerants, and 2 were organic synthesis compounds (appendix 10). *MtBE*, a fuel oxygenate, was the most frequently occurring VOC (36 percent) at concentrations ≥ 0.02 $\mu\text{g/L}$ in the domestic well samples (appendix 10; fig. 35). Although groundwater from these domestic wells is not chlorinated before use, chloroform (or trichloromethane) was detected (≥ 0.02 $\mu\text{g/L}$) in 33 percent of the domestic well samples (appendix 10; fig. 35). Ten other VOCs were detected (≥ 0.02 $\mu\text{g/L}$) in two or more water samples from the domestic wells: toluene (15 samples), carbon disulfide (10 samples), perchloroethene (7 samples), 1,1,1-trichloroethane (6 samples), 1,1-dichloroethane (5 samples), dichlorodifluoromethane (5 samples), *tert*-amyl methyl ether (3 samples), trichloroethene (2 samples), benzene (2 samples), and diisopropyl ether (2 samples) (appendix 10). Toluene, a fuel hydrocarbon, was detected (≥ 0.02 $\mu\text{g/L}$) in 42 percent of the blank samples (table 3) at concentrations similar to those reported for the environmental samples. This may have resulted in a higher toluene occurrence rate in the environmental samples than was actually present. Similar findings were reported when toluene was analyzed from blank and environmental samples collected from 1996 to 2008 from all available NAWQA groundwater and surface-water sampling sites (Bender and others (2011)).

Seven of the nine VOCs shown in figure 35 occurred more frequently (at concentrations ≥ 0.02 $\mu\text{g/L}$) in water samples from the domestic wells in this study than in domestic wells (DeSimone, 2009) or all wells in major aquifers

(Carter and others, 2008) studied nationally for the NAWQA Program. NECR aquifers can be highly vulnerable to VOC contamination because of their low capacity for storing groundwater and their potentially high Darcian (linear) flow velocities in open fractures.

Forty-three water samples from 86 domestic wells (50 percent) in NECR aquifers contained two or more detectable VOCs (≥ 0.02). The most common mixture of VOCs in the NAWQA domestic wells with two or more detectable concentrations consisted of *MtBE* and chloroform. Three of the four water samples with measureable chloroform (≥ 0.2 $\mu\text{g/L}$) from the domestic wells in the CONN study also contained measurable *MtBE* (≥ 0.2 $\mu\text{g/L}$). Twelve of the 25 water samples from the LINJ and NECB studies with measureable chloroform (> 0.02 $\mu\text{g/L}$) also had measureable *MtBE* (≥ 0.02 $\mu\text{g/L}$).

Two wells had 10 VOCs each (≥ 0.02 $\mu\text{g/L}$) in the same sample. One of the domestic wells sampled by the NECB study contained low total concentrations (0.79 $\mu\text{g/L}$ summed) of chloroform, 1,2,3-trimethylbenzene, 1,2,4-trimethylbenzene, 1,3,5-trimethylbenzene, ethyl-toluene, isopropylbenzene, *n*-propylbenzene, xylene, carbon disulfide, and toluene. The other domestic well, sampled by the LINJ study, contained variable concentrations (31.6 $\mu\text{g/L}$ summed) of chloroform, dichlorodifluoromethane, trichlorofluoromethane, *MtBE*, methyl *tert*-pentyl ether, tetrachloroethylene, trichloroethylene, 1,1-dichloroethane, 1,1,1-trichloroethane, and diisopropyl ether. *MtBE* accounted for 96 percent of the summed VOC concentration in this water sample.

Chloroform

The maximum chloroform concentration was 2.82 $\mu\text{g/L}$ in water samples from 115 domestic wells sampled for the NAWQA Program, substantially lower than the MCL (80 $\mu\text{g/L}$) that the USEPA has established for total trihalomethanes (TTHMs) (appendix 10). The spatial distribution of chloroform concentration in water samples collected from the domestic wells is illustrated in figure 36. The highest chloroform concentrations (> 1 $\mu\text{g/L}$) were associated with the NJ-NY domestic wells (fig. 36).

Chloroform concentrations in samples from domestic wells correlated positively with concentrations of NO_3 , *MtBE*, Cl, and DO, and with percent developed lands and population density (appendix 11)—water-quality constituents and ancillary variables known to be associated with human activities (Ivahnenko and Barbash, 2004; Carter and others, 2008). Chloroform concentrations correlated inversely with well depth and pH (appendix 11). Depths of the NJ-NY domestic wells were relatively shallower (median well depth = 202 ft) than the domestic wells in New England (median well depth = 263 ft). The shallower well depths, lower pH values, and higher DO concentrations associated with the NJ-NY domestic well samples are indicative of relatively shallow and younger groundwater that may be more vulnerable to human activities in comparison to the generally deeper and

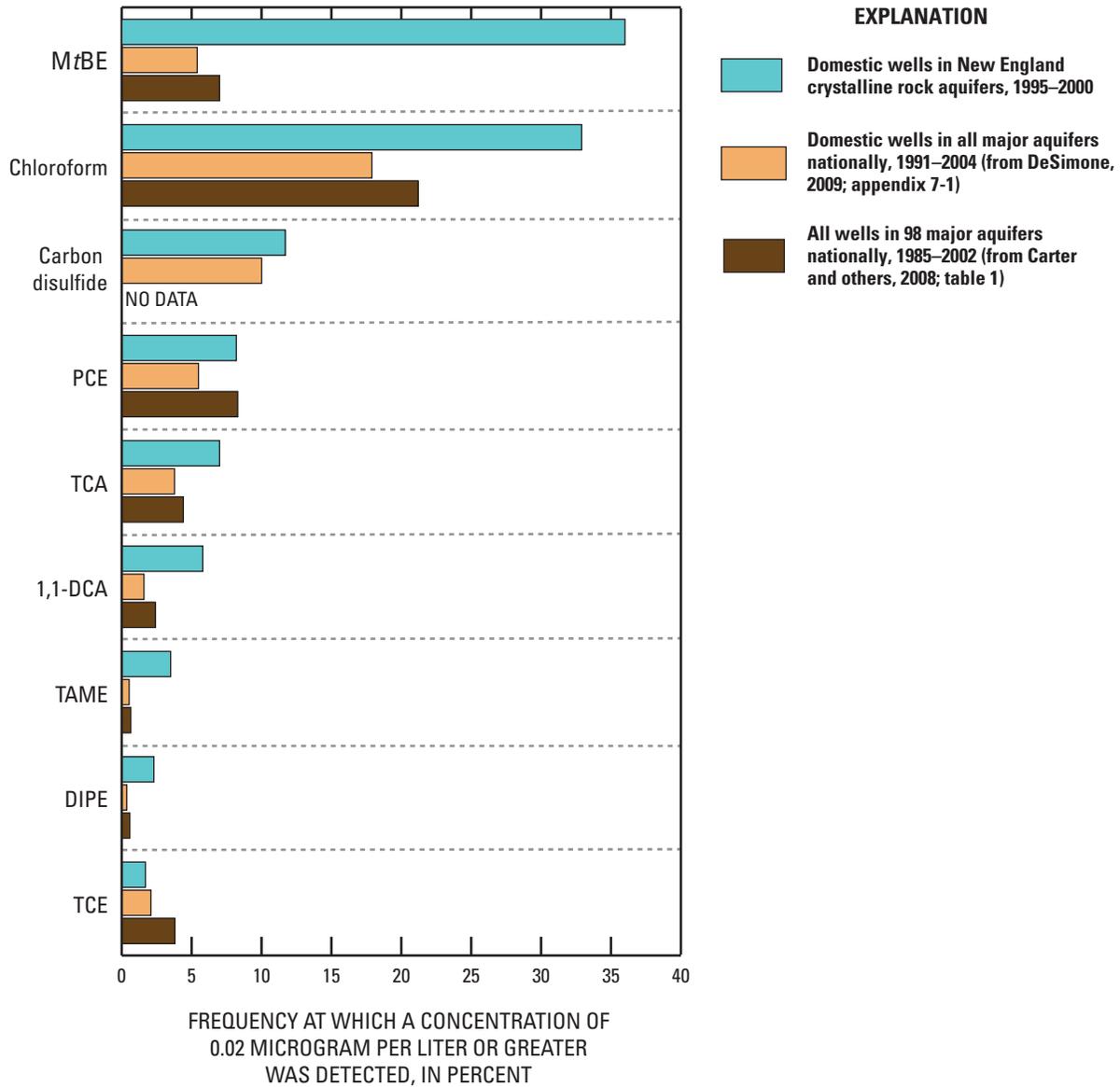
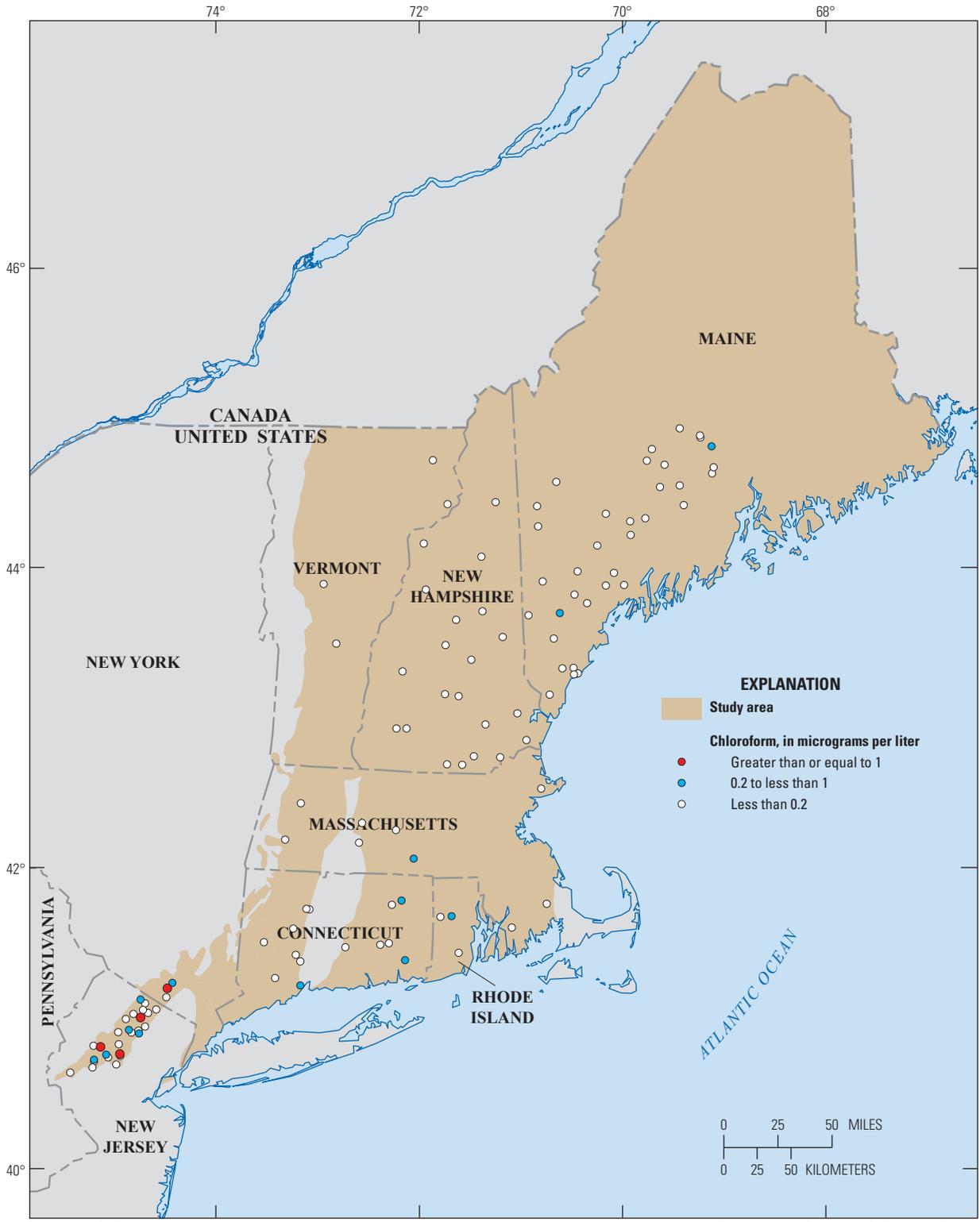


Figure 35. Detection frequencies for the nine most common volatile organic compounds in water samples collected from domestic wells in New England crystalline rock aquifers, 1995–2000. (MtBE, methyl-*tert*-butyl ether; TCA, 1,1,1-trichloroethane; PCE, perchloroethene; 1,1-DCA, 1,1-dichloroethane; TCE, trichloroethene; DIPE, diisopropyl ether; TAME, tert-amyl methyl ether)



Base from U.S. Geological Survey digital data, 1:2,000,000, Albers Projection

Study area modified from U.S. Geological Survey Ground Water Atlas of the United States (Olcott, 1995).

Figure 36. Spatial distribution of chloroform concentrations in water samples collected from domestic wells in New England crystalline rock aquifers, 1995–2000.

older groundwater associated with the domestic wells in New England. These factors may explain the occurrence rate of chloroform ($\geq 0.2 \mu\text{g/L}$) that is higher in the NJ-NY domestic well samples (34 percent) than in the domestic wells from New England (8.1 percent). Potential sources of chloroform and other THMs to both public and domestic wells include the use of municipally supplied chlorinated water to irrigate lawns, golf courses, gardens, and other areas; the use of septic systems; the regulated discharge of chlorinated wastewater to surface waters; and leakage of chlorinated water from distribution systems for drinking water or wastewater sewers (Ivahnenko and Zorgorski, 2006).

Methyl *tert*-Butyl Ether

MtBE concentration in water samples from 1,299 domestic and public-supply wells were mostly in the range of <1 to $1 \mu\text{g/L}$ (table 8). The maximum MtBE concentration in 115 domestic well samples was $30.2 \mu\text{g/L}$ (appendix 10) and the maximum MtBE concentration in 1,184 public-supply well samples was $190 \mu\text{g/L}$ (appendix 3). The spatial distribution of MtBE concentrations in water samples from the domestic and public-supply wells is illustrated in figure 37. MtBE concentrations were $\geq 1 \mu\text{g/L}$ in 11.3 percent of the domestic well samples and in nearly 10 percent of the public-supply well samples. Currently (2011), there are no national enforceable drinking-water standards for MtBE, although the USEPA has established an advisory level of 20 to $40 \mu\text{g/L}$ for taste and odor (U.S. Environmental Protection Agency, 1997). The State of New Hampshire Department of Environmental Services (NHDES) has established a maximum contaminant level of $13 \mu\text{g/L}$ for community water systems in New Hampshire (New Hampshire Department of Environmental Services, 2009). Groundwater from 6 of 1,299 studied wells (0.46 percent) equaled or exceeded the USEPA advisory levels (table 9), and groundwater from 9 of the studied wells (0.7 percent) equaled or exceeded the NHDES MCL of $13 \mu\text{g/L}$.

On a regional scale, the frequency of MtBE concentrations $\geq 1 \mu\text{g/L}$ in water samples from all wells was significantly different when compared to categories of population density and land use (fig. 38). Water samples from 13.6 percent of wells in areas of high population density (≥ 50 persons/ km^2) had MtBE concentrations $\geq 1 \mu\text{g/L}$; 4.7 percent of wells in areas of low population density (<50 persons/ km^2) had concentrations $\geq 1 \mu\text{g/L}$ (fig. 38A). Similar relations with population density were found in a statewide investigation of MtBE in New Hampshire (Ayotte and others, 2008). Nationally, Moran and others (2005) found that population density was an important factor relating to the detection and concentrations of MtBE in underlying groundwater. In this study, MtBE concentrations $\geq 1 \mu\text{g/L}$ occurred in 16 percent of wells in predominantly developed land, 5 percent of wells in predominantly undeveloped land (fig. 38B), and in 4 percent in wells in predominantly agricultural lands.

MtBE concentrations in water samples from the studied wells correlated positively with concentrations of specific conductance, Cl, and chloroform; percentage of developed lands; and population density—factors that generally relate to human activities (appendix 11). MtBE concentrations in water samples from the domestic wells correlated inversely with apparent residence time (ages) and pH (appendix 11), indicating that younger groundwaters in NECR aquifers are more vulnerable to MtBE contamination than are older groundwaters. MtBE concentrations in samples from domestic wells relative to apparent ages, DO concentrations, field pH, water levels, depth to bottom of well casing, and well depths are shown in figure 39. Water samples with younger apparent ages (<25 years) had more MtBE measurements ($>0.2 \mu\text{g/L}$) than did water samples with older apparent ages (≥ 25 years; fig. 39A). MtBE was first introduced into gasoline in 1979, as lead was being phased out, and was in widespread use by 1992 in response to the USEPA mandate to increase the octane level of gasoline (New Hampshire Department of Environmental Services, 2009). Since MtBE was not in use prior to 1979, it is not surprising that MtBE was not detected in the samples with older apparent ages. In contrast to NO_3 , MtBE concentrations in the domestic wells were not significantly correlated with well depth (fig. 39F), indicating that deeper wells are equally vulnerable to MtBE contamination as shallower wells. Ayotte and others (2004) had similar findings with wells depths and hypothesized that deep, low-yielding wells in NECR aquifers need large contributing areas to achieve adequate yields, which in turn, increases the likelihood of intercepting MtBE-contaminated groundwater.

Temporal Variability of Selected Water-Quality Constituents in Groundwater from New England Crystalline Rock Aquifers

Six of the 28 domestic wells from the NECB well network, where the geologic units are dominated by calcareous metasedimentary rocks, were resampled up to four times for the NAWQA Program from 1999 to 2007 (fig. 40). Biennial sampling occurred during July to remove the potential effects that seasonal sampling might have on water quality. Well depths for the six wells ranged from 100 to 310 feet, and the water-level depth in the wells generally increased as the total depth of the well increased. Although the number of samples is too low for statistical analysis, graphical observations provide initial indications of both potential trends and variability of groundwater quality.

