

Shallow Ground-Water Quality in the Boston, Massachusetts Metropolitan Area

—By Sarah M. Flanagan, Denise L. Montgomery, and Joseph D. Ayotte

Analyses of water samples collected from 29 wells across the Boston metropolitan area indicate that shallow ground water in recently urbanized settings often contains trace amounts of nutrients, fuel, and industrial-based organic compounds. Most of the samples that contained detectable amounts of organic compounds also had elevated levels of iron and total dissolved solids. Nitrate was detected in 83 percent of the samples, but the U.S. Environmental Protection Agency's (USEPA) drinking-water standard of 10 milligrams per liter nitrate was exceeded in just one sample. Low levels of volatile organic compounds (VOCs) were detected in 76 percent of the samples, with as many as 13 different VOCs detected in a single sample. The concentration of methyl-tert-butyl ether (MTBE) in one sample was 267 micrograms per liter, which exceeds the Massachusetts Department of Environmental Protection drinking-water guideline of 70 micrograms per liter. Chloroform and MTBE were the two most frequently detected VOCs. MTBE was detected at the same frequency in ground water in the Boston metropolitan area as in other urban areas of New England. Chloroform is detected at higher frequency in old, densely populated areas in New England than in more recently developed, less densely populated areas. Pesticide detections were few, but only at trace concentrations, and none of the concentrations exceeded any drinking-water standard.

INTRODUCTION

The effect of urbanization on water quality is an important issue to many water-resource managers and is a major focus of the U.S. Geological Survey's (USGS) National Water-Quality Assessment Program (NAWQA) (Ayotte and Robinson, 1997). As part of the NAWQA program, New England Coastal Basins (NECB) study, the USGS installed and sampled 29 monitoring wells in unconsolidated surficial aquifers in suburban parts of the Boston, Mass. metropolitan area (figs. 1 and 2) to determine the quality of shallow ground water in recently urbanized areas.

Description of Study Area

The Boston metropolitan area (BMA), which includes the city of Boston and the surrounding smaller cities and suburban communities, covers 4,800 square miles (mi²) in eastern Massachusetts and southern New Hampshire (fig. 2). The study area had an estimated population of more than 5.4 million in 1998. The older, more densely populated areas in and near Boston grew at a rate of 5 percent between 1970 and 1998, while the outlying suburban areas grew at a rate of almost 20 percent over the same period (Dr. Stephen Coelen, Massachusetts Institute of Social and Economic Research, written commun., 1999).

Unconsolidated surficial aquifers cover 47 percent of the BMA and are an important source of public-supplied water to local municipalities (fig. 2). These aquifers consist of layered sediments ranging from clay to coarse gravel and cobbles, are generally less than 100 ft thick, highly permeable, and capable of yielding large amounts of water to wells for public supply. The water table ranges from 0 to 30 ft below land surface (Flanagan and others, 1999). These characteristics make the water in these aquifers highly vulnerable to contamination by human activities.



(Photograph by Joseph R. Melanson, Aero Photo, Inc.)

Aerial view of Boston metropolitan area from Newton, Massachusetts, eastward to Boston.