The water levels, pH values, and concentrations of DO, NO_3 , As, and MtBE for the four sampling events from 1999 to 2007 are shown in figure 41. Samples from three wells (TW3, TW4, and TW6; not shown) had NO_3 concentrations below the LRL of 0.06 mg/L during the 8-year sampling period. Samples

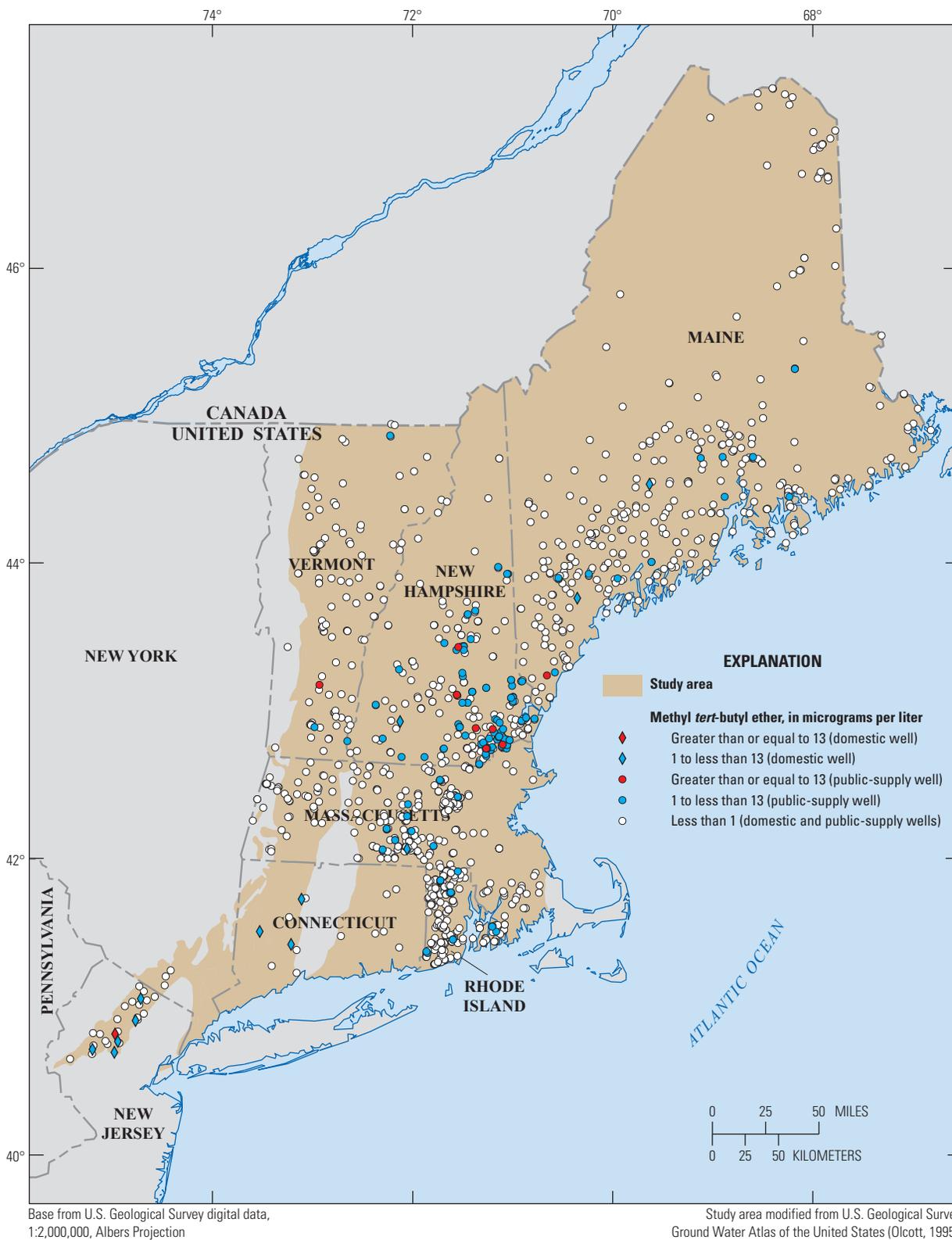


Figure 37. Spatial distribution of methyl *tert*-butyl ether concentration in water samples collected from domestic and public-supply wells in New England crystalline rock aquifers, 1995–2007.

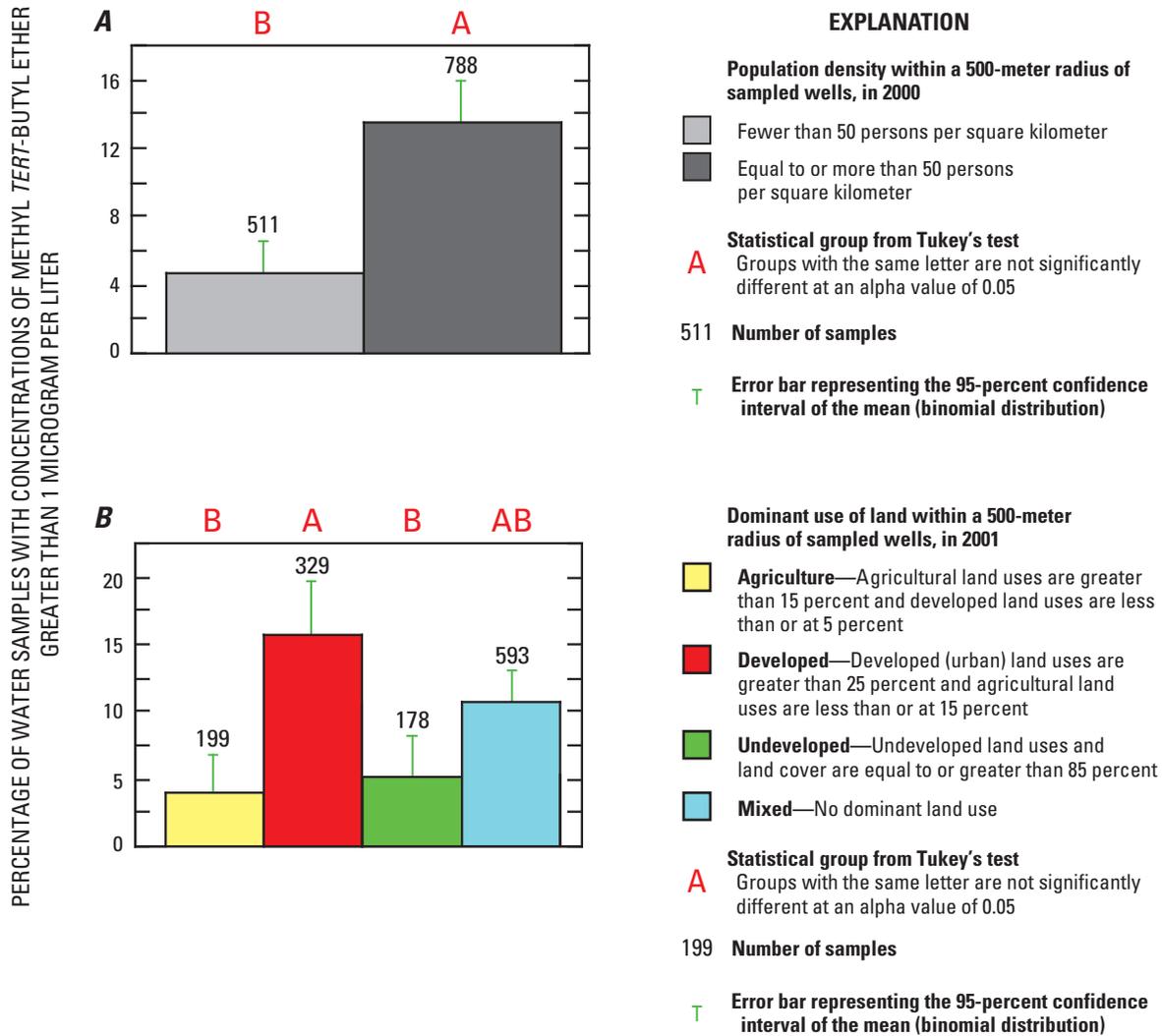


Figure 38. Distribution of percentages of water samples collected from public-supply and domestic wells in New England crystalline rock aquifers with concentrations of methyl *tert*-butyl ether greater than 1 microgram per liter, by categories of *A*, population density and *B*, land use, 1995–2007.

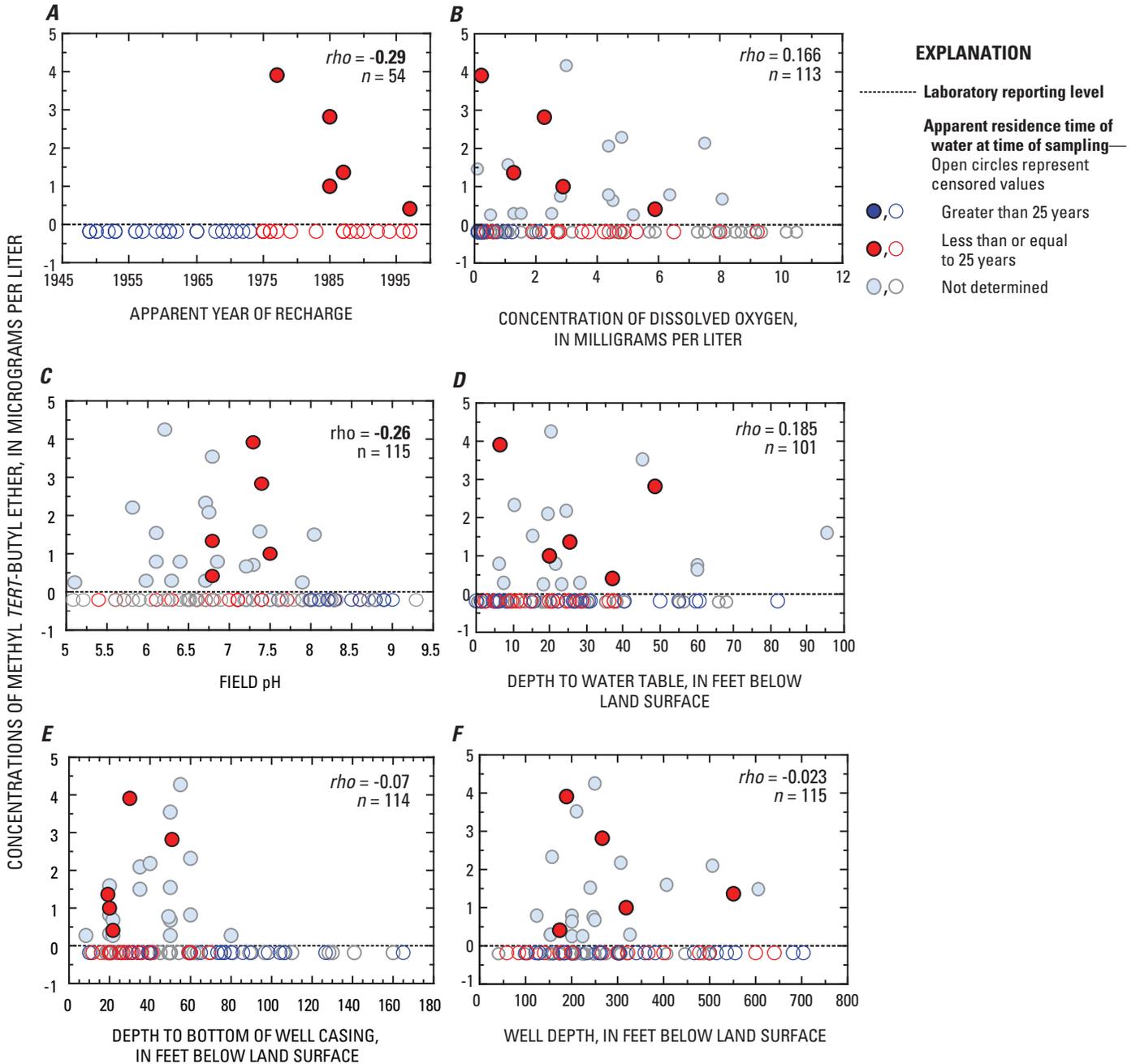


Figure 39. Concentrations of methyl *tert*-butyl ether in water samples collected from domestic wells in New England crystalline rock aquifers in relation to *A*, apparent year of recharge; *B*, dissolved oxygen concentrations; *C*, field pH; *D*, depth to groundwater table; *E*, depth to bottom of well casing; and *F*, well depth, 1995–2000. Rho coefficient values are from Spearman correlations and are considered significant (**in bold**) when the probability values are less than 0.05. Methyl-*tert*-butyl ether concentrations greater than 5 micrograms per liter are not shown.

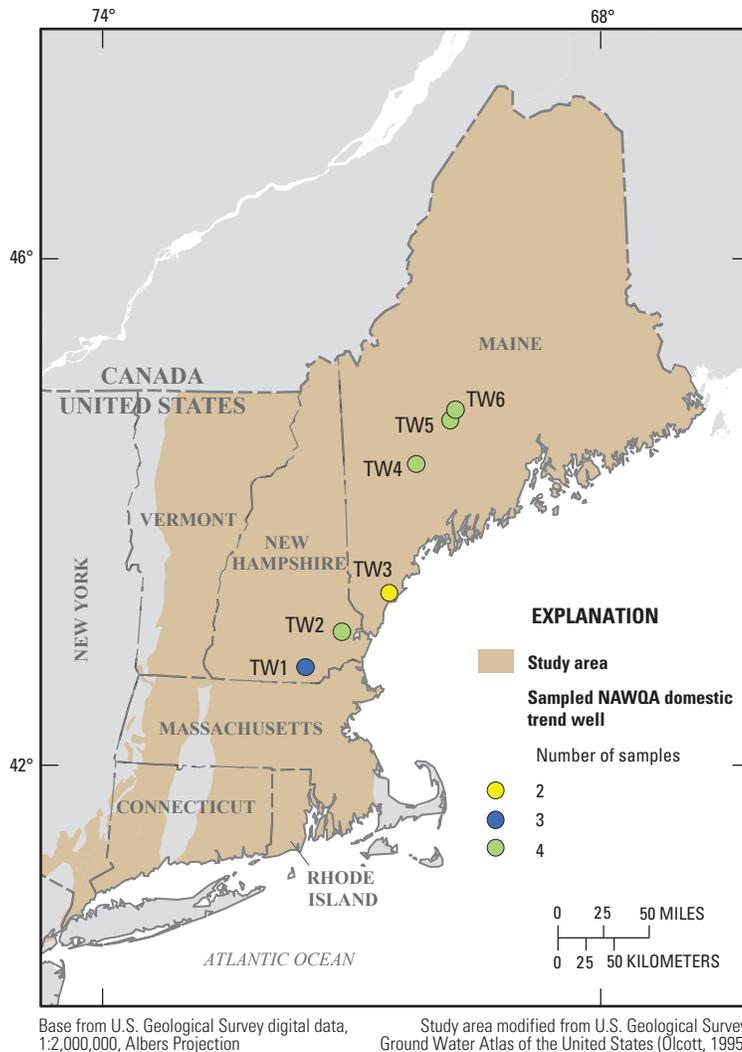


Figure 40. Location of six domestic trend wells in New England crystalline rock aquifers that were sampled biannually for the National Water-Quality Assessment Program to determine trends in selected physiochemical properties and water-quality constituents, 1999–2007. Color of circle represents the number of samples collected from the trend well.

from three wells (TW4, TW5, and TW6; not shown) had As concentrations below the LRL of 1 $\mu\text{g/L}$ during the 8-year sampling period. Two water samples from TW3 (not shown) had *MtBE* concentrations below 0.2 $\mu\text{g/L}$. In general, water-quality conditions were similar at each well over the 8-year period of the study. Three wells yielded oxic water samples ($\text{DO} > 4 \text{ mg/L}$) throughout the 8-year sampling period, and three wells yielded anoxic water samples ($\text{DO} < 0.5 \text{ mg/L}$) throughout the 8-year sampling period (fig. 41C). Three wells yielded alkaline water samples ($\text{pH} > 7$) throughout the 8-year sampling period, and two wells yielded acidic water samples ($\text{pH} < 7$) over the 8-year sampling period. One well (TW5) yielded both alkaline and acidic water samples, but over a narrow range of the pH scale (fig. 41B).

In groundwater from these six trend wells, concentrations of the trace element As varied less than concentrations of the anthropogenic compounds NO_3 and *MtBE* (figs. 41D–F). The importance of this observation is that As concentrations in the trend wells were effectively stable over the 8-year sampling period. Since the mobility of As in groundwater is strongly controlled by redox conditions, the relative stability of DO and field pH may partially explain the stability of As concentrations in the six trend wells.

MtBE detections in groundwater depend greatly on the amount and timing of *MtBE* releases in the environment; thus, the concentrations of *MtBE* showed the largest variation over time. However, these variations were small in absolute magnitude and occurred near the lower limits of the LRL (fig. 41F).

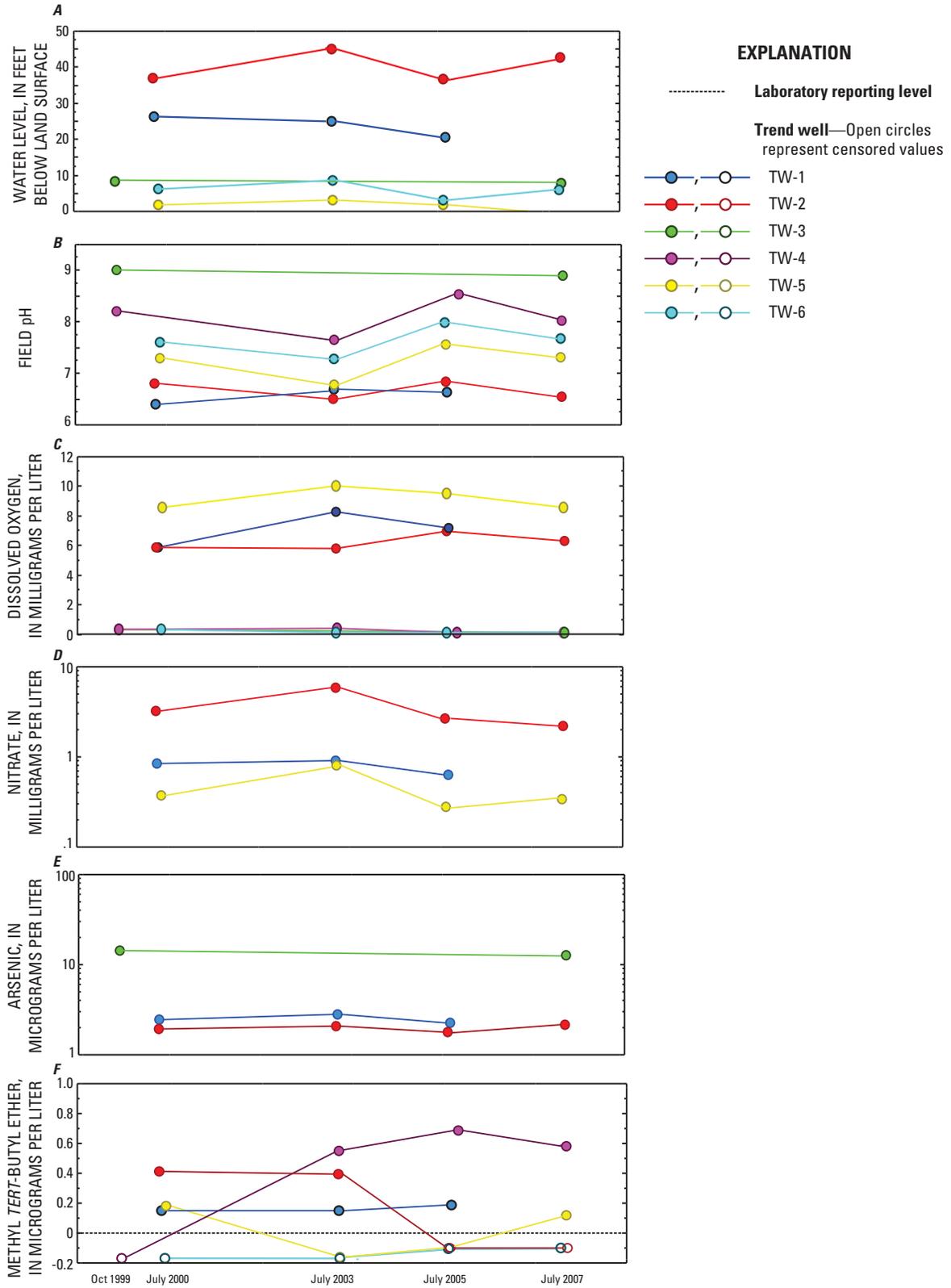


Figure 41. A, Water levels, B, pH, and concentrations of C, dissolved oxygen, D, nitrate, E, arsenic, and F, methyl *tert*-butyl ether in water samples collected from six domestic trend wells in New England crystalline rock aquifers, 1999–2007. Locations of trend wells shown in figure 40.

Summary and Conclusions

The water quality of New England crystalline rock (NECR) aquifers was assessed using water-quality data from 117 domestic wells [88 in New England and 29 in New Jersey and New York (NY-NJ)] sampled for the National Water-Quality Assessment (NAWQA) Program during 1995–2007. This study also assessed data from 4,775 public-supply wells in New England sampled for the U.S. Environmental Protection Agency (USEPA) Safe Drinking Water Act Program during 1997–2007. All water samples used for this study were obtained before any treatment that may have been in place and, thus, do not necessarily represent water that homeowners consumed from their domestic wells or from public-supply wells that deliver drinking water through distribution systems. Some distribution systems are either part of multiwell community water systems or water systems that blend waters from different sources. This study assessed regional water-quality patterns on the basis of lithogeologic setting, land use and population density, well construction properties, and geochemical conditions.

The median pH of 2,019 sampled wells was 7.6. Nine percent of the pH values in the sampled wells were below the recommended lower limit of 6.5, and 4 percent were greater than the recommended upper limit of 8.5. Overall, pH values were significantly higher in the sampled wells in New England than in the sampled NJ-NY wells. The sampled wells in New England are significantly deeper in depth than the NJ-NY wells and may tap into groundwaters that are older and more chemically evolved, and thus, have higher pH values.

The apparent residence time (age) of groundwater in samples from 55 domestic wells ranged from 3 to greater than 51 years, with a median value of 25 years. The strong, positive correlation between apparent ages and pH indicates that high pH (>7.5) groundwaters are generally associated with older, chemically evolved groundwaters. Concentrations of nitrate (NO_3), copper (Cu), lead (Pb), nickel (Ni), and zinc (Zn) correlated inversely with apparent ages, indicating that the largest concentrations of these constituents occurred in generally younger groundwater. Concentrations of iron (Fe), manganese (Mn), fluoride (F), lithium (Li), sodium (Na), and molybdenum (Mo) correlated positively with apparent ages, indicating that some of the largest concentrations of these constituents likely occurred in older groundwater.

Nitrate (as N) concentrations in 4,781 water samples from all sampled wells were mostly in the range of <0.5 to 1.6 milligrams per liter (mg/L), with a maximum value of 18.4 mg/L. Only 5 of 4,664 water samples (0.1 percent) from the public-supply wells had NO_3 concentrations equal to or greater than the maximum contaminant level (MCL) of 10 mg/L. None of the 117 water samples from the domestic wells had NO_3 concentrations equal to or greater than the MCL. In this study, NO_3 concentrations greater than 3 mg/L—a concentration that represents greater than background levels—were present more frequently in groundwater from domestic wells than from public-supply wells, possibly as a result of greater flexibility

in siting public-supply wells within community-owned property boundaries.

The major ion chemistry of samples from domestic wells was dominated by calcium-bicarbonate (Ca-HCO_3) type waters; calcium-chloride (Ca-Cl), sodium-chloride (Na-Cl), sodium-bicarbonate (Na- HCO_3), and sodium-sulfate (Na- SO_4) type waters were found less frequently. Chloride to bromide (Cl:Br) mass ratios indicate that the potable groundwater was probably affected by at least three halogen sources: (1) local precipitation and recharge waters, with Cl:Br mass ratios ranging from 50 to 200, with Cl concentrations less than 6 mg/L, and with variable Na:Cl molar ratios; (2) seawater and connate waters (evolved from seawater), with Cl:Br mass ratios ranging from 200 to 400, with highly variable Cl concentrations, and with Na:Cl molar ratios greater than 1; and (3) recharge waters affected by NaCl sources such as road salt (from mined halite) used for de-icing roadways and possibly discharges from water softeners, with Cl:Br mass ratios exceeding 1,000, with Cl concentrations greater than 30 mg/L, and with Na:Cl molar ratios less than 1. Most of the Ca-Cl and Na-Cl type waters are probably affected by road de-icing salts dissolved in recharge waters. The high pH (8 to 9.3) of Na- HCO_3 type waters probably resulted from (1) ion exchange of Ca for Na on Na-enriched aquifer materials, from post-glacial seawater inundation, or from connate waters; with Cl concentrations less than 30 mg/L, and Na:Cl molar ratios greater than 1; or (2) by extensive water-rock interactions, and leaching of low-sodium granitic rocks, resulting in groundwaters with Cl concentrations greater than 30 mg/L and elevated concentrations of F (>2 mg/L).

The highest F concentration in water samples from the sampled wells was 17.9 mg/L. Virtually all F concentrations greater than the MCL of 4 mg/L were in samples from wells in felsic igneous bedrock. More than 10 percent of wells in alkali granite (I_a) had F concentrations greater than the MCL. Elevated F concentrations (>2 mg/L) in the domestic wells generally occurred in older, high pH (>8) Na- HCO_3 type waters in felsic igneous bedrock enriched in fluorine minerals.

Iron and Mn concentrations in the sampled wells were strongly and positively correlated with each other, suggesting that Fe and Mn commonly co-occur in NECR aquifers. Iron concentrations were equal to or greater than the secondary MCL (SMCL) of 300 $\mu\text{g/L}$ in 22 percent of 1,632 sampled wells. Manganese concentrations were equal to or greater than the SMCL of 50 $\mu\text{g/L}$ in 38 percent of 1,759 sampled wells and were equal to or greater than the USEPA lifetime health advisory level (LHA) of 300 $\mu\text{g/L}$ in 7.3 percent of these wells. Water samples from wells in the M_{nb} lithology group had significantly higher concentrations of Fe and Mn than the other studied lithology groups. Iron and Mn concentrations were significantly greater in the public-supply well samples than in the domestic well samples. The difference in sample collection (filtered samples from the NAWQA wells and unfiltered samples from the SDWA wells) may explain the differences in Fe and Mn concentrations between the two data programs.

Arsenic (As) concentrations in 2,054 water samples collected from the domestic and public-supply wells were mostly in the range of <5 to 13 $\mu\text{g/L}$; the maximum concentration was 2,400 $\mu\text{g/L}$. For the 2,054 wells studied, 13.3 percent of water samples had As concentrations greater than the MCL [10 micrograms per liter (10 $\mu\text{g/L}$)], nearly double the national rate for community-supply systems and domestic wells in the United States. Arsenic concentrations in samples from studied wells in the belt of calcareous metasedimentary rocks in the New Hampshire-Maine geologic province (M_c -nm), in peraluminous granite (I_p), and in pelitic rocks (M_p) were significantly higher than in all other lithology groups studied, and wells in M_c -nm rocks had a greater percentage of samples with As concentrations greater than the MCL. Elevated As concentrations in domestic well samples tended to occur in these high-arsenic rock lithologies under conditions of low DO (<1 mg/L) and of high pH (>7.5), probably as a result of the release of sorbed As from Fe oxides by reductive dissolution or by desorption from Fe oxides.

High As concentrations (>10 $\mu\text{g/L}$) occurred in nearly 20 percent of domestic well samples where well depths exceeded 300 feet (ft) and casing lengths exceeded 50 ft compared to only 6 percent of samples where well depths were less than 300 ft and casing lengths were less than 50 ft. This is not surprising since deep bedrock wells with long casing lengths are more likely to tap into fractures yielding older, high-pH groundwater than shallower wells—a condition that favors As mobility.

Gross alpha activities equaled or exceeded the MCL in 15.5 percent of water samples from 57 domestic wells and in 11.6 percent of water samples from 835 public-supply wells, and were highest in wells completed in peraluminous (I_p) and alkali (I_a) granite rocks. Five samples (9 percent) from 58 domestic wells had gross beta-particle activities equal to or greater than the MCL. Activities of combined radium (^{226}Ra plus ^{228}Ra) were equal to or greater than the MCL in 2 water samples (about 4 percent) from the 56 domestic wells in New England and in 16 water samples (3.15 percent) from 508 public-supply wells.

The median radon activities in the water samples were 2,060 picocuries per liter (pCi/L) for 112 domestic wells and 2,600 pCi/L for 831 public-supply wells. Ninety-five percent of water samples from these 943 wells had radon activities greater than the proposed MCL of 300 pCi/L, and 33 percent had radon activities greater than the proposed alternative MCL (AMCL) of 4,000 pCi/L. Radon activities were highest for wells in alkali granite (I_a), peraluminous granite (I_p), and Narragansett metasedimentary (M_{nb}) rocks.

The maximum U concentrations were 429 $\mu\text{g/L}$ in samples from 117 domestic wells and 3,640 $\mu\text{g/L}$ in samples from 439 public-supply wells. Uranium concentrations were greater than the MCL in 4.3 percent of the water samples from the domestic wells and in 16.9 percent from the public-supply wells. Uranium concentrations greater than the MCL of 30 $\mu\text{g/L}$ occurred more frequently (47.4 percent) in water samples from wells in the peraluminous granite (I_p) lithology

group than in samples from all other studied lithology groups. Using Spearman correlation, U concentrations in the water samples were significantly correlated with activities of gross alpha, gross beta, radon, and combined radium, indicating that uranium is a useful indicator in assessing the overall radioactivity of groundwater from NECR aquifers.

When detected, all pesticide concentrations were estimated, and no concentration exceeded human health benchmarks. Thirty-one water samples from 114 domestic wells (about 27 percent) contained one or more pesticides, detected at an estimated concentration equal to or greater than 0.001 $\mu\text{g/L}$, and 7 of the 114 domestic well samples (about 6 percent) contained one or more pesticides, detected at concentrations equal to or greater than 0.01 $\mu\text{g/L}$. Of 47 pesticide analytes, 6 herbicides (atrazine, EPTC, metolachlor, prometon, pronamide, and simazine), 2 pesticide degradates (deethylatrazine, p-p'-DDE), and 1 insecticide (dieldrin) were detected in 114 domestic well samples at estimated concentrations greater than 0.001 $\mu\text{g/L}$; four of these compounds (atrazine, deethylatrazine, metolachlor, and prometon) were detected at concentrations greater than 0.01 $\mu\text{g/L}$. Two pesticide compounds—deethylatrazine, a degradate of atrazine (18 percent frequency detection) and atrazine (8 percent frequency detection)—were detected (≥ 0.001 $\mu\text{g/L}$) in more than 3 percent of the sampled domestic wells. The largest pesticide concentration measured was an estimated concentration of 0.06 $\mu\text{g/L}$ for metolachlor, an herbicide that is relatively soluble in water, from a NJ-NY domestic well.

At the 0.02 $\mu\text{g/L}$ threshold level, MzBE, a fuel additive, and chloroform, a trihalomethane, were the two most frequently detected (36 and 32.9 percent, respectively) VOCs in samples from 86 domestic wells. The most common mixture of volatile organic compounds (VOCs) in the domestic wells with two or more measureable concentrations (≥ 0.02 $\mu\text{g/L}$) was chloroform and MzBE. Twelve of the 25 water samples from 86 domestic wells with measureable chloroform (≥ 0.02 $\mu\text{g/L}$) had measureable MzBE (≥ 0.02 $\mu\text{g/L}$).

The maximum chloroform concentration was 2.82 $\mu\text{g/L}$ in water samples from 115 domestic wells. None of the samples collected from the domestic wells had chloroform concentrations greater than the MCL of 80 $\mu\text{g/L}$ that the USEPA established for total trihalomethanes (TTHMs). Chloroform concentrations in samples from the domestic wells were correlated most strongly and positively with concentrations of NO_3 , MzBE, Cl, and total dissolved solids. The maximum MzBE concentrations were 30.2 $\mu\text{g/L}$ in samples from the domestic wells and 190 $\mu\text{g/L}$ in samples from the public-supply wells. Only 6 of 1,299 samples from the domestic and public-supply wells exceeded the USEPA advisory level of 20 to 40 $\mu\text{g/L}$ for MzBE. MzBE concentrations in water samples from the studied wells correlated positively with concentrations of specific conductance, Cl, chloroform, and with percentage of developed lands and population density surrounding the wells.

MzBE concentrations in water samples from domestic wells correlated inversely with apparent residence time (age)

of water and with pH, indicating that younger groundwaters in NECR aquifers are more vulnerable to *MtBE* contamination than are older groundwaters. Water samples with apparent ages less than 25 years had more detections of *MtBE* than water samples with older apparent ages. This finding is consistent with the time period of high *MtBE* use in areas in the United States where reformulated gasoline was mandated. In contrast to NO_3 , *MtBE* concentrations in NECR aquifers did not correlate with well depth, suggesting that their loading, transport and degradation rates differ.

Six of the 28 domestic wells from the NECB well network where the geologic units are dominated by calcareous metasedimentary rocks were resampled up to four times from 1999 to 2007. In general, DO and field pH were similar for each well over the 8-year period. In groundwater from these six trend wells, concentrations of the trace element As varied less than concentrations of the anthropogenic compounds NO_3 and *MtBE*. Since the mobility of As in groundwater is strongly controlled by redox conditions, the relative stability of DO and field pH may partially explain the stability of As concentrations in the six trend wells. *MtBE* detections in groundwater depend greatly on the amount and timing of *MtBE* releases in the environment; thus, the concentrations of *MtBE* showed the largest variation over time.

The frequency of detections above human health benchmarks or advisory levels, for a wide variety of contaminants studied—Na, Cl, F, Fe, Mn, As, gross alpha, combined radium, radon, uranium, and *MtBE*—in both domestic and public-supply wells shows the vulnerability of NECR aquifers to naturally occurring and anthropogenic contamination. The highly variable water quality and the association with highly variable lithology of crystalline bedrock underscores the importance of testing individual wells to determine if concentrations for the most commonly detected contaminants exceed human health benchmarks or advisory levels.

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Appendixes 1–11

Tables

1–1.	Summary statistics for selected physiochemical properties of, and inorganic water-quality constituents in water samples collected for the U.S. Geological Survey National Water-Quality Assessment Program from 88 domestic wells in crystalline rock aquifers in New England, 1995–2000.....	82
2–1.	Summary statistics for selected physiochemical properties of, and inorganic water-quality constituents in water samples collected for the U.S. Geological Survey National Water-Quality Assessment Program from 29 domestic wells in crystalline rock aquifers in New Jersey and New York, 1997.....	84
3–1.	Summary statistics for selected physiochemical properties and water-quality constituents in untreated water samples collected for the U.S. Environmental Protection Agency Safe Drinking Water Act Program from 4,664 public-supply wells in New England crystalline rock aquifers, 1997–2007.....	86
4–1.	Rho and probability values from Spearman correlations of selected water-quality properties and constituents, and well construction properties with apparent residence time of groundwater from water samples collected for the U.S. Geological Survey National Water-Quality Assessment Program in domestic wells in New England crystalline rock aquifers, 1999–2000.....	87
5–1.	Rho and probability values from Spearman correlations of selected water-quality properties and constituents, land-use data, human population data, and well construction properties, with nitrate and chloride concentrations in water samples collected from domestic and public-supply wells in New England crystalline rock aquifers, 1995–2007.....	88
6–1.	Highest five concentrations for selected water-quality constituents in water samples from domestic and public-supply wells in New England crystalline rock aquifers, 1995–2007.....	90
7–1.	Rho and probability values from Spearman correlations of selected water-quality properties and constituents, land-use and human population data, well construction properties, and National Uranium Resource Evaluation Program streambed-sediment data, with fluoride and arsenic concentrations in water samples collected from domestic and public-supply wells in New England crystalline rock aquifers, 1995–2007.....	92
8–1.	Rho and probability values from Spearman correlations of selected water properties and constituents, land-use and human population data, well construction properties, National Uranium Resource Evaluation Program streambed-sediment data, and terrestrial gamma-ray emissions data with uranium concentrations and ²²² radon activities in water samples collected from domestic and public-supply wells in New England crystalline rock aquifers, 1995–2007.....	95
9–1.	Summary of pesticide concentrations in water samples collected for the U.S. Geological Survey National Water-Quality Assessment Program from domestic wells in New England crystalline rock aquifers in New England, New Jersey, and New York, 1995–2000.....	98
10–1.	Summary of volatile organic compound concentrations in water samples collected for the U.S. Geological Survey National Water-Quality Assessment Program from domestic wells in New England crystalline rock aquifers in New England, New Jersey, and New York, 1995–2000.....	100
11–1.	Rho and probability values from Spearman correlations of selected water-quality properties and constituents, land-use and human population data, and well construction properties with chloroform and methyl <i>tert</i> -butyl ether concentrations in water samples collected from domestic and public-supply wells in New England crystalline rock aquifers, 1995–2007.....	103

Table 1–1. Summary statistics for selected physiochemical properties of, and inorganic water-quality constituents in water samples collected for the U.S. Geological Survey National Water-Quality Assessment Program from 88 domestic wells in crystalline rock aquifers in New England, 1995–2000.