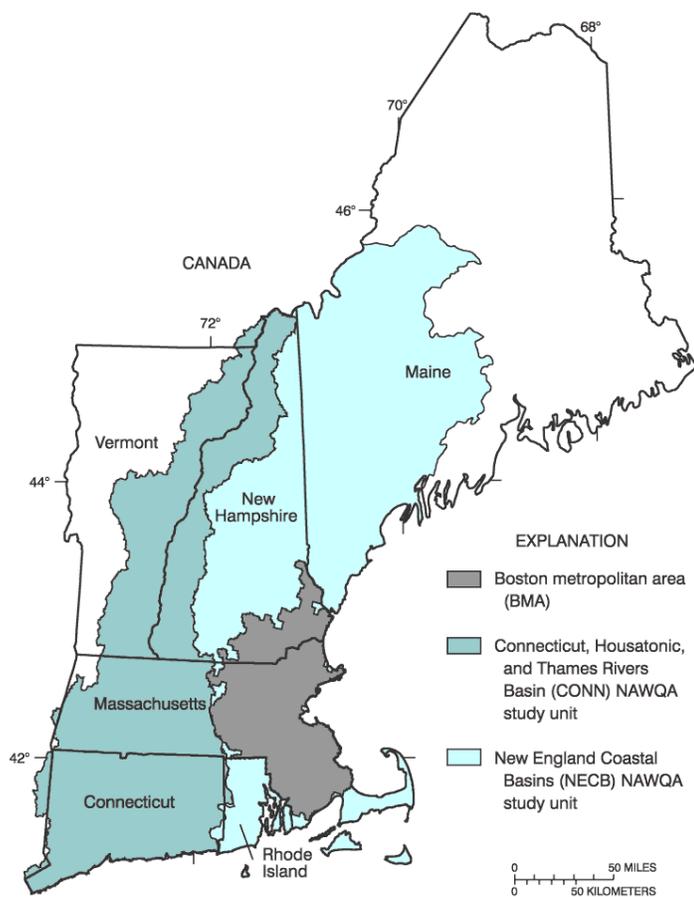


Figure 1. Location of the Boston metropolitan study area (BMA) and its relation to the NAWQA Connecticut, Housatonic, and Thames River Basins (CONN), and the New England Coastal Basins (NECB) study areas.

Site Selection, Well Installation, and Monitoring

The 29 sampling sites were selected in residential and commercial areas developed between 1970 and 1990 and underlain by unconsolidated surficial deposits (fig. 2). The older, densely populated areas of Boston and its neighboring cities and towns were excluded because urban land uses in these areas pre-date 1970. Industrial areas were not sampled because these areas contain numerous point sources of contaminants and known contaminated sites (Flanagan and others, 1999). Finally, areas developed after 1990 were not included in this investigation because of the inadequate time necessary for new construction to affect ground-water quality (Squillace and Price, 1996).

Sites were randomly chosen on the basis of the above criteria using a computer program developed for the NAWQA program (Scott, 1990). Final well locations were based on the randomly chosen sites and landowner permissions. The USGS wells were installed during 1998-99 according to NAWQA protocols (Lapham and others, 1995). Seventy-nine percent of the wells were installed in residential areas. The remaining wells were in areas that included a mix of light commercial, residential, and undeveloped land.



Drilling a shallow well in an urban area in the Boston metropolitan study area.

Water samples were collected from these wells during the summer of 1999, and analyzed for major ions, nutrients, trace elements, radon gas, radionuclides, chlorofluorocarbons, 48 different pesticide compounds, and 86 different volatile organic compounds (VOCs) (Coakley and others, 1999; and Socolow and others, 2000). Sampling protocols were followed to obtain and evaluate accurate water-quality data (Koterba and others, 1995). Water samples were processed in the field and then shipped to the USGS National Water Quality Laboratory (NWQL) for analysis.

Acknowledgments

The authors thank the many home- and small-business owners, and State and local officials in the Boston metropolitan area who allowed USGS personnel access to their properties for the purpose of installing and sampling monitoring wells. Additional appreciation is extended to Lora Barlow and Eric Ferguson of the USGS for their assistance in finding drill sites and installing wells.

NATURAL CHEMISTRY OF SHALLOW GROUND WATER IN UNCONSOLIDATED, SURFICIAL AQUIFERS

Shallow ground water in the BMA is young (recently recharged) and is not fully chemically evolved because the predominant minerals in the aquifer sediments, quartz and feldspar, are not easily dissolved. Typical characteristics include relatively high concentrations of dissolved oxygen (median of 3.7 mg/L), low pH (less than 6.5), low specific conductance (median of 290 $\mu\text{s}/\text{cm}$) and low concentrations of dissolved ions (median of 166 mg/L) (table 1). These characteristics reflect the chemistry of precipitation, which is the dominant source of recharge to shallow ground water. In general, concentrations of major ions and other inorganic compounds were comparable to these reported in previous investigations of water quality in surficial aquifers in eastern Massachusetts (Klinger, 1996, and Lapham, 1988).