Water-quality properties and constituents	Units	N	Common LRL	Percent of samples above LRL	Concentration									
					Min	5th	10th	25th	50th	75th	90th	95th	Max	
Physiochemical properties														
Oxygen, dissolved (as O ₂)	mg/L	88	na	100	0.1	0.1	0.1	0.3	1	4.4	7.9	8.6	10.5	
pH, field	Standard units	88	na	100	5.1	5.7	6.04	6.8	7.6	8.2	8.7	8.9	9.3	
pH, laboratory	Standard units	88	na	100	5	6.3	6.6	7.1	7.5	7.9	8.1	8.4	8.8	
Specific conductance, field	µS/cm at 25°C	88	5	100	36	91	111	142	205	323.5	548	689	1,484	
Specific conductance, laboratory	µS/cm at 25°C	87	5	100	44.5	95	114	146	217	338	556	675	1,460	
Water temperature	°C	88	na	100	7.9	9	9.7	10.5	11.4	12	12.8	13.3	15.3	
Turbidity	NTU	57	na	100	0.03	0.06	0.11	0.23	0.4	1	2.62	4.6	6.35	
Major ions														
Total dissolved solids, summed (as TDS)	mg/L	88	10	100	29	60	72	89	126	196	305	382	876	
Hardness, filtered, calculated (as CaCO ₃)	mg/L	87	na	100	12.6	20.2	32.4	44.7	67.1	103.7	167	214	280	
Calcium, filtered (as Ca)	mg/L	88	0.04	100	2.72	6.1	9.4	14	19.9	30.25	51	62.2	90.5	
Magnesium, filtered (as Mg)	mg/L	88	0.02	100	0.36	1.37	1.7	2.35	3.49	6.56	11.84	14.34	30.87	
Potassium, filtered (as K)	mg/L	88	0.06	100	0.2	0.48	0.58	1.025	1.7	2.64	3.98	5.7	11.5	
Sodium, filtered (as Na)	mg/L	88	0.1	100	2.03	2.6	3.5	5.35	9.9	18.1	45.11	85.46	257.5	
Alkalinity, filtered, field (as CaCO ₃)	mg/L	88	na	100	7	13	25	46	65.5	93.5	150	184	518	
Bicarbonate, filtered, field (as HCO ₃)	mg/L	88	na	100	9	16	31	56	79	114	183	220	606	
Bromide, filtered (as Br)	mg/L	88	0.01	73.9	<0.1	<0.1	<0.1	<0.1	0.02	0.034	0.077	0.18	0.67	
Chloride, filtered (as Cl)	mg/L	88	0.12	100	0.3	0.8	1.4	2.3	5.62	22.9	79.6	120	435.2	
Fluoride, filtered (as F)	mg/L	88	0.1	58	<1	<1	<1	<1	0.185	0.43	1.29	1.76	17.9	
Hydrogen sulfide, unfiltered, field (as H ₂ S)	µg/L	54	0.001	77.8	<0.001	<0.001	<0.001	0.001	0.002	0.005	0.011	0.041	0.2	
Silica, filtered (as SiO ₂)	mg/L	88	0.06	100	5.9	8.68	9.02	10.8	13.5	16.9	19.2	20.9	35.6	
Sulfate, filtered (as SO ₄)	mg/L	88	0.18	100	0.31	2.93	5.55	8.33	11.63	19.26	24	33.6	68.5	
Nutrients														
Nitrogen, organic plus ammonia, filtered (as N)	mg/L	58	0.1	8.6	<1	<1	<1	<1	<1	<1	<1	<1	0.12	0.3
Nitrogen, ammonia, filtered (as N)	mg/L	88	0.02	11.4	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	0.03	0.04	0.22	
Nitrogen, nitrite plus nitrate, filtered (as N)	mg/L	88	0.05	50	<0.5	<0.5	<0.5	<0.5	<0.5	0.4	2	4.06	8.96	
Nitrogen, nitrite, filtered (as N)	mg/L	88	0.01	1.14	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.08	
Phosphorus, orthophosphate, filtered (as P)	mg/L	88	0.01	26.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.011	0.024	0.04	0.22	
Phosphorus, filtered (as P)	mg/L	88	0.01	28.4	<0.1	<0.1	<0.1	<0.1	<0.1	0.013	0.04	0.08	0.22	
Dissolved gases														
Carbon dioxide, (as CO ₂)	mg/L	56	na	100	0.18	0.39	0.49	1.09	4.7	12.5	37.22	63.05	134.9	
Nitrogen, (as N ₂)	mg/L	56	na	100	17.6	20.29	20.52	21.61	23	24.26	25.85	27.64	29.8	
Argon, (as Ar)	mg/L	56	na	100	0.53	0.71	0.74	0.77	0.8	0.82	0.83	0.87	0.9	
Methane, (as CH ₄)	mg/L	56	0.001	32.1	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	0.046	0.292	15.5	

Table 1-1. Summary statistics for selected physiochemical properties of, and inorganic water-quality constituents in water samples collected for the U.S. Geological Survey National Water-Quality Assessment Program from 88 domestic wells in crystalline rock aquifers in New England, 1995–2000.—Continued

[N, number of samples; LRL, laboratory reporting level; Min, minimum; Max, maximum; $\mu\text{S}/\text{cm}$ at 25°C , microsiemens per centimeter at 25 degrees Celsius; na, not applicable; $^\circ\text{C}$, degrees Celsius; NTU, nephelometric turbidity units; <, less than; >, greater than; mg/L , milligrams per liter; $\mu\text{g}/\text{L}$, micrograms per liter; pCi/L , picocuries per liter. Filtered samples processed through a 0.45 micron pore size, disposable Supor® (inherently hydrophilic polyethersulfone) single-use, capsule filter. This table summarizes water-quality data from 30 wells sampled by the Connecticut, Housatonic, and Thames Rivers Basins National Water-Quality Assessment Program study unit and 58 wells sampled by the New England Coastal Basins National Water-Quality Assessment Program study unit]

Water-quality properties and constituents	Units	N	Common LRL	Percent of samples above LRL	Concentration Percentiles									
					Min	5th	10th	25th	50th	75th	90th	95th	Max	
Trace elements														
Aluminum, filtered (as Al)	$\mu\text{g}/\text{L}$	57	1	36.8	<1	<1	<1	<1	<1	<1	1.2	2.93	140	360
Barium, filtered (as Ba)	$\mu\text{g}/\text{L}$	58	1	81	<1	<1	<1	1.39	<1	6.7	29.6	80.9	92.7	114
Beryllium, filtered (as Be)	$\mu\text{g}/\text{L}$	58	1	5	<1	<1	<1	<1	<1	<1	<1	<1	1.6	7.54
Cadmium, filtered (as Cd)	$\mu\text{g}/\text{L}$	58	1	2	<1	<1	<1	<1	<1	<1	<1	<1	<1	1.53
Chromium, filtered (as Cr)	$\mu\text{g}/\text{L}$	58	1	3.4	<1	<1	<1	<1	<1	<1	<1	<1	<1	2.96
Cobalt, filtered (as Co)	$\mu\text{g}/\text{L}$	58	1	0	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Copper, filtered (as Cu)	$\mu\text{g}/\text{L}$	58	1	50	<1	<1	<1	<1	<1	<1	6.6	12.3	17.4	416
Iron, ferrous, unfiltered (as Fe^{2+})	$\mu\text{g}/\text{L}$	56	10	37.5	<10	<10	<10	<10	<10	<10	50	260	620	1,500
Iron, total, filtered, (as Fe)	$\mu\text{g}/\text{L}$	88	10	44.3	<10	<10	<10	<10	<10	<10	53.8	213	400	1,470
Lead, filtered (as Pb)	$\mu\text{g}/\text{L}$	58	1	20.7	<1	<1	<1	<1	<1	<1	<1	2.2	7.08	12.9
Lithium, filtered (as Li)	$\mu\text{g}/\text{L}$	54	0.6	92.6	<6	<6	1	3.15	<1	5.25	8.7	19.8	35.1	1,230
Manganese, filtered (as Mn)	$\mu\text{g}/\text{L}$	88	1	71.6	<1	<1	<1	<1	<1	7.5	32.7	114.4	193	703
Molybdenum, filtered (as Mo)	$\mu\text{g}/\text{L}$	58	1	55.2	<1	<1	<1	<1	<1	<1	2.4	4.96	5.9	18.8
Nickel, filtered (as Ni)	$\mu\text{g}/\text{L}$	58	1	34.5	<1	<1	<1	<1	<1	<1	1.68	3.13	3.47	11.6
Silver, filtered (as Ag)	$\mu\text{g}/\text{L}$	58	1	0	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Strontium, filtered (as Sr)	$\mu\text{g}/\text{L}$	58	0.4	100	17.5	42.8	54.5	79.2	167.5	275.5	470	517	1,660	<9
Thallium, filtered (as Tl)	$\mu\text{g}/\text{L}$	58	0.9	0	<9	<9	<9	<9	<9	<9	<9	<9	<9	<9
Vanadium, filtered (as V)	$\mu\text{g}/\text{L}$	47	1	8.5	<1	<1	<1	<1	<1	<1	<1	<1	1.73	2.11
Zinc, filtered (as Zn)	$\mu\text{g}/\text{L}$	57	1	57.9	<1	<1	<1	<1	<1	1.28	3.29	6.5	9.7	463
Antimony, filtered (as Sb)	$\mu\text{g}/\text{L}$	58	1	9	<1	<1	<1	<1	<1	<1	<1	<1	2.9	4.8
Arsenic, filtered (as As)	$\mu\text{g}/\text{L}$	88	2	28.4	<2	<2	<2	<2	<2	<2	2.31	13.6	21.5	50.9
Boron, filtered (as B)	$\mu\text{g}/\text{L}$	50	12	30	<12	<12	<12	<12	<12	<12	13.25	33.25	51.7	132.7
Selenium, filtered (as Se)	$\mu\text{g}/\text{L}$	58	0.7	5.2	<7	<7	<7	<7	<7	<7	<7	<7	0.81	1.01
Radionuclides														
Gross alpha-particle radioactivity (as alpha)	pCi/L	57	3	64.9	<3	<3	<3	<3	<3	4.3	8.4	33	39	667
Gross beta-particle radioactivity (as beta)	pCi/L	58	4	46.6	<4	<4	<4	<4	<4	<4	7.2	26.1	76	653
^{224}Ra Radium, filtered (as ^{224}Ra)	pCi/L	55	1	5	<1	<1	<1	<1	<1	<1	<1	<1	1.11	1.36
^{226}Ra Radium, filtered (as ^{226}Ra)	pCi/L	56	1	10	<1	<1	<1	<1	<1	<1	<1	1.19	2.69	6.75
^{228}Ra Radium, filtered (as ^{228}Ra)	pCi/L	56	1	10	<1	<1	<1	<1	<1	<1	<1	1.36	1.64	2.1
Combined radium (^{226}Ra plus ^{228}Ra)	pCi/L	56	1	25	<1	<1	<1	<1	<1	<1	1.16	2.46	3.15	6.75
^{222}Rn Radon gas (as ^{222}Rn)	pCi/L	86	20	100	75	556	750	1,263	2,184	5,600	12,780	22,430	215,200	
Uranium, filtered (as U)	$\mu\text{g}/\text{L}$	88	1	51.1	<1	<1	<1	<1	<1	1.05	3.2	13.72	21.8	152
Miscellaneous constituents														
Dissolved organic carbon (as C)	mg/L	52	0.3	53.9	<3	<3	<3	<3	<3	0.35	0.63	0.81	0.99	1.65
Apparent residence time (age) of groundwater	Years	55	na	100	3	3	8	13	25	41	48	>51	>51	>51

Table 2-1. Summary statistics for selected physiochemical properties of, and inorganic water-quality constituents in water samples collected for the U.S. Geological Survey National Water-Quality Assessment Program from 29 domestic wells in crystalline rock aquifers in New Jersey and New York, 1997.

[N, number of samples; LRL, laboratory reporting level; Min, minimum; Max, maximum; $\mu\text{S}/\text{cm}$ at 25°C , microsiemens per centimeter at 25°C ; degrees Celsius; na, not applicable; <, less than; mg/L, milligrams per liter; $\mu\text{g}/\text{L}$, micrograms per liter; pCi/L, picocuries per liter. Filtered samples were processed through a 0.45 micron pore size, disposable Supor® (inherently hydrophilic polyethersulfone) single-use capsule filter]

Water-quality properties and constituents	Units	N	Most common LRL	Percent of samples above LRL	Concentration								
					Min	5th	10th	25th	50th	75th	90th	95th	Max
Physiochemical properties													
Oxygen, dissolved (as O ₂)	mg/L	27	na	100	0.1	0.5	1.1	2.2	3.2	7.3	8.7	9.2	10.2
pH, field	Standard units	29	na	100	5.2	5.6	5.7	6.2	6.5	7.2	7.6	7.9	8.1
pH, laboratory	Standard units	29	na	100	5.9	6	6.1	6.4	6.6	7.2	7.6	7.8	7.9
Specific conductivity, field	$\mu\text{S}/\text{cm}$ at 25°C	29	5	100	74	92	94	125	202	365	671	791	798
Specific conductivity, laboratory	$\mu\text{S}/\text{cm}$ at 25°C	29	5	100	76.6	101	102	125	213	376	718	767	769
Water temperature	$^\circ\text{C}$	29	na	100	10.2	10.2	10.2	10.6	11.1	11.6	12.4	12.8	13.2
Major ions													
Total dissolved solids, summed (as TDS)	mg/L	29	10	100	55	60	71	92	134	223	425	537	545
Calcium, filtered (as Ca)	mg/L	29	0.04	100	5.9	8.6	8.7	11.8	19.5	40	68.4	74.5	98.5
Magnesium, filtered (as Mg)	mg/L	29	0.02	100	1.4	1.6	2	3.6	6.13	12.8	23.4	23.4	26.3
Potassium, filtered (as K)	mg/L	29	0.06	100	0.46	0.47	0.49	0.68	0.87	1.48	1.86	2.22	2.6
Sodium, filtered (as Na)	mg/L	29	0.1	100	1.83	2.65	3.06	4.97	6.27	12.4	19.5	20.6	48.9
Bicarbonate, filtered, laboratory (as CaCO ₃)	mg/L	28	na	100	9.2	22	25.5	32.3	46.4	72.7	125	166	178
Bromide, filtered (mg/L as Br)	mg/L	29	0.01	82.8	<0.01	<0.01	<0.01	0.011	0.017	0.044	0.07	0.09	0.15
Chloride, filtered (mg/L as Cl)	mg/L	29	0.12	100	1.79	1.86	1.88	3.86	13	49.5	106	151	156
Fluoride, filtered (mg/L as F)	mg/L	29	0.1	37.9	<0.1	<0.1	<0.1	<0.1	<0.1	0.12	0.395	0.57	0.6
Silica, filtered (SiO ₂)	mg/L	29	0.06	100	7.6	10.5	12.1	15.7	17.9	23.6	30.1	33.4	37.8
Sulfate, filtered (as SO ₄)	mg/L	29	0.18	100	3	6.4	7.1	13.4	15.2	21.4	28.2	35.2	36.8
Nutrients													
Nitrogen, organic plus ammonia, filtered (as N)	mg/L	29	0.2	0	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Nitrogen, ammonia, filtered (as N)	mg/L	29	0.02	20.7	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.035	0.08	0.1

Table 2-1. Summary statistics for selected physiochemical properties of, and inorganic water-quality constituents in water samples collected for the U.S. Geological Survey National Water-Quality Assessment Program from 29 domestic wells in crystalline rock aquifers in New Jersey and New York, 1997.—Continued

[N, number of samples; LRL, laboratory reporting level; Min, minimum; Max, maximum; $\mu\text{S/cm}$ at 25°C, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; na, not applicable; <, less than; mg/L, milligrams per liter; $\mu\text{g/L}$, micrograms per liter; pCi/L, picocuries per liter. Filtered samples were processed through a 0.45 micron pore size, disposable Supor® (inherently hydrophilic polyethersulfone) single-use capsule filter]

Water-quality properties and constituents	Units	N	Most common LRL	Percent of samples above LRL	Min	Concentration								
						5th	10th	25th	50th	75th	90th	95th	Max	
Nutrients—Continued														
Nitrogen, nitrite plus nitrate, filtered (as N)	mg/L	29	0.05	96.6	<0.05	0.05	0.08	0.28	1.04	2.3	5.28	5.62	6.61	
Nitrogen, nitrite, filtered (as N)	mg/L	29	0.01	13.8	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.015	0.016	0.03	
Phosphorus, orthophosphate, filtered (as P)	mg/L	29	0.01	58.6	<0.01	<0.01	<0.01	<0.01	0.013	0.023	0.06	0.06	0.06	
Phosphorus, filtered (as P)	mg/L	29	0.01	41.4	<0.01	<0.01	<0.01	<0.01	<0.01	0.02	0.05	0.05	0.06	
Trace elements														
Aluminum, filtered (as Al)	$\mu\text{g/L}$	29	1	96.6	<1	2.45	2.51	3.65	4.37	5.36	5.95	6.35	28.2	
Barium, filtered (as Ba)	$\mu\text{g/L}$	29	1	93.1	<1	<1	1.04	1.74	4	7.28	17.8	31.1	46.9	
Beryllium, filtered (as Be)	$\mu\text{g/L}$	29	1	0	<1	<1	<1	<1	<1	<1	<1	<1	<1	
Cadmium, filtered (as Cd)	$\mu\text{g/L}$	29	1	0	<1	<1	<1	<1	<1	<1	<1	<1	<1	
Chromium, filtered (as Cr)	$\mu\text{g/L}$	29	1	58	<1	<1	<1	<1	1.22	1.57	2.51	3.36	4.1	
Cobalt, filtered (as Co)	$\mu\text{g/L}$	29	1	0	<1	<1	<1	<1	<1	<1	<1	<1	<1	
Copper, filtered (as Cu)	$\mu\text{g/L}$	29	1	79.3	<1	<1	1.07	2.64	15.1	27.85	43.5	43.5	140.5	
Iron, total, filtered (as Fe)	$\mu\text{g/L}$	29	10	31	<10	<10	<10	<10	<10	19.88	79.3	187.3	274	
Lead, filtered (as Pb)	$\mu\text{g/L}$	29	1	7	<1	<1	<1	<1	<1	<1	<1	1.02	4.8	
Manganese, filtered (as Mn)	$\mu\text{g/L}$	29	1	65.5	<1	<1	<1	<1	1.97	9.03	28.64	77.09	171.6	
Molybdenum, filtered (as Mo)	$\mu\text{g/L}$	29	1	17.2	<1	<1	<1	<1	<1	<1	2.7	3.28	12.1	
Nickel, filtered (as Ni)	$\mu\text{g/L}$	29	1	34.5	<1	<1	<1	<1	<1	1.29	2.34	2.41	2.51	
Silver, filtered (as Ag)	$\mu\text{g/L}$	29	1	0	<1	<1	<1	<1	<1	<1	<1	<1	<1	
Zinc, filtered (as Zn)	$\mu\text{g/L}$	29	1	48.3	<1	<1	<1	<1	<1	4.83	11.4	28.06	44.8	
Antimony, filtered (as Sb)	$\mu\text{g/L}$	29	1	0	<1	<1	<1	<1	<1	<1	<1	<1	<1	
Arsenic, filtered (as As)	$\mu\text{g/L}$	29	1	3.45	<1	<1	<1	<1	<1	<1	<1	<1	29	
Boron, filtered (as B)	$\mu\text{g/L}$	29	12	72.4	<12	<12	<12	<12	15.34	21.8	31.3	36	54.3	
Selenium, filtered (as Se)	$\mu\text{g/L}$	29	1	3	<1	<1	<1	<1	<1	<1	<1	<1	1.7	
Radionuclides														
Radon-222 gas (as ^{222}Rn)	pCi/L	26	20	100	218	224	245	573	1,580	3,124	4,738	4,899	31,820	
Uranium, filtered (as U)	$\mu\text{g/L}$	29	1	27.6	<1	<1	<1	<1	<1	1.24	8.58	12.83	428.9	

Table 3-1. Summary statistics for selected physiochemical properties and water-quality constituents in untreated water samples collected for the U.S. Environmental Protection Agency Safe Drinking Water Act Program from 4,664 public-supply wells in New England crystalline rock aquifers, 1997–2007.

[N, number of samples; $\mu\text{S}/\text{cm}$ at 25°C , microsiemens per centimeter at 25°C ; na, not applicable; <, less than; Min, minimum; Max, maximum; mg/L, milligrams per liter; $\mu\text{g}/\text{L}$, micrograms per liter; pCi/L, picocuries per liter. The common LRL is the most common laboratory reporting level (LRL) among the six state Safe Drinking Water Act databases for each constituent]

Water-quality properties and constituents	Units	N	Common LRL	Per-cent of samples above LRL	Min	Concentration						Max	
						Percentiles							
						5th	10th	25th	50th	75th	90th		95th
pH, field/lab	Standard units	1,908	na	100	5.2	6.3	6.6	7.1	7.6	8	8.2	8.4	12
Specific conductance, field/lab	$\mu\text{S}/\text{cm}$ at 25°C	704	na	100	20	101	124	250	250	393	621	910	5,260
Sodium, total (as Na)	mg/L	2,402	na	100	0.41	3	4.5	7.1	12.6	24.7	51.6	85.4	958
Chloride, total (as Cl)	mg/L	1,750	2.5	95.1	<2.5	2.8	3	6	18	51	119	209	1,800
Fluoride, total (as F)	mg/L	2,050	0.2	70	<0.2	<0.2	<0.2	<0.2	0.36	0.8	1.75	2.6	12.9
Nitrogen, nitrite plus nitrate, filtered (as N)	mg/L	4,664	0.5	25.2	<0.5	<0.5	<0.5	<0.5	<0.5	0.5	1.6	2.5	18.4
Iron, total (as Fe)	$\mu\text{g}/\text{L}$	1,516	50	65.2	<50	<50	<50	<50	84.5	271	987	2,060	100,000
Manganese, total (as Mn)	$\mu\text{g}/\text{L}$	1,642	20	60.5	<20	<20	<20	<20	32	92	232	452	3,420
Arsenic, total (as As)	$\mu\text{g}/\text{L}$	1,937	5	23.5	<5	<5	<5	<5	<5	<5	13	24	2,400
Methyl <i>tert</i> -butyl ether (as M/BE)	$\mu\text{g}/\text{L}$	1,184	1	9.97	<1	<1	<1	<1	<1	<1	<1	2	190
Gross alpha-particle radioactivity	pCi/L	835	3	47.7	<3	<3	<3	<3	<3	7	17	33	2,560
Combined radium (^{226}Ra plus ^{228}Ra)	pCi/L	508	1	33.9	<1	<1	<1	<1	<1	1.3	2.7	3.6	16.0
^{222}Rn radon gas (as ^{222}Rn)	pCi/L	831	100	98.4	<100	310	521	1,200	2,600	5,300	11,400	20,000	175,040
Uranium, total (as U)	$\mu\text{g}/\text{L}$	439	1	75.2	<1	<1	<1	1	3	15	44	84	3,643

Table 4-1. Rho and probability values from Spearman correlations of selected water-quality properties and constituents, and well construction properties with apparent residence time of groundwater from water samples collected for the U.S. Geological Survey National Water-Quality Assessment Program in domestic wells in New England crystalline rock aquifers, 1999–2000.

[The order of the correlation variable is from the highest correlation (either negative or positive) value to the lowest correlation value. Spearman's coefficients (rho) are considered significant when the *P*-values are less than or equal to 0.05; a negative rho value indicates an inverse relation. N, number of samples; (F), filtered sample; <, less than; Na:Cl, sodium to chloride; --, *P*-value not calculated]

Correlation variable	N	Spearman's coefficient (rho)	<i>P</i> -value	Correlation variable	N	Spearman's coefficient (rho)	<i>P</i> -value
Apparent residence time (age) of groundwater in well	55	1	--	Boron (F)	47	0.183	--
Dissolved oxygen	55	-0.712	<0.0001	Well depth	55	0.154	0.2616
pH, field	55	0.705	<0.0001	Bromide (F)	55	0.151	0.2713
Zinc (F)	54	-0.680	<0.0001	Specific conductance, field	55	0.144	0.2930
Copper (F)	55	-0.680	<0.0001	²²² Radon	53	-0.142	0.3104
Carbon dioxide (CO ₂) gas	53	-0.668	<0.0001	Aluminum (F)	54	0.134	0.3335
Deuterium	55	-0.566	<0.0001	Total dissolved solids (F)	55	0.132	0.3383
Length of well casing	54	0.560	<0.0001	Chromium (F)	55	0.127	0.3541
¹⁸ Oxygen	55	-0.538	<0.0001	Calcium (F)	55	-0.125	0.3613
Methane (CH ₄) gas	53	0.532	<0.0001	Altitude of the well	55	0.123	0.3708
Nitrate (F)	55	-0.510	<0.0001	Radium-226 (F)	55	0.103	0.4535
Total iron (F)	55	0.490	0.0001	Silica (F)	55	0.097	0.4798
Molybdenum (F)	55	0.475	0.0002	Antimony (F)	55	-0.094	0.4933
Fluoride (F)	55	0.462	0.0004	Radium-228 (F)	55	0.082	0.5506
Na:Cl molar ratio	55	0.380	0.0037	Cadmium (F)	55	-0.082	0.5542
Argon gas	53	0.369	0.0065	Vanadium (F)	44	-0.072	0.6407
Nitrogen (N ₂) gas	53	0.361	0.0079	Water level in well	54	0.061	0.6607
Lead, total (F)	55	-0.356	0.0077	Potassium (F)	55	-0.059	0.6689
Nickel (F)	55	-0.334	0.0128	Magnesium (F)	55	-0.050	0.7191
Sodium (F)	55	0.320	0.0173	Gross alpha-particle activity (F)	54	0.045	0.7475
Strontium (F)	55	0.312	0.0205	Water temperature	55	0.045	0.7452
Barium (F)	55	0.311	0.0206	Uranium (F)	55	-0.041	0.7667
Alkalinity (F)	55	0.310	0.0214	Gross beta-particle activity (F)	55	0.022	0.8722
Manganese (F)	55	0.299	0.0268	Arsenic (F)	50	-0.022	0.8801
Phosphate, ortho (F)	55	0.292	0.0308	Chloride (F)	55	-0.019	0.8912
Lithium (F)	51	0.231	0.1033	Selenium (F)	44	0.016	0.9203
Beryllium (F)	55	-0.197	0.1484	Sulfate (F)	55	0.008	0.9546

Table 5–1. Rho and probability values from Spearman correlations of selected water-quality properties and constituents, land-use data, human population data, and well construction properties, with nitrate and chloride concentrations in water samples collected from domestic and public-supply wells in New England crystalline rock aquifers, 1995–2007.

[Spearman's coefficients (rho) are considered significant (in **bold**) when the *P*-values are less than or equal to 0.05; a negative rho value indicates an inverse relation. Rho, Spearman's rho coefficient; *P*-value, Spearman's probability value; N, number of water samples; <, less than; X, no data; --, *P*-value not calculated; persons/km², persons per square kilometer; USGS NAWQA, domestic bedrock wells sampled for the U.S. Geological Survey National Water-Quality Assessment Program in New England, New Jersey, and New York; USEPA SDWA, public-supply bedrock wells sampled for the U.S. Environmental Protection Agency Safe Drinking Water Act Program in New England]

Correlation variable	Spearman's correlation variables	Nitrate			Chloride		
		USGS NAWQA	USEPA SDWA	All wells in study	USGS NAWQA	USEPA SDWA	All wells in study
Physiochemical properties and water-quality constituents determined from water samples							
Bicarbonate	Rho	-0.19	X	-0.19	0.176	X	0.176
	<i>P</i> -value	0.0375	X	0.0412	0.0583	X	0.0583
	N	116	X	116	116	X	116
Arsenic	Rho	-0.33	-0.164	-0.169	0.017	0.008	0.016
	<i>P</i> -value	0.0003	<.0001	<.0001	0.8628	0.7692	0.5568
	N	111	1,915	2,032	111	1,259	1,376
Bromide	Rho	0.181	X	0.181	0.659	X	0.659
	<i>P</i> -value	0.0511	X	0.0512	<0.0001	X	<0.0001
	N	117	X	117	117	X	117
Calcium	Rho	0.295	X	0.295	0.48	X	0.4802
	<i>P</i> -value	0.0012	X	0.0012	<0.0001	X	<0.0001
	N	117	X	117	117	X	117
Chloride	Rho	0.474	0.172	0.190	1	1	1
	<i>P</i> -value	<.0001	<.0001	<.0001	--	--	--
	N	117	1,737	1,854	117	1,750	1,867
Dissolved oxygen	Rho	0.602	X	0.602	0.106	X	0.106
	<i>P</i> -value	<0.0001	X	<0.0001	0.2608	X	0.2608
	N	115	X	115	115	X	115
Fluoride	Rho	-0.512	-0.323	-0.332	-0.2	-0.133	-0.104
	<i>P</i> -value	<.0001	<.0001	<.0001	0.0302	<0.0001	<0.0001
	N	117	2,040	2,157	117	1,396	1,513
Iron, total	Rho	-0.422	-0.216	-0.235	0.03	0.063	0.084
	<i>P</i> -value	<.0001	<.0001	<.0001	0.7521	0.0312	0.0025
	N	117	1,503	1,620	117	1,160	1,277
Magnesium	Rho	0.295	X	0.295	0.467	X	0.467
	<i>P</i> -value	0.0012	X	0.0012	<0.001	X	<0.0001
	N	117	X	117	117	X	117
Manganese	Rho	-0.361	-0.247	-0.255	0.045	0.121	0.137
	<i>P</i> -value	<.0001	<.0001	<.0001	0.6315	<0.0001	<0.0001
	N	117	1,632	1,749	117	1,228	1,345
Nitrate	Rho	1	1	1	0.474	0.172	0.19
	<i>P</i> -value	--	--	--	<0.0001	<0.0001	<0.0001
	N	117	4,664	4,781	117	1,737	1,854
pH	Rho	-0.587	-0.296	-0.312	-0.209	-0.179	-0.17
	<i>P</i> -value	<0.0001	<0.0001	<0.0001	0.0236	<0.0001	<0.0001
	N	117	1,883	2,000	117	1,522	1,639

Table 5-1. Rho and probability values from Spearman correlations of selected water-quality properties and constituents, land-use data, human population data, and well construction properties, with nitrate and chloride concentrations in water samples collected from domestic and public-supply wells in New England crystalline rock aquifers, 1995–2007.—Continued

[Spearman's coefficients (rho) are considered significant (in **bold**) when the *P*-values are less than or equal to 0.05; a negative rho value indicates an inverse relation. Rho, Spearman's rho coefficient; *P*-value, Spearman's probability value; N, number of water samples; <, less than; X, no data; --, *P*-value not calculated; persons/km², persons per square kilometer; USGS NAWQA, domestic bedrock wells sampled for the U.S. Geological Survey National Water-Quality Assessment Program in New England, New Jersey, and New York; USEPA SDWA, public-supply bedrock wells sampled for the U.S. Environmental Protection Agency Safe Drinking Water Act Program in New England]

Correlation variable	Spearman's correlation variables	Nitrate			Chloride		
		USGS NAWQA	USEPA SDWA	All wells in study	USGS NAWQA	USEPA SDWA	All wells in study
Physiochemical properties and water-quality constituents determined from water samples—Continued							
Potassium	Rho	0.064	X	0.065	0.466	X	0.466
	<i>P</i> -value	0.4891	X	0.4892	<0.0001	X	<0.0001
	N	117	X	117	117	X	117
Specific conductance	Rho	0.27	0.166	0.183	0.762	0.823	0.821
	<i>P</i> -value	0.0032	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
	N	117	703	820	117	613	730
Sodium	Rho	0.06	0.062	0.062	0.6	0.617	0.624
	<i>P</i> -value	0.5188	0.0024	0.0020	<0.0001	<0.0001	<0.0001
	N	117	2,393	2,510	117	1,687	1,804
Sulfate	Rho	0.185	X	0.185	0.318	X	0.318
	<i>P</i> -value	0.0456	X	0.0456	0.0004	X	0.0005
	N	117	X	117	117	X	117
Land use and population density, within a 500-meter radius of sampled wells							
Percent agricultural lands	Rho	-0.108	0.125	0.121	-0.038	0.025	0.031
	<i>P</i> -value	0.2472	<0.0001	<0.0001	0.6862	0.2966	0.1851
	N	117	4,663	4,780	117	1,750	1,867
Percent developed lands	Rho	0.287	0.144	0.148	0.388	0.266	0.283
	<i>P</i> -value	0.0018	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
	N	117	4,663	4,780	117	1,750	1,867
Percent undeveloped lands	Rho	-0.263	-0.195	-0.198	-0.306	-0.222	-0.239
	<i>P</i> -value	0.0042	<0.0001	<0.0001	0.0007	<0.0001	<0.0001
	N	117	4,663	4,780	117	1,750	1,867
Population density, in persons/km ²	Rho	0.328	0.164	0.168	0.303	0.201	0.212
	<i>P</i> -value	0.0003	<0.0001	<0.0001	0.0009	<0.0001	<0.0001
	N	117	4,664	4,781	117	1,750	1,867
Well construction properties							
Well depth, in ft	Rho	-0.223	-0.139	-0.15	0.002	-0.06	-0.03
	<i>P</i> -value	0.0155	<0.0001	<0.0001	0.975	0.078	0.3441
	N	117	2,143	2,260	117	861	978
Water level, in ft	Rho	0.103	0.176	0.111	-0.094	-0.028	-0.092
	<i>P</i> -value	0.2994	0.038	0.0858	0.3444	0.9082	0.315
	N	103	139	242	103	19	122
Casing length, in ft	Rho	-0.161	-0.126	-0.133	-0.149	-0.115	-0.091
	<i>P</i> -value	0.0848	0.0002	<0.0001	0.1113	0.0341	0.0526
	N	116	886	1,002	116	340	456
Miscellaneous variables							
Carbon dioxide gas	Rho	0.627	X	0.66	0.334	X	0.124
	<i>P</i> -value	<0.0001	X	<0.0001	0.0017	X	0.375
	N	85	X	53	85	X	53

Table 6–1. Highest five concentrations for selected water-quality constituents in water samples from domestic and public-supply wells in New England crystalline rock aquifers, 1995–2007.

[n, number of water samples; Ag, agricultural land; Devel, developed or urban land; Undev, undeveloped land; µg/L, micrograms per liter; mg/L, milligrams per liter; pCi/L, picocuries per liter; M_p, pelitic rocks; I_p, peraluminous granite; M_{c-nm}, calcareous metasedimentary rocks-NH–Maine geologic province; I_m, metaluminous granite; M_{ot}, metasedimentary rocks, other; M_{nb}, Narragansett Basin metasedimentary rocks; CT, Connecticut; ME, Maine; NH, New Hampshire; NJ, New Jersey; RI, Rhode Island; VT, Vermont; dom, domestic well sampled for the U.S. Geological Survey National Water-Quality Assessment Program; PS, public-supply well sampled for the U.S. Environmental Protection Agency Safe Drinking Water Act Program. Detailed information on State geologic map codes, geologic unit names, and their definitions can be found at <http://nh.water.usgs.gov/projects/nawqa/lithogeo.htm> or at <http://tin.er.usgs.gov/geology/state/>. In **bold**, rows with the two most common ‘geologic unit names’ in this table. The lithology groups are described in table 7 and are illustrated in figure 5B]

Concentration	State geologic map code	Geologic unit name	Lithology group	Location of well (State)	Type of well	Percent land use within 500-meter radius of well, in 2001		
						Ag	Devel	Undev
Arsenic, in µg/L (n = 2,054)								
2,400	Ssa	Sangerville Formation	M _p	ME	PS	10	12	78
499.5	Dc1m	Concord Granite	I_p	NH	PS	0	38	62
114	Sob	Berwick Formation	M_{c-nm}	NH	PS	2.4	35.6	62
105.5	Srl	Rangely Formation: Lower Part	M _p	NH	PS	4.7	28.8	66.5
87.1	Dk2x	Kinsman Granodiorite	I _m	NH	PS	33.7	14.7	51.7
Beryllium, in µg/L (n = 87)								
7.54	Dc1m	Concord Granite	I_p	NH	Dom	3.4	3.8	92.8
1.72	Jc1b	Conway Granite–mesoperthitic biotite granite	I _a	NH	Dom	1.6	0	98.4
1.61	Dsg	Scituate Igneous Suite	I _a	RI	Dom	0.6	23	76.4
Chloride, in mg/L (n = 1,867)								
1,800	Dc1m	Concord Granite	I_p	NH	PS	12	60	28
1,100	Ds1-6	Spaulding Tonalite	I _m	NH	PS	6	13	81
890	C-ph	Pinney Hollow Formation	M _p	VT	PS	22	40	38
851	C-o	Ottawaquechee Formation	M _p	VT	PS	13	18	69
760	SOe	Eliot Formation	M _{c-nm}	NH	PS	51	15	34
Combined radium (²²⁶ radium plus ²²⁸ radium), in pCi/L (n = 562)								
16	SOB	Berwick Formation	M_{c-nm}	NH	PS	4.6	34.2	61.2
14	C-ufp	Underhill Formation, Fairfield Pong Member	M _p	VT	PS	18.4	9.5	72
12.81	Dsg	Scituate Igneous Suite	I _m	RI	PS	10.4	22	67.6
12.5	Sob	Berwick Formation	M_{c-nm}	NH	PS	8.3	26.6	65.1
12.5	SOe	Eliot Formation	M _{c-nm}	NH	PS	22	13.9	64.1
Fluoride, in mg/L (n = 2,167)								
17.9	Dw3A	Winnepesaukee Tonalite	I _m	NH	Dom	1	13	86
12.9	Dw3A	Winnepesaukee Tonalite	I _m	NH	PS	1	11	88
12.7	Dw3A	Winnepesaukee Tonalite	I _m	NH	PS	1	10	88
11.1	Dw3A	Winnepesaukee Tonalite	I _m	NH	PS	1	11	87
10.5	Sm	Madrid Formation	M _{c-nm}	NH	PS	8	14	78
Gross alpha-particle radioactivity, in pCi/L (n = 828)								
2,560	SOB	Berwick Formation	M_{c-nm}	NH	PS	2	52	47
819	SOB	Berwick Formation	M_{c-nm}	NH	PS	52	27	22
667	DI	Littleton Formation	M_p	ME	Dom	3	4	93
639	Jc1b	Conway Granite–mesoperthitic biotite granite	I _a	NH	PS	1	9	90
280	Sobc	Berwick Formation	M_{c-nm}	NH	PS	8	27	65