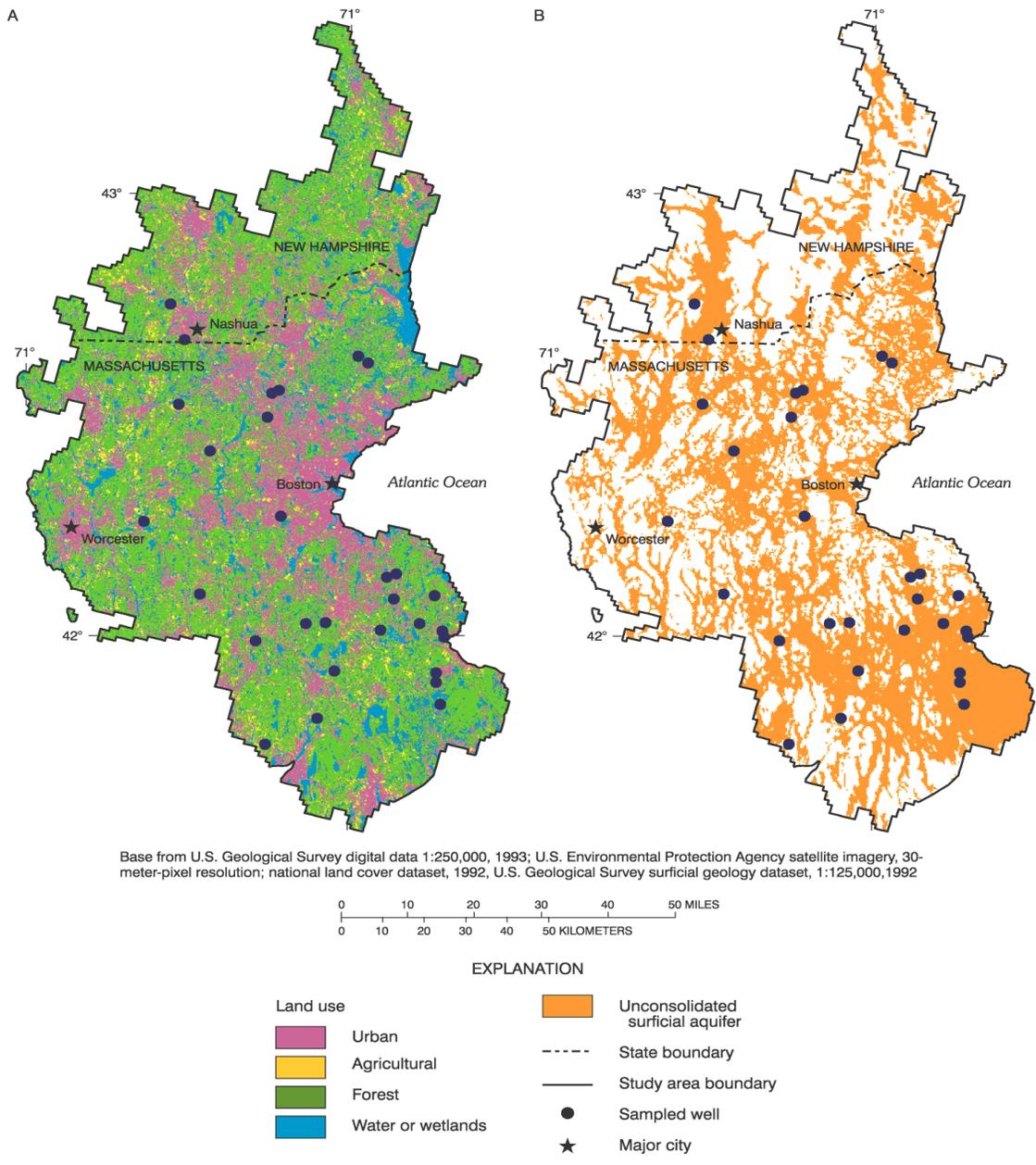


Figure 2. Land uses (A), unconsolidated surficial aquifers (B), and sampled wells in the Boston metropolitan area.

COMMON SOURCES OF CONTAMINANTS TO SHALLOW GROUND WATER

Land-use practices in residential and commercial areas include the use and disposal of fertilizers, treated wastewater, pesticides, solvents, and other chemicals. Elevated nutrient (nitrogen and phosphorus) concentrations in ground water (more than 3 mg/L for nitrogen) usually are the result of human activities. Common sources of nutrients in urban areas are septic system and sanitary-sewer effluents, domestic animal wastes, infiltration of runoff from streets and parking lots, home and farm usage of fertilizers, and atmospheric deposition. Nitrogen is present in water primarily as the nitrate (NO_3^-) anion, but under reducing conditions, can be present as the ammonium (NH_4^+) cation. Phosphorus is present in water primarily as the phosphate (PO_4^{3-}) anion. Nitrate and phosphate are an environmental concern as potential sources of nutrient enrichment in rivers, lakes, wetlands, and coastal embayments. The USEPA's Maximum Contaminant Level (MCL) drinking-water standard for nitrate is 10 mg/L (U.S. Environmental Protection Agency, 2000).