Table 6–1. Highest five concentrations for selected water-quality constituents in water samples from domestic and public-supply wells in New England crystalline rock aquifers, 1995–2007.—Continued

[n, number of water samples; Ag, agricultural land; Devel, developed or urban land; Undev, undeveloped land; µg/L, micrograms per liter; mg/L, milligrams per liter; pCi/L, picocuries per liter; M_p, pelitic rocks; I_p, peraluminous granite; M_{c-nm}, calcareous metasedimentary rocks-NH–Maine geologic province; I_m, metaluminous granite; M_{ot}, metasedimentary rocks, other; M_{nb}, Narragansett Basin metasedimentary rocks; CT, Connecticut; ME, Maine; NH, New Hampshire; NJ, New Jersey; RI, Rhode Island; VT, Vermont; dom, domestic well sampled for the U.S. Geological Survey National Water-Quality Assessment Program; PS, public-supply well sampled for the U.S. Environmental Protection Agency Safe Drinking Water Act Program. Detailed information on State geologic map codes, geologic unit names, and their definitions can be found at <http://nh.water.usgs.gov/projects/nawqa/lithogeo.htm> or at <http://tin.er.usgs.gov/geology/state/>. In **bold**, rows with the two most common ‘geologic unit names’ in this table. The lithology groups are described in table 7 and are illustrated in figure 5B]

Concentration	State geologic map code	Geologic unit name	Lithology group	Location of well (State)	Type of well	Percent land use within 500-meter radius of well, in 2001		
						Ag	Devel	Undev
Manganese (n = 1,759)								
3,420	SOB	Berwick Formation	M_{c-nm}	NH	PS	12	23	65
3,400	SZb	Berwick Formation	M_{c-nm}	ME	PS	6.9	15.3	77.8
3,100	OC-p	Penobscot Formation	M _p	ME	PS	0	6.7	93
2,790	Dsg	Scituate Igneous Suite	I _a	RI	PS	8	27.4	64.7
2,780	DI+Sc	Littleton Formation + Clough Quartzite-orthoquartzite, muscovite schist	M _{ot}	NH	PS	11.4	20	68.7
Methyl <i>tert</i> -butyl ether, in µg/L (n = 1,299)								
190	SOB	Berwick Formation	M_{c-nm}	NH	PS	10	15	75
109	DI	Granite	I _m	ME	PS	6	11	82
54	SOB	Berwick Formation	M_{c-nm}	NH	PS	30	9	61
46.6	pC	Mount Holly Complex	M _{ot}	VT	PS	16	28	55
30.2	--	Granite	I _m	NJ	Dom	0	68	32
Nitrate, in mg/L (n = 4,781)								
18.4	DI	Littleton Formation	M _p	VT	PS	12	27	62
14.1	C1b(m)	Biotite-muscovite granite	I _p	ME	PS	29	14	56
14	Ob	Brookfield Gneiss	M _m	CT	PS	6	19	75
13	C1b(m)	Biotite-muscovite granite	I _p	ME	PS	3	16	82
11.1	Pnbr	Narragansett Bay Group–Rhode Island Formation	M _{nb}	RI	PS	67	22	8
²²² Radon, in pCi/L (n = 943)								
215,200	Dc1m	Concord Granite	I_p	NH	Dom	2	6	92
175,000	Dc1m	Concord Granite	I_p	NH	PS	14	21	65
101,800	DI	Littleton Formation	M _p	ME	Dom	3	4	93
100,000	SOB	Berwick Formation	M_{c-nm}	NH	PS	10	18	72
100,000	Dc1m	Concord Granite	I_p	NH	PS	13	22	65
Sodium, in mg/L (n = 2,521)								
958	Dc1m	Concord Granite	I_p	NH	PS	11.9	60.1	28
380	OZma	Massabesic Gneiss Complex	I _m	NH	PS	0	33.7	66.3
380	Dw3A	Winnepesaukee Tonalite	I _m	NH	PS	1.4	10.1	88.5
360	Ozma	Massabesic Gneiss Complex	I _m	NH	PS	18.9	13.7	67.4
348	Ds1-6	Spaulding Tonalite	I _m	NH	PS	6.3	13	80.7
Uranium, in µg/L (n = 556)								
3,640	SOB	Berwick Formation	M_{c-nm}	NH	PS	2	51	47
1,160	Jc1b	Conway Granite–mesoperthitic biotite granite	I _a	NH	PS	1	9	90
583	SOv	Vassalboro Formation	M _{c-nm}	ME	PS	52	27	21
429	--	Quartz-oligoclase gneiss	M _{ot}	NJ	Dom	1	55	44
420	Sobc	Berwick Formation	M_{c-nm}	NH	PS	8	27	65

Table 7–1. Rho and probability values from Spearman correlations of selected water-quality properties and constituents, land-use and human population data, well construction properties, and National Uranium Resource Evaluation Program streambed-sediment data, with fluoride and arsenic concentrations in water samples collected from domestic and public-supply wells in New England crystalline rock aquifers, 1995–2007.

[Spearman's coefficients (rho) are considered significantly correlated (in **bold**) when the *P*-values are less than or equal to 0.05; a negative rho value indicates an inverse relation. Rho, Spearman's rho coefficient; *P*-value, Spearman's probability value; N, number of water samples; <, less than; X, no data; --, *P*-value not calculated; na, did not perform correlation; persons/km², persons per square kilometer; Fe₂O₃, iron oxide; ppm, parts per million; USGS NAWQA, domestic bedrock wells sampled for the U.S. Geological Survey National Water-Quality Assessment Program in New England, New Jersey, and New York; USEPA SDWA, public-supply bedrock wells sampled for the U.S. Environmental Protection Agency Safe Drinking Water Act Program in New England]

Correlation variable	Spearman's correlation variables	Fluoride			Arsenic		
		USGS NAWQA	USEPA SDWA	All wells in study	USGS NAWQA	USEPA SDWA	All wells in study
Physiochemical properties and water-quality constituents determined from water samples							
Bicarbonate	Rho	0.127	X	0.127	0.294	X	0.294
	<i>P</i> -value	0.1738	X	0.1738	0.0018	X	0.0018
	N	116	X	116	110	X	110
Arsenic	Rho	0.183	0.207	0.201	1	1	1
	<i>P</i> -value	0.054	<0.0001	<0.0001	--	--	--
	N	111	1,612	1,729	111	1,937	2,054
Calcium	Rho	-0.223	X	-0.223	0.094	X	0.077
	<i>P</i> -value	0.0154	X	0.0154	0.3282	X	0.0011
	N	117	X	117	111	X	1,801
Dissolved oxygen	Rho	-0.433	X	-0.433	-0.279	X	-0.279
	<i>P</i> -value	<0.0001	X	<0.0001	0.0033	X	0.0033
	N	115	X	115	109	X	109
Fluoride	Rho	1	1	1	0.183	0.207	0.201
	<i>P</i> -value	--	--	--	0.0540	<0.0001	<0.0001
	N	117	2,050	2,167	111	1,612	1,729
Iron, total	Rho	0.223	0.206	0.236	0.135	0.142	0.149
	<i>P</i> -value	0.016	<0.0001	<0.0001	0.1585	<0.0001	<0.0001
	N	117	1,223	1,340	111	1,143	1,260
Lithium	Rho	0.582	X	0.582	0.193	X	0.187
	<i>P</i> -value	<0.0001	X	<0.0001	0.1748	X	0.1765
	N	54	X	54	51	X	54
Manganese	Rho	0.247	0.164	0.193	0.136	0.173	0.174
	<i>P</i> -value	0.007	<0.0001	<0.0001	0.154	<0.0001	<0.0001
	N	117	1,302	1,419	111	1,231	1,348
Nitrate	Rho	-0.512	-0.323	-0.332	-0.334	-0.164	-0.169
	<i>P</i> -value	<0.0001	<0.0001	<0.0001	0.0003	<0.0001	<0.0001
	N	117	2,040	2,157	111	1,915	2,032
pH	Rho	0.376	0.352	0.371	0.292	0.211	0.224
	<i>P</i> -value	<0.0001	<0.0001	<0.0001	0.0019	<0.0001	<0.0001
	N	117	1,466	1,583	111	1,251	1,368
Specific conductance	Rho	-0.026	-0.143	-0.072	0.129	0.105	0.116
	<i>P</i> -value	0.78	0.0006	0.0599	0.179	0.0192	0.0039
	N	117	566	683	111	501	618

Table 7-1. Rho and probability values from Spearman correlations of selected water-quality properties and constituents, land-use and human population data, well construction properties, and National Uranium Resource Evaluation Program streambed-sediment data, with fluoride and arsenic concentrations in water samples collected from domestic and public-supply wells in New England crystalline rock aquifers, 1995–2007.—Continued

[Spearman's coefficients (rho) are considered significantly correlated (in **bold**) when the *P*-values are less than or equal to 0.05; a negative rho value indicates an inverse relation. Rho, Spearman's rho coefficient; *P*-value, Spearman's probability value; N, number of water samples; <, less than; X, no data; --, *P*-value not calculated; na, did not perform correlation; persons/km², persons per square kilometer; Fe₂O₃, iron oxide; ppm, parts per million; USGS NAWQA, domestic bedrock wells sampled for the U.S. Geological Survey National Water-Quality Assessment Program in New England, New Jersey, and New York; USEPA SDWA, public-supply bedrock wells sampled for the U.S. Environmental Protection Agency Safe Drinking Water Act Program in New England]

Correlation variable	Spearman's correlation variables	Fluoride			Arsenic		
		USGS NAWQA	USEPA SDWA	All wells in study	USGS NAWQA	USEPA SDWA	All wells in study
Physiochemical properties and water-quality constituents determined from water samples—Continued							
Sulfate	Rho	-0.174	X	-0.174	0.209	X	0.209
	<i>P</i> -value	0.0605	X	0.0605	0.0276	X	0.0276
	N	117	X	117	111	X	111
Sodium	Rho	0.234	0.137	0.163	0.221	0.066	0.077
	<i>P</i> -value	0.0112	<0.0001	<0.0001	0.0199	0.0065	0.0011
	N	117	1,842	1,959	111	1,684	1,801
Uranium	Rho	0.130	0.229	0.267	0.200	0.017	0.063
	<i>P</i> -value	0.1625	<0.0001	<0.0001	0.0350	0.765	0.189
	N	117	354	471	111	319	436
Land use and population density, in a 500-meter radius of sampled wells							
Percent agricultural lands	Rho	-0.066	-0.18	-0.138	0.341	0.025	0.004
	<i>P</i> -value	0.4763	<0.0001	<0.0001	0.0002	0.2966	0.852
	N	117	2,050	1,632	111	1,750	2,054
Percent developed lands	Rho	-0.120	-0.110	-0.096	0.037	0.052	0.051
	<i>P</i> -value	0.1959	<0.0001	<0.0001	0.6977	0.0216	0.021
	N	117	2,050	2,167	111	1,937	2,054
Percent undeveloped lands	Rho	0.182	0.193	0.070	-0.147	-0.041	-0.053
	<i>P</i> -value	0.0492	<0.0001	0.0049	0.1245	0.0716	0.0167
	N	117	2,050	1,632	111	1,937	2,054
Population density, in persons/km ²	Rho	-0.122	-0.146	-0.141	-0.021	0.050	0.048
	<i>P</i> -value	0.191	<0.0001	<0.00001	0.8258	0.0267	0.0280
	N	117	2,050	2,167	111	1,937	2,054
Well construction properties							
Well depth, in ft	Rho	0.261	0.203	0.236	0.167	0.064	0.075
	<i>P</i> -value	0.0045	<0.0001	<0.0001	0.0781	0.0509	0.0152
	N	117	1,022	1,139	111	938	1,055
Water level, in ft	Rho	0.046	0.089	0.022	0.153	0.187	0.065
	<i>P</i> -value	0.6415	0.59	0.7957	0.1318	0.1765	0.417
	N	103	39	142	98	54	157
Casing length, in ft	Rho	0.313	0.092	0.172	0.027	0.081	0.082
	<i>P</i> -value	0.0006	0.0562	<0.0001	0.7829	0.1097	0.065
	N	116	428	544	110	393	509

Table 7–1. Rho and probability values from Spearman correlations of selected water-quality properties and constituents, land-use and human population data, well construction properties, and National Uranium Resource Evaluation Program streambed-sediment data, with fluoride and arsenic concentrations in water samples collected from domestic and public-supply wells in New England crystalline rock aquifers, 1995–2007.—Continued

[Spearman's coefficients (rho) are considered significantly correlated (in **bold**) when the *P*-values are less than or equal to 0.05; a negative rho value indicates an inverse relation. Rho, Spearman's rho coefficient; *P*-value, Spearman's probability value; N, number of water samples; <, less than; X, no data; --, *P*-value not calculated; na, did not perform correlation; persons/km², persons per square kilometer; Fe₂O₃, iron oxide; ppm, parts per million; USGS NAWQA, domestic bedrock wells sampled for the U.S. Geological Survey National Water-Quality Assessment Program in New England, New Jersey, and New York; USEPA SDWA, public-supply bedrock wells sampled for the U.S. Environmental Protection Agency Safe Drinking Water Act Program in New England]

Correlation variable	Spearman's correlation variables	Fluoride			Arsenic		
		USGS NAWQA	USEPA SDWA	All wells in study	USGS NAWQA	USEPA SDWA	All wells in study
National Uranium Resource Evaluation Program streambed-sediment chemistry ¹							
Arsenic, in ppm	Rho	-0.121	-0.177	-0.170	0.222	0.187	0.189
	<i>P</i> -value	0.263	<0.0001	<0.0001	0.038	<0.0001	<0.0001
	N	88	2,050	2,138	88	1,937	2,025
Calcium, in percent weight	Rho	-0.001	-0.046	-0.046	-0.075	-0.158	-0.158
	<i>P</i> -value	0.989	0.039	0.0320	0.489	<0.0001	<0.0001
	N	88	2,050	2,138	88	1,937	2,025
Fe ₂ O ₃ , in ppm	Rho	X	-0.201	-0.201	X	-0.183	-0.183
	<i>P</i> -value	X	<0.0001	<0.0001	X	<0.0001	<0.0001
	N	X	1,993	1,993	X	1,879	1,879
Uranium, in ppm	Rho	X	0.368	0.368	X	0.117	0.117
	<i>P</i> -value	X	<0.0001	<0.0001	X	<0.0001	<0.0001
	N	X	1,986	1,986	X	1,872	1,872
Miscellaneous data							
New England arsenic probability map (Ayotte and others, 2006)	Rho	na	na	na	0.522	0.404	0.408
	<i>P</i> -value	na	na	na	<0.0001	<0.0001	<0.0001
	N	na	na	na	88	1,937	1,952
Carbon dioxide gas	Rho	-0.344	X	-0.406	-0.235	X	-0.343
	<i>P</i> -value	0.0013	X	0.0026	0.0355	X	0.0159
	N	85	X	53	80	X	49

¹These variables are geochemical data for the United States based primarily on streambed sediments and analyzed using a consistent set of methods as part of the USGS National Geochemical Survey (U.S. Geological Survey Open-File Report 2004–1001). Most of the original samples were collected as part of the U.S. Geological Survey National Uranium Resource Evaluation Program from 1975 to 1983 and re-analyzed (accessed May 2005, at <http://tin.er.usgs.gov/geochem/doc/home.htm>).

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Table 8-1. Rho and probability values from Spearman correlations of selected water properties and constituents, land-use and human population data, well construction properties, National Uranium Resource Evaluation Program streambed-sediment data, and terrestrial gamma-ray emissions data with uranium concentrations and ²²²radon activities in water samples collected from domestic and public-supply wells in New England crystalline rock aquifers, 1995–2007.