Historically, pesticides, which include insecticides, herbicides, and fungicides, have been used in agricultural areas to control weeds and insects. Pesticide usage in urban areas, once limited primarily to home insect and weed control, has increased as a result of the growth of the commercial lawn care business and the development and use of new herbicides and insecticides. In the BMA, pesticides are applied to lawns, gardens, small farms, golf courses, business parks, and cemeteries. Herbicides are used to control vegetation along roadways, fence lines, and utility rights-of-way. These uses are potential sources of pesticide contamination to ground water.

VOCs are components of petroleum-based products, such as solvents, degreasers, refrigerants, and fuels. Direct industrial and wastewater discharges, exhaust from fuel combustion, accidental



Hydrologist collecting a water sample.

fuel and oil spills, storm-water runoff, and chlorinated public-drinking-water supplies are potential sources of VOCs in ground water. Relations between land use and the detection of specific VOCs in ground water often are impossible to determine because of the varied and widespread uses of VOCs and atmospheric deposition of these compounds from vehicle and industrial emissions. VOC contamination of drinking-water supplies is a human health concern because many are toxic and are known or suspected human carcinogens (U.S. Environmental Protection Agency, 2000).

GROUND-WATER QUALITY IN THE BOSTON METROPOLITAN AREA

Analyses of water samples from the 29 urban wells showed that shallow ground water in recently urbanized settings in the BMA commonly contains trace amounts of nutrients, fuel, and industrial-based organic compounds. Most of the samples that contained detectable amounts of organic compounds also had excessive levels of inorganic constituents such as iron and total dissolved solids.

Nutrients

Nitrite plus nitrate, reported as nitrogen (N), was detected in 83 percent of the 29 ground-water samples (fig. 3). All detections of nitrite were less than the reporting level of 0.01 mg/L, indicating that nitrate concentrations and nitrate plus nitrite concentrations were the same. Nitrate concentrations in the water samples ranged from less than 0.05 to 10.9 mg/L. One sample had a nitrate concentration (10.9 mg/L), which exceeds the MCL for nitrate of 10 mg/L (U.S. Environmental Protection Agency, 2000). Ammonium concentrations exceeded 3 mg/L as N in two samples (fig. 3). These two samples also had excessive concentrations of methane gas (more than 3.2 mg/L), ferrous and total iron (more than 3.3 mg/L), and low concentrations of dissolved oxygen (less than 1.8 mg/L) (table 1), indicating a chemically reduced ground-water environment. Phosphorus was detected in 62 percent of the water samples, but at concentrations less than 0.02 mg/L (table 1; fig. 3).

Pesticides

Pesticides were detected at trace concentrations in a few water samples (table 2). Three of 48 pesticides were detected: atrazine, deethyl atrazine, and diazinon. Atrazine, a commonly used herbicide, was detected in four samples at concentrations ranging from 0.005 to 0.011 $\mu\text{g/L}$ —well below the USEPA's MCL of 3 $\mu\text{g/L}$ (U.S. Environmental Protection Agency, 2000). Deethyl atrazine, a break-down product of atrazine, was detected in four samples, at estimated concentrations below 0.01 $\mu\text{g/L}$. Diazinon was detected in two samples.

Table 1. Statistical summary of selected water-quality data at 29 shallow wells in surficial aquifers in the Boston metropolitan area

[MCL, Maximum Contaminate Level; SDWR, Secondary Drinking Water Regulation; mg/L, milligrams per liter (parts per million); --, no value; <, less than the laboratory reporting level; >, greater than; ntu, nephelometric turbidity units; E, estimated value; µg/L, micrograms per liter (parts per billion); Some of the values in the maximum column correspond to monitoring wells with degraded water quality.]

Constituent (percent detected)	Laboratory reporting level	Minimum	Median	Maximum	MCL ¹	SDWR ²
Field parameters						
Alkalinity, filtered, as calcium carbonate (CaCO ₃), in mg/L (100)	--	1	10	106	--	--
Dissolved oxygen (100)	--	0.2	3.7	13	--	--
Specific conductance (100)	--	88	290	2,630	--	--
pH (100)	--	4.5	5.5	6.5	--	6.5 - 8.5
Iron, ferrous, in mg/L (66)	0.01	<0.01	.01	>3.3	--	--
Sulfide, as S, in mg/L	0.001	<0.001	0.004	0.2	--	--
Turbidity (ntu) (100)	--	0.04	2.5	970	--	--
Dissolved gases						
Carbon dioxide, as CO ₂ , in mg/L (100)	--	21	52	390	--	--
Methane, as CH ₄ , in mg/L	--	0	0	9	--	--
Nitrogen, as N ₂ , in mg/L (100)	--	9.5	21	25	--	--
Argon, as A, in mg/L	--	0.5	0.7	0.8	--	--
Major ions						
Bromide, in mg/L (97)	0.01	<0.01	0.04	0.5	--	--
Calcium, in mg/L (100)	0.02	1.3	12.4	70.3	--	--
Chloride, in mg/L (97)	0.1	10	60.2	728	--	250
Fluoride, in mg/L (7)	0.1	< 0.1	0.1	0.4	4	2
Iron, total, in µg/L(50)	10	E 5	< 10	38,000	--	300
Magnesium, in mg/L (100)	0.12	1.07	2.7	20	--	--
Manganese, in µg/L (100)	2.2	1.4	63.4	28,200	--	50
Nitrate, as N, in mg/L (83)	0.05	< 0.05	1.1	10.9	10	--
Ammonium, as N, in mg/L (17)	0.02	< 0.02	< 0.02	3.7	--	--
Phosphorus, in mg/L (62)	0.004	<0.004	0.005	0.02	--	--
Potassium, in mg/L (100)	0.24	0.68	1.7	9.0	--	--
Silica, in mg/L (100)	0.09	6.5	11	19	--	--
Sodium, in mg/L (100)	0.09	5.0	28.8	377	--	--
Sulfate, in mg/L (97)	0.01	< 0.01	14	75	--	250
Total dissolved solids, in mg/L (100)	--	52	166	1,460	--	500
Trace elements						
Aluminum, in µg/L (97)	1	< 1	24	819	--	--
Arsenic, in µg/L (7)	1	< 1	< 1	2	³ 10	--
Barium, in µg/L (100)	1	8	39	214	2,000	--
Cobalt, in µg/L (28)	1	< 1	< 1	95	--	--
Copper, in µg/L (24)	1	< 1	< 1	17	--	--
Strontium, in µg/L (100)	0.2	13	96	290	--	--

¹Maximum Contaminant Level. The highest level of a contaminant that is allowed in drinking water. MCLs are enforceable standards set by the U.S. Environmental Protection Agency (2000).

²Secondary Drinking Water Regulations are non-enforceable federal guidelines, regarding cosmetic effects or aesthetic effects of drinking water established by the U.S. Environmental Protection Agency (2000).

³The U.S. Environmental Protection Agency recently (January 2001) passed a final ruling, which lowers the drinking-water MCL for arsenic to be phased in over 5 years (U.S. Environmental Protection Agency, 2001).