[Spearman's coefficients (rho) are considered significant (in **bold**) when the *P*-values are equal to or less than 0.05; a negative rho value indicates an inverse relation. Rho, Spearman's rho coefficient; *P*-value, Spearman's probability value; N, number of samples; <, less than; X, no data; Fe₂O₃, iron oxide; ppm, parts per million; USGS NAWQA, domestic bedrock wells sampled for the U.S. Geological Survey National Water-Quality Assessment Program in New England, New Jersey, and New York; USEPA SDWA, public-supply bedrock wells sampled for the U.S. Environmental Protection Agency Safe Drinking Water Act Program in New England]

Correlation variable	Spearman's correlation variables	Uranium			²²² Radon		
		USGS NAWQA	USEPA SDWA	All wells in study	USGS NAWQA	USEPA SDWA	All wells in study
Physiochemical properties and water-quality constituents determined from water samples							
Bicarbonate	Rho	0.19	X	0.173	-0.132	X	-0.154
	<i>P</i> -value	0.0435	X	0.0632	0.1665	X	0.1075
	N	116	X	116	111	X	111
Calcium	Rho	0.254	X	0.254	-0.055	X	-0.055
	<i>P</i> -value	0.0057	X	0.0057	0.5618	X	0.5618
	N	117	X	117	112	X	112
Chloride	Rho	<0.01	0.115	0.142	-0.04	-0.067	-0.053
	<i>P</i> -value	0.9904	0.0302	0.002	0.6464	0.0942	0.151
	N	117	354	471	112	631	743
Dissolved oxygen	Rho	-0.05	X	-0.054	0.114	X	0.114
	<i>P</i> -value	0.5663	X	0.5663	0.2355	X	0.2354
	N	115	X	115	110	X	110
Fluoride	Rho	0.13	0.229	0.267	0.167	0.161	0.161
	<i>P</i> -value	0.1625	<0.0001	<0.0001	0.078	<0.0001	<0.0001
	N	117	354	471	112	677	789
Gross alpha	Rho	0.712	0.794	0.776	0.52	0.459	0.465
	<i>P</i> -value	<0.0001	<0.0001	<0.0001	0.00005	<0.0001	<0.0001
	N	57	399	456	55	559	615
Iron, total	Rho	-0.282	-0.209	-0.101	-0.131	0.011	-0.006
	<i>P</i> -value	0.0025	0.001	0.054	1682	0.7935	0.879
	N	117	246	363	112	555	667
Lead, total	Rho	0.257	X	0.257	0.378	X	0.378
	<i>P</i> -value	0.0163	X	0.0163	0.0005	X	0.0005
	N	87	X	87	82	X	82
Manganese	Rho	-0.159	-0.144	-0.054	-0.051	0.146	0.113
	<i>P</i> -value	0.0863	0.0175	0.287	0.593	0.0004	0.0029
	N	117	271	388	112	586	698
Nitrate	Rho	-0.015	0.090	0.047	-0.027	0.042	0.027
	<i>P</i> -value	0.868	0.063	0.2776	0.7804	0.2288	0.404
	N	117	430	547	112	821	933
pH	Rho	0.107	-0.004	0.048	-0.032	-0.169	-0.144
	<i>P</i> -value	0.2507	0.935	0.283	0.7401	<0.0001	<0.0001
	N	117	379	496	112	708	820

Table 8–1. Rho and probability values from Spearman correlations of selected water properties and constituents, land-use and human population data, well construction properties, National Uranium Resource Evaluation Program streambed-sediment data, and terrestrial gamma-ray emissions data with uranium concentrations and ²²²radon activities in water samples collected from domestic and public-supply wells in New England crystalline rock aquifers, 1995–2007.—Continued

[Spearman’s coefficients (rho) are considered significant (in **bold**) when the *P*-values are equal to or less than 0.05; a negative rho value indicates an inverse relation. Rho, Spearman’s rho coefficient; *P*-value, Spearman’s probability value; N, number of samples; <, less than; X, no data; Fe₂O₃, iron oxide; ppm, parts per million; USGS NAWQA, domestic bedrock wells sampled for the U.S. Geological Survey National Water-Quality Assessment Program in New England, New Jersey, and New York; USEPA SDWA, public-supply bedrock wells sampled for the U.S. Environmental Protection Agency Safe Drinking Water Act Program in New England]

Correlation variable	Spearman’s correlation variables	Uranium			²²² Radon		
		USGS NAWQA	USEPA SDWA	All wells in study	USGS NAWQA	USEPA SDWA	All wells in study
Physiochemical properties and water-quality constituents determined from water samples—Continued							
²²² Radon	Rho	0.582	0.537	0.553	1	1	1
	<i>P</i> -value	<0.0001	<0.0001	<0.0001	--	--	--
	N	112	305	417	112	831	943
²²⁶ Radium	Rho	0.244	X	0.244	0.227	X	0.219
	<i>P</i> -value	0.0645	X	0.0645	0.092	X	0.1053
	N	58	X	58	56	X	56
²²⁸ Radium	Rho	-0.194	X	-0.113	-0.03	X	-0.009
	<i>P</i> -value	0.1411	X	0.2953	0.8255	X	0.935
	N	58	X	58	57	X	86
Specific conductance	Rho	0.160	0.124	0.157	-0.107	-0.089	-0.093
	<i>P</i> -value	0.0853	0.033	0.0013	0.2608	0.0374	0.018
	N	117	295	412	112	537	649
Sulfate	Rho	-0.012	X	-0.012	-0.3	X	-0.301
	<i>P</i> -value	0.899	X	0.8990	0.0013	X	0.0010
	N	117	X	117	112	X	112
Total dissolved solids	Rho	0.143	X	0.143	-0.130	X	-0.130
	<i>P</i> -value	0.125	X	0.1250	0.1714	X	0.1714
	N	117	X	117	112	X	112
Uranium	Rho	1	1	1	0.582	0.537	0.553
	<i>P</i> -value	--	--	--	<0.0001	<0.0001	<0.0001
	N	117	439	556	112	305	417
Well construction properties							
Well depth, in ft	Rho	0.156	0.212	0.260	-0.045	0.091	-0.110
	<i>P</i> -value	0.0935	0.0009	<0.0001	0.6314	0.122	0.0084
	N	117	243	360	112	290	573
Water level, in ft	Rho	0.121	X	0.121	0.089	X	0.064
	<i>P</i> -value	0.2234	X	0.223	0.3847	X	0.531
	N	103	X	103	98	X	99
Casing length, in ft	Rho	-0.038	-0.247	-0.085	-0.005	0.033	-0.029
	<i>P</i> -value	0.6827	0.026	0.2345	0.9572	0.66	0.626
	N	116	81	197	111	176	287

Table 8–1. Rho and probability values from Spearman correlations of selected water properties and constituents, land-use and human population data, well construction properties, National Uranium Resource Evaluation Program streambed-sediment data, and terrestrial gamma-ray emissions data with uranium concentrations and ²²²Rn activities in water samples collected from domestic and public-supply wells in New England crystalline rock aquifers, 1995–2007.—Continued

[Spearman's coefficients (rho) are considered significant (in **bold**) when the *P*-values are equal to or less than 0.05; a negative rho value indicates an inverse relation. Rho, Spearman's rho coefficient; *P*-value, Spearman's probability value; N, number of samples; <, less than; X, no data; Fe₂O₃, iron oxide; ppm, parts per million; USGS NAWQA, domestic bedrock wells sampled for the U.S. Geological Survey National Water-Quality Assessment Program in New England, New Jersey, and New York; USEPA SDWA, public-supply bedrock wells sampled for the U.S. Environmental Protection Agency Safe Drinking Water Act Program in New England]

Correlation variable	Spearman's correlation variables	Uranium			²²² Rn		
		USGS NAWQA	USEPA SDWA	All wells in study	USGS NAWQA	USEPA SDWA	All wells in study
National Uranium Resource Evaluation Program streambed-sediment chemistry ¹							
Calcium, in percent weight	Rho	0.033	-0.194	-0.157	0.045	-0.083	-0.069
	<i>P</i> -value	0.7580	<0.0001	0.0003	0.6825	0.0164	0.0355
	N	88	439	527	86	831	917
Fe ₂ O ₃ , in ppm	Rho	X	-0.312	-0.312	X	-0.288	-0.288
	<i>P</i> -value	X	<0.0001	<0.0001	X	<0.0001	<0.0001
	N	X	363	363	X	822	822
Uranium, in ppm	Rho	0.156	0.205	0.205	0.11	0.166	0.165
	<i>P</i> -value	0.1564	<0.0001	<0.0001	0.3158	<0.0001	<0.0001
	N	88	439	439	84	819	819
Terrestrial gamma-ray emissions of near-surface sediment ²							
²³² Thorium, in ppm equivalent TH (eTH)	Rho	0.148	0.1	0.161	0.197	0.119	0.138
	<i>P</i> -value	0.1796	0.04	0.0002	0.075	0.0008	<0.0001
	N	88	415	528	82	788	896
²³⁸ Uranium, in ppm U	Rho	0.213	0.200	0.187	0.216	0.202	0.190
	<i>P</i> -value	0.052	<0.0001	<0.0001	0.052	<0.0001	<0.0001
	N	84	415	528	82	788	896

¹These variables consist of geochemical data for the United States based primarily on streambed sediments and analyzed for using a consistent set of methods as part of the USGS National Geochemical Survey (U.S. Geological Survey Open-File Report 2004–1001). Most of the original samples were collected as part of the U.S. Geological Survey National Uranium Resource Evaluation Program from 1975 to 1983 and re-analyzed (accessed May 2005 at <http://tin.er.usgs.gov/geochem/doc/home.htm>). Gamma-ray emissions data documented in Phillips and others, 1993.

²These variables consist of terrestrial gamma-ray emissions of near-surface sediments and are documented in Phillips and others, 1993.

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Table 9-1. Summary of pesticide concentrations in water samples collected for the U.S. Geological Survey National Water-Quality Assessment Program from domestic wells in New England crystalline rock aquifers in New England, New Jersey, and New York, 1995–2000.

Organic compound	USGS-NWIS parameter code	CAS Registry number ²	Predominant use group	LRL (µg/L)	Num-ber of samples	Number of samples with detections equal to or exceeding (µg/L):		Maximum detected concentration (µg/L)	Detection frequency, in percent, exceeding 0.001 µg/L	Human-health benchmark (µg/L)	
						0.001	0.01				
						Type					Value
alpha-HCH	34253	319-84-6	Insecticide	<0.002, <0.005	114	ND	ND	ND	0	na	na
Acetochlor	49260	34256-82-1	Herbicide	<0.002, <0.004	114	ND	ND	ND	0	na	na
Alachlor	46342	15972-60-8	Herbicide	<0.002	114	ND	ND	ND	0	MCL	2
Atrazine	39632	1912-24-9	Herbicide	<0.001, <0.004, <0.005, <0.007	114	9	1	0.016	8	MCL	3
Azinphos-methyl	82686	86-50-0	Insecticide	<0.001, <0.05	114	ND	ND	ND	0	na	na
Benfluralin	82673	1861-40-1	Herbicide	<0.002, <0.01	114	ND	ND	ND	0	HBSL	4
Butylate	04028	2008-41-5	Herbicide	<0.002	114	ND	ND	ND	0	HBSL	400
Carbaryl	82680	63-25-2	Insecticide	<0.003, <0.041, <0.008	114	ND	ND	ND	0	RSD5	400
Carbofuran	82674	1563-66-2	Herbicide	<0.003, <0.02	114	ND	ND	ND	0	MCL	40
Chlorpyrifos	38933	2921-88-2	Insecticide	<0.004, <0.005	114	ND	ND	ND	0	HBSL	2
Cyanazine	04041	21725-46-2	Herbicide	<0.004, <0.018	114	ND	ND	ND	0	HBSL	1
Dacthal (DCPA)	82682	1861-32-1	Herbicide	<0.002, <0.003	114	ND	ND	ND	0	HBSL	70
Deethylatrazine (CIAT)	04040	6190-65-4	Herbicide degradate	<0.002, <0.005, <0.006, <0.008	114	20	4	E.014	18	na	na
p,p'-DDE	34653	72-55-9	Insecticide degradate	<0.003, <0.006	114	4	ND	E.003	4	na	na
Diazinon	39572	333-41-5	Insecticide	<0.002, <0.005	114	ND	ND	ND	0	HBSL	1
Dieldrin	39381	60-57-1	Insecticide	<0.001, <0.005	114	1	ND	E.002	1	RSD5	0.02
2,6-Diethylamine	82660	579-66-8	Herbicide degradate	<0.002, <0.003	114	ND	ND	ND	0	na	na
Disulfoton	82677	298-04-4	Insecticide	<0.002	114	ND	ND	ND	0	HBSL	0.9
EPTC	82668	759-94-4	Herbicide	<0.002, <0.007	114	1	ND	E.001	1	HBSL	200
Ethalfuralin	82663	55283-68-6	Herbicide	<0.004, <0.009	114	ND	ND	ND	0	HBSL	30
Ethoprophos	82672	13194-48-4	Insecticide	<0.003, <0.005	114	ND	ND	ND	0	na	na
Fonofos	04095	944-22-9	Insecticide	<0.003	114	ND	ND	ND	0	HBSL	10
Lindane	39341	04095	Insecticide	<0.003, <0.004	114	ND	ND	ND	0	na	na
Linuron	82666	330-55-2	Herbicide	<0.002, <0.035	114	ND	ND	ND	0	na	na
Malathion	39532	121-75-5	Insecticide	<0.005, <0.027	114	ND	ND	ND	0	HBSL	50
Metolachlor	39415	51218-45-2	Herbicide	<0.002, <0.013	114	2	1	E.06	2	HBSL	700
Metribuzin	82630	21087-64-9	Herbicide	<0.004, <0.006	114	ND	ND	ND	0	HBSL	90
Molinate	82671	2212-67-1	Herbicide	<0.002, <0.004	114	ND	ND	ND	0	LHA	0.7
Napropamide	82684	15299-99-7	Herbicide	<0.003, <0.007	114	ND	ND	ND	0	na	na
1-Naphthol	49295	90-15-3	Insecticide degradate	<0.01	30	ND	ND	ND	0	na	na

[USGS-NWIS, U.S. Geological Survey National Water Information System; CAS Registry number; Chemical Abstract Registry number; ND, none detected; LRL, laboratory reporting level; E, estimated concentration; µg/L, micrograms per liter; na, not available; MCL, U.S. Environmental Protection Agency (USEPA) maximum contaminant level; RSD5, USEPA risk-specific dose at a risk factor of 10⁻⁵; LHA, USEPA lifetime health advisory; HBSL, Health based screening levels (HBSLs) are benchmark concentrations of contaminants in water that may, if exceeded, be of potential concern for human health. HBSLs are non-enforceable human-health benchmarks that were developed by the USGS in collaboration with USEPA and others using USEPA methodologies for establishing drinking-water guidelines (Toccalino and Norman, 2006; Toccalino and others, 2008)]

Table 9-1. Summary of pesticide concentrations in water samples collected for the U.S. Geological Survey National Water-Quality Assessment Program from domestic wells in New England crystalline rock aquifers in New England, New Jersey, and New York, 1995–2000.—Continued

[USGS-NWIS, U.S. Geological Survey National Water Information System; CAS Registry number; Chemical Abstract Registry number; ND, none detected; LRL, laboratory reporting level; E, estimated concentration; µg/L, micrograms per liter; na, not available; MCL, U.S. Environmental Protection Agency (USEPA) maximum contaminant level; RSD5, USEPA risk-specific dose at a risk factor of 10⁻⁵; LHA, USEPA lifetime health advisory; HBSL, Health based screening levels (HBSLs) are benchmark concentrations of contaminants in water that may, if exceeded, be of potential concern for human health. HBSLs are non-enforceable human-health benchmarks that were developed by the USGS in collaboration with USEPA and others using USEPA methodologies for establishing drinking-water guidelines (Toccalino and Norman, 2006; Toccalino and others, 2008)]

Organic compound	USGS-NWIS parameter code	CAS Registry number ²	Predominant use group	LRL (µg/L)	Num-ber of samples	Number of samples with detections equal to or exceeding (µg/L):		Maximum detected concentration (µg/L)	Detection frequency, in percent, exceeding 0.001 µg/L	Human-health benchmark (µg/L)
						0.001	0.01			
						Type	Value			
Parathion-ethyl	39542	56-38-2	Insecticide	<0.004, <0.007	114	ND	ND	ND	0	HBSL 0.02
Parathion-methyl	82667	298-00-0	Insecticide	<0.006	114	ND	ND	ND	0	HBSL 1
Pebulate	82669	1114-71-2	Herbicide	<0.002, <0.004	114	ND	ND	ND	0	HBSL 50
Pendimethalin	82683	40487-42-1	Herbicide	<0.1, <0.004	114	ND	ND	ND	0	HBSL 70
cis-Permethrin	82687	61949-76-6	Insecticide	<0.005, <0.006	114	ND	ND	ND	0	na
Phorate	82664	298-02-2	Insecticide	<0.002, <0.011	113	ND	ND	ND	0	HBSL 4
Prometon	04037	1610-18-0	Herbicide	<0.1, <0.2	114	3	3	0.021	3	na
Pronamide (Propyzamide)	82676	23950-58-5	Herbicide	<0.003, <0.004	114	1	ND	E.002	1	RSD5 20
Propachlor	04024	1918-16-7	Herbicide	<0.007, <0.01	114	ND	ND	ND	0	HBSL 1–100
Propanil	82679	709-98-8	Herbicide	<0.004, <0.007, <0.01	114	ND	ND	ND	0	LHA 6
Propargite	82685	2312-35-8	Insecticide	<0.01, <0.2	113	ND	ND	ND	0	na
Simazine	04035	122-34-9	herbicide	<0.005, <0.011	114	3	ND	E.004	3	MCL 4
Tebuthiuron	82670	34014-18-1	Herbicide	<0.01, <0.2	114	ND	ND	ND	0	LHA 500
Terbacil	82665	5902-51-2	Herbicide	<0.007, <0.034, <0.1	114	ND	ND	ND	0	HBSL 90
Terbufos	82675	13071-79-9	Insecticide	<0.01, <0.2	114	ND	ND	ND	0	LHA 0.4
Thiobencarb	82681	28249-77-6	Herbicide	<0.002, <0.005	114	ND	ND	ND	0	HBSL 70
Triallate	82678	2303-17-5	Herbicide	<0.001, <0.002	114	ND	ND	ND	0	HBSL 20
Trifluralin	82661	1582-09-8	Herbicide	<0.002, <0.009	114	ND	ND	ND	0	LHA 10

¹Most common laboratory reporting level.

²This report contains CAS Registry Numbers®, which is a Registered Trademark of the American Chemical Society. CAS recommends the verification of the CASRNs through CAS Client ServicesSM.

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Table 10-1. Summary of volatile organic compound concentrations in water samples collected for the U.S. Geological Survey National Water-Quality Assessment Program from domestic wells in New England crystalline rock aquifers in New England, New Jersey, and New York, 1995–2000.

[USGS NWIS, U.S. Geological Survey National Water Information System; CAS Registry number; Chemical Abstract Registry number; LRL, laboratory reporting level; ND, none detected; E, estimated concentration; THM, trihalomethane; na, not applicable; MCL, U.S. Environmental Protection Agency (USEPA) maximum contaminant level; NH MCL, New Hampshire maximum contaminant level; HBSL, Health based screening levels (HBSLs) are nonenforceable benchmark concentrations of contaminants in water that may, if exceeded, be of potential concern for human health. HBSLs were developed by the USGS in collaboration with USEPA and others using USEPA methodologies for establishing drinking-water guidelines (Toccalino and Norman, 2006; Toccalino and others, 2008)]

Organic compound	USGS NWIS parameter code	CAS Registry number ³	Predominant use group	LRL (µg/L)	Number of samples	Number of samples with detections equal to or exceeding (µg/L):		Maximum detected concentration (µg/L)	Detection frequency, in percent, above 0.02 µg/L ²	Human-health benchmark (µg/L)
						0.02	0.2			
						Type	Value			
Acetone	81552	67-64-1	Solvent	<4.9, ¹ <7	86	ND	ND	ND	0	HBSL 6,000
Acrylonitrile	34215	107-13-1	Organic synthesis	<1.2	86	ND	ND	ND	0	HBSL 0.06–6
Benzene	34030	71-43-2	Fuel hydrocarbon	<.03, <.2	115	2	ND	E.02	2.3	na
Bromobenzene	81555	460-00-4	Solvent	<.04, <.2	115	ND	ND	ND	0	na
Bromochloromethane	77297	74-97-5	Fire retardant	<.04, <.2	115	ND	ND	ND	0	HBSL 90
Bromodichloromethane	32101	75-27-4	THM	<.05, <.2	115	1	1	0.33	1.2	na
Bromoform	32104	75-25-2	THM	<.06, <.1, <.2	115	1	ND	E.04	1.2	na
Bromomethane	34413	74-83-9	Fumigant	<.15, <.2, <.26	115	ND	ND	ND	0	HBSL 100
Dibromochloromethane	32105	124-48-1	THM	<.18, <.2	115	ND	ND	ND	0	na
Dichlorodifluoromethane (CFC-12)	34668	75-71-8	Refrigerant	<.2, <.27	115	5	7	1.2	6	HBSL 1,000
Carbon disulfide	77041	75-15-0	Organic synthesis	<.07, <.08	115	10	ND	E.08	11.7	HBSL 700
Carbon tetrachloride	32102	56-23-5	Solvent	<.06, <.2	115	1	ND	E.06	1.2	na
Chlorobenzene	34301	108-86-1	Solvent	<.03, <.2	115	ND	ND	ND	0	na
Chloroethane	34311	75-00-3	Solvent	<.12, <.2	115	ND	ND	ND	0	na
Chloroform	32106	67-66-3	THM	<.02, <.05, <.2	115	28	17	2.82	32.9	na
Chloromethane (Methylchloride)	34418	74-87-3	Solvent	<.2, <.25, <.5	115	1	ND	E.02	1.2	HBSL 30
Dibromochloropropane (DBCP)	82625	96-12-8	Fumigant	<.21, <.1	115	ND	ND	ND	0	na
Dibromomethane	30217	74-95-3	Solvent	<.05, <.2	115	ND	ND	ND	0	na
Diethyl ether	81576	60-29-7	Solvent	<.17	86	ND	ND	ND	0	HBSL 1,000
Diisopropyl ether (DIPE)	81577	108-20-3	Fuel oxygenate	<.1	86	2	ND	0.16	2.3	na
Ethylbenzene	34371	100-41-4	Fuel hydrocarbon	<.03, <.2	115	ND	ND	ND	0	na
Ethylene dibromide (EDB)	77651	106-93-4	Fumigant	<.04, <.2	115	ND	ND	ND	0	MCL 50
Ethyl <i>tert</i> -butyl ether (ETBE)	50004	637-92-3	Fuel oxygenate	<.05	86	ND	ND	ND	0	na
Hexachlorobutadiene	39702	87-68-3	Organic synthesis	<.14, <.2	115	ND	ND	ND	0	HBSL 0.9–90
Hexachloroethane	34396	67-72-1	Solvent	<.19, <.36	86	ND	ND	ND	0	HBSL 0.7
Isopropylbenzene	77223	98-82-8	Fuel hydrocarbon	<.03, <.2	115	1	ND	E.03	1.2	HBSL 700
Methyl acrylate	49991	96-33-3	Organic synthesis	<.6, <.1.4	86	ND	ND	ND	0	na
Methyl acrylonitrile	81593	126-98-7	Organic synthesis	<.6	86	ND	ND	ND	0	HBSL 0.7
Methyl iodide (Iodomethane)	77424	74-88-4	Organic synthesis	<.08, <.12	86	ND	ND	ND	0	na
Methyl isobutyl ketone (MIBK)	78133	108-10-1	Solvent	<.37	86	ND	ND	ND	0	na

Table 10-1. Summary of volatile organic compound concentrations in water samples collected for the U.S. Geological Survey National Water-Quality Assessment Program from domestic wells in New England crystalline rock aquifers in New England, New Jersey, and New York, 1995–2000.—Continued

[USGS NWIS, U.S. Geological Survey National Water Information System; CAS Registry number, Chemical Abstract Registry number; LRL, laboratory reporting level; ND, none detected; E, estimated concentration; THM, trihalomethane; na, not applicable; MCL, U.S. Environmental Protection Agency (USEPA) maximum contaminant level; NH MCL, New Hampshire maximum contaminant level; HBSL, Health based screening levels (HBSLs) are nonenforceable benchmark concentrations of contaminants in water that may, if exceeded, be of potential concern for human health. HBSLs were developed by the USGS in collaboration with USEPA and others using USEPA methodologies for establishing drinking-water guidelines (Toccalino and Norman, 2006; Toccalino and others, 2008)]

Organic compound	USGS NWIS parameter code	CAS Registry number ³	Predominant use group	LRL (µg/L)	Number of samples	Number of samples with detections equal to or exceeding (µg/L):		Maximum detected concentration (µg/L)	Detection frequency, in percent above 0.02 µg/L ²	Human-health benchmark (µg/L)
						0.02	0.2			
						Type	Value			
Methyl methacrylate	81597	80-62-6	Organic synthesis	<35	86	ND	ND	ND	0	na
Methylene chloride	34423	75-09-2	Solvent	<16, <2, <38	115	ND	ND	ND	0	na
Methyl <i>tert</i> -butyl ether (MTBE)	78032	1634-04-4	Fuel oxygenate	<11, <17, <2	115	31	25	30.2	36	NH MCL 13
Naphthalene	34696	91-20-3	Fuel hydrocarbon	<2, <25	115	ND	ND	ND	0	HBSL 100
Perchloroethene (PCE)	34475	127-18-4	Solvent	<04, <1, <2	115	7	2	0.275	8.2	na
Styrene	77128	100-42-5	Fuel hydrocarbon	<04, <2	115	ND	ND	ND	0	na
Tetrahydrofuran	81607	109-99-9	Solvent	<1.15, <2.2	86	1	1	1.93	1.2	na
Toluene	34010	108-88-3	Fuel hydrocarbon	<05, <2	115	15	4	1.8	13	MCL 1,000
Trichloroethene ³ (TCE)	39180	79-01-6	Solvent	<04, <2	115	2	1	0.37	1.7	MCL 5
Trichlorofluoromethane (CFC-11)	34488	75-69-4	Refrigerant	<09, <2	115	1	1	1.06	1.2	HBSL 2,000
Trichlorotrifluoroethane (CFC-113)	77652	76-13-1	Refrigerant	<03, <06, <2	115	ND	ND	E.015	0	HBSL 200,000
Vinyl bromide	50002	593-60-2	Organic synthesis	<1	86	ND	ND	ND	0	na
Vinyl chloride	39175	75-01-4	Organic synthesis	<0.11, <2	115	ND	ND	ND	0	MCL 2
<i>cis</i> -1,2-Dichloroethene (<i>cis</i> -1,2-DCE)	77093	156-59-2	Solvent	<04, <2	115	1	ND	E.04	1.2	na
<i>cis</i> -1,3-Dichloropropene	34704	10061-01-5	Fumigant	<09, <2	115	ND	ND	ND	0	HBSL 0.3–30
<i>m</i> - and <i>p</i> -Xylene	85795	179601-23-1	Fuel hydrocarbon	<06	86	1	ND	0.02	1.2	na
<i>n</i> -Butylbenzene	77342	104-51-8	Fuel hydrocarbon	<19, <2	115	ND	ND	ND	0	na
<i>n</i> -Propylbenzene	77224	103-65-1	Solvent	<04, <2	115	1	ND	E.05	1.2	na
<i>o</i> -Xylene	77135	95-47-6	Fuel hydrocarbon	<04	86	1	ND	E.05	1.2	na
<i>sec</i> -Butylbenzene	77350	135-98-8	Fuel hydrocarbon	<03, <04, <2	115	ND	ND	ND	0	na
<i>tert</i> -Amyl methyl ether (TAME)	50005	994-05-8	Fuel oxygenate	<11	86	3	ND	0.11	3.5	na
<i>tert</i> -Butylbenzene	77353	98-06-6	Fuel hydrocarbon	<06, <1, <2	115	ND	ND	ND	0	na
<i>trans</i> -1,4-Dichloro-2-butene	73547	110-57-6	Organic synthesis	<7	86	ND	ND	ND	0	na
<i>trans</i> -1,2-Dichloroethene	34546	156-60-5	Solvent	<03, <2	115	ND	ND	ND	0	na
<i>trans</i> -1,2-Dichloropropene	34699	10061-02-6	Fumigant	<09, <13, <2	115	ND	ND	ND	0	na
1,1-Dichloroethane (1,1-DCA)	34496	75-34-3	Solvent	<04, <07, <2	115	5	1	0.24	5.8	na
1,1-Dichloropropene	77168	563-58-6	Organic synthesis	<03, <2	115	ND	ND	ND	0	na
1,1,1-Trichloroethane (TCA)	34506	71-55-6	Solvent	<03, <2	115	6	2	ND	7	MCL 200
1,1,2-Trichloroethane	34511	79-00-5	Solvent	<06, <2	115	ND	ND	ND	0	MCL 5
1,1,1,2-Tetrachloroethane	77562	630-20-6	Solvent	<03, <04, <2	115	ND	ND	ND	0	HBSL 70

Table 10-1. Summary of volatile organic compound concentrations in water samples collected for the U.S. Geological Survey National Water-Quality Assessment Program from domestic wells in New England crystalline rock aquifers in New England, New Jersey, and New York, 1995–2000.—Continued

Organic compound	USGS NWIS parameter code	CAS Registry number ³	Predominant use group	LRL (µg/L)	Num- ber of samples	Number of samples with detections equal to or exceeding (µg/L):		Maximum detected concen- tration (µg/L)	Detection frequency, in percent above 0.02 µg/L ²	Human-health benchmark (µg/L)		
						0.02	0.2				Type	Value
						1,1,2,2-Tetrachloroethane	34516				79-34-5	Solvent
1,2-Dichloroethane (1,2-DCA)	32103	107-06-2	Solvent	<.13, <.2	115	ND	ND	ND	0	na	na	
1,2-Dichlorobenzene	34536	95-50-1	Solvent	<.03, <.05, <.2	115	ND	ND	ND	0	na	na	
1,2-Dichloropropane	34541	78-87-5	Fumigant	<.03, <.07, <.2	115	ND	ND	ND	0	na	na	
1,2,3-Trichlorobenzene	77613	87-61-6	Organic synthesis	<.2, <.27	115	ND	ND	ND	0	na	na	
1,2,3-Trimethylbenzene	77221	526-73-8	Fuel hydrocarbon	<.1	86	1	ND	E.05	1.2	na	na	
1,2,3-Trichloropropane	77443	96-18-4	Fumigant	<.07, <.16, <.2	115	ND	ND	ND	0	HBSL	40	
1,2,3,4-Tetramethylbenzene	49999	488-23-3	Fuel hydrocarbon	<.23	86	ND	ND	ND	0	na	na	
1,2,3,5-Tetramethylbenzene	50000	527-53-7	Fuel hydrocarbon	<.2	86	ND	ND	ND	0	na	na	
1,2,4-Trimethylbenzene	77222	95-63-6	Fuel hydrocarbon	<.06, <.2	115	1	ND	0.13	1.2	na	na	
1,3-Dichlorobenzene	34566	541-73-1	Solvent	<.03, <.05, <.2	115	ND	ND	ND	0	HBSL	600	
1,3-Dichloropropane	77173	142-28-9	Fumigant	<.12, <.2	115	ND	ND	ND	0	na	na	
1,3,5-Trimethylbenzene	77226	108-67-8	Organic synthesis	<.04, <.2	115	1	ND	E.09	1.2	na	na	
1,4-Dichlorobenzene	34571	106-46-7	Fumigant	<.05, <.2	115	ND	ND	E.01	0	na	na	
1,1-Dichloroethene (1,1-DCE)	34501	75-35-4	Organic synthesis	<.04, <.2	115	ND	ND	ND	0	na	na	
1-Ethyl-2-methylbenzene (o-Ethyl toluene)	77220	611-14-3	Fuel hydrocarbon	<.06	86	1	ND	E.09	1.2	na	na	
2-Chlorotoluene	77275	95-49-8	Solvent	<.03, <.04, <.2	115	ND	ND	ND	0	HBSL	100	
2-Hexanone (<i>n</i> -Butyl methyl ketone)	77103	591-78-6	Solvent	<.7	86	ND	ND	ND	0	na	na	
2,2-Dichloropropane	77170	594-20-7	Fumigant	<.05, <.2	115	ND	ND	ND	0	na	na	
3-Chloro-1-propene	78109	107-05-1	Organic synthesis	<.07, <.08, <.2	115	ND	ND	ND	0	na	na	
4-Chlorotoluene	77277	106-43-4	Solvent	<.06, <.2	115	ND	ND	ND	0	HBSL	100	
4-Isopropyl-1-methylbenzene	77356	99-87-6	Fuel hydrocarbon	<.07, <.11, <.2	115	ND	ND	ND	0	na	na	

¹Most common laboratory reporting level.²Twenty-nine water samples were excluded from this calculation, as their volatile organic compound measurements were assessed at a higher LRL of 0.2 µg/L.³This report contains CAS Registry Numbers®, which is a Registered Trademark of the American Chemical Society. CAS recommends the verification of the CASRNs through CAS Client ServicesSM.**References Cited**

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Table 11–1. Rho and probability values from Spearman correlations of selected water-quality properties and constituents, land-use and human population data, and well construction properties with chloroform and methyl *tert*-butyl ether concentrations in water samples collected from domestic and public-supply wells in New England crystalline rock aquifers, 1995–2007.

[Spearman's coefficients (rho) are considered significant (in **bold**) when the *P*-values are less than or equal to 0.05; a negative rho value indicates an inverse relation. Rho, Spearman's rho coefficient; *P*-value, Spearman's probability value; MtBE, methyl *tert*-butyl ether; N, number of samples; <, less than; X, no data; km², square kilometer; USGS NAWQA, domestic bedrock wells sampled for the U.S. Geological Survey National Water-Quality Assessment Program in New England, New Jersey, and New York; USEPA SDWA, public-supply bedrock wells sampled for the U.S. Environmental Protection Agency Safe Drinking Water Act Program in New England]

Factor definition	Spearman's correlation variables	Chloroform		Methyl <i>tert</i> -butyl ether	
		USGS NAWQA	USGS NAWQA	USEPA SDWA	All wells in study
Physiochemical properties and water-quality constituents determined from water samples					
Bicarbonate	Rho	-0.27	0.107	X	0.107
	<i>P</i> -value	0.0030	0.0100	X	0.0100
	N	114	114	X	114
Calcium	Rho	0.060	0.429	X	0.429
	<i>P</i> -value	0.5166	<.0001	X	<.0001
	N	115	115	X	115
Chloride	Rho	0.29	0.419	0.265	0.257
	<i>P</i> -value	0.0020	<.0001	<.0001	<.0001
	N	115	115	476	591
Chloroform	Rho	1	0.364	X	0.236
	<i>P</i> -value	--	<.0001	X	0.0112
	N	115	115	X	115
Dissolved oxygen	Rho	0.345	0.166	X	0.246
	<i>P</i> -value	0.0002	0.0782	X	0.0086
	N	113	113	X	113
Iron, total	Rho	-0.2	-0.209	0.193	0.150
	<i>P</i> -value	0.0299	0.0250	<.0001	<.0001
	N	115	115	576	691
Manganese	Rho	0.15	-0.14	0.223	0.183
	<i>P</i> -value	0.1088	0.1355	<.0001	<.0001
	N	115	115	623	738
MtBE	Rho	0.364	1	1	1
	<i>P</i> -value	<.0001	--	--	--
	N	115	115	1,184	1,299
Nitrate	Rho	0.525	0.488	0.001	0.024
	<i>P</i> -value	<.0001	<.0001	0.97	0.4013
	N	115	115	1,131	1,246
pH	Rho	-0.42	-0.261	-0.07	-0.092
	<i>P</i> -value	<.0001	0.0048	0.153	0.033
	N	115	115	422	537
Specific conductance	Rho	0.061	0.370	0.323	0.315
	<i>P</i> -value	0.5144	<.0001	<.0001	<.0001
	N	115	115	172	287

Table 11–1. Rho and probability values from Spearman correlations of selected water-quality properties and constituents, land-use and human population data, and well construction properties with chloroform and methyl *tert*-butyl ether concentrations in water samples collected from domestic and public-supply wells in New England crystalline rock aquifers, 1995–2007.—Continued

[Spearman’s coefficients (rho) are considered significant (in **bold**) when the *P*-values are less than or equal to 0.05; a negative rho value indicates an inverse relation. Rho, Spearman’s rho coefficient; *P*-value, Spearman’s probability value; *MtBE*, methyl *tert*-butyl ether; N, number of samples; <, less than; X, no data; km², square kilometer; USGS NAWQA, domestic bedrock wells sampled for the U.S. Geological Survey National Water-Quality Assessment Program in New England, New Jersey, and New York; USEPA SDWA, public-supply bedrock wells sampled for the U.S. Environmental Protection Agency Safe Drinking Water Act Program in New England]

Factor definition	Spearman’s correlation variables	Chloroform		Methyl <i>tert</i> -butyl ether	
		USGS NAWQA	USGS NAWQA	USEPA SDWA	All wells in study
Physiochemical properties and water-quality constituents determined from water samples—Continued					
Sodium	Rho	-0.005	0.221	0.166	0.153
	<i>P</i> -value	0.9508	0.0177	<0.0001	<0.0001
	N	115	115	819	934
Sulfate	Rho	0.13	0.357	X	0.357
	<i>P</i> -value	0.1582	0.0001	X	0.0001
	N	115	115	X	115
Total dissolved solids	Rho	0.122	0.397	X	0.397
	<i>P</i> -value	0.1956	<.0001	X	<.0001
	N	115	115	X	115
Apparent residence time of water	Rho	0.067	-0.29	X	-0.29
	<i>P</i> -value	0.6318	0.0365	X	0.0365
	N	54	54	X	54
Land use and population density within 500-meter radius of sampled wells					
Percent agricultural lands	Rho	-0.308	-0.104	-0.059	-0.055
	<i>P</i> -value	0.0008	0.2695	0.0429	0.0495
	N	115	115	1,184	1,299
Percent developed lands	Rho	0.247	0.259	0.160	0.155
	<i>P</i> -value	0.0078	0.0051	<0.0001	<0.0001
	N	115	115	1,184	1,299
Percent undeveloped lands	Rho	-0.12	-0.211	-0.074	-0.079
	<i>P</i> -value	0.2030	0.0235	0.011	0.0044
	N	115	115	1,184	1,299
Population density, in persons/km ²	Rho	0.406	0.242	0.197	0.187
	<i>P</i> -value	<.0001	0.0093	<0.0001	<0.0001
	N	115	115	1,184	1,299
Well construction properties					
Well depth, in ft	Rho	-0.24	0.023	0.038	0.05
	<i>P</i> -value	0.0100	0.8108	0.38	0.2023
	N	115	115	548	663
Water level, in ft	Rho	0.185	0.156	X	0.156
	<i>P</i> -value	0.0636	0.1193	X	0.1193
	N	101	101	X	101
Casing length, in ft	Rho	0.153	-0.067	-0.023	-0.009
	<i>P</i> -value	0.1035	0.4811	0.727	0.8615
	N	114	114	234	348

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