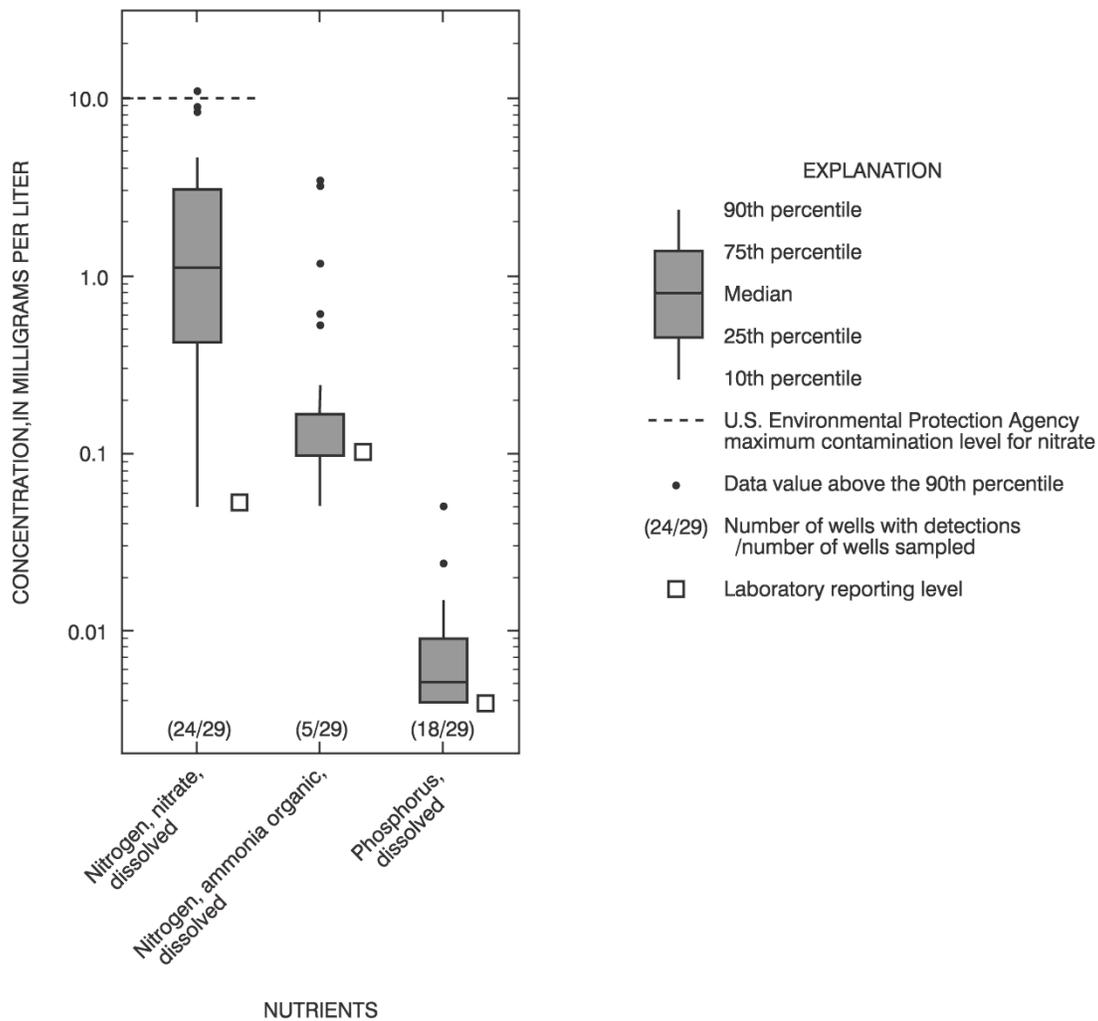


Figure 3. Distributions of concentrations of selected nutrients in water samples from 29 shallow wells in the Boston metropolitan area. [Includes estimated concentration values for organic nitrogen ammonia.]

Table 2. Statistical summary of pesticide compounds detected in water samples from 29 shallow wells in the surficial aquifers in the Boston metropolitan area

[µg/L, micrograms per liter; MCL, Maximum Contaminant Level established by the U.S. Environmental Protection Agency (2000); E, estimated concentration; --, no data; Concentration values are written as reported by the National Water Quality Laboratory without rounding.]

Pesticide compound name	Number of samples	Number of detections	Laboratory reporting level, in µg/L	Minimum concentration, in µg/L	Maximum concentration, in µg/L	MCL, in µg/L
Atrazine	29	4	0.001	0.0049	0.0109	3
Deethyl atrazine	29	4	.002	E .0012	E .0099	--
Diazinon	29	2	.002	E .0018	.0041	--

WHAT IS A DETECTION?

In this report, 'detection' refers to a given compound being identified in a water sample. Until recently (2000), results of laboratory analyses by USGS were reported either as quantified above or below a Laboratory Reporting Level (LRL). Recent improvements in laboratory analytical techniques, however, enable the chemist to report an estimated concentration when a compound meets all identification criteria, but the concentration value is less than the LRL (Conner and others, 1998; Childress and others, 1999). In rare instances, a compound is reported at an estimated concentration above the standard LRL because of laboratory uncertainty about the actual concentration measured. These problems are usually related to the performance of the laboratory instruments or interference created by other compounds in the water sample.

Volatile Organic Compounds (VOCs)

VOCs were detected in water samples from 76 percent of the 29 wells, with as many as 13 different VOCs detected in a single sample. Thirty-six of 86 VOCs were detected (fig. 4). Many of these VOC detections were at estimated concentrations below the reporting level for these compounds (see box). The most frequently detected VOC, chloroform, was present in 69 percent of the samples. Potential sources of chloroform to ground water in urban areas include domestic use of solvents and cleaning agents,

leakage from water mains, or lawn irrigation with chlorinated municipal drinking water (Grady, 1994). None of the water samples exceeded the Massachusetts Department of Environmental Protection (1990) recommended drinking-water guideline of 5 µg/L for chloroform. Methyl-*tert*-butyl ether (MTBE) was the second most frequently detected VOC and was present in 52 percent of the samples. Since the late 1970's, MTBE has been added to gasoline either seasonally or year round in many parts of the United States, including New England, to increase the combustibility of gasoline in automobiles, and thus to reduce carbon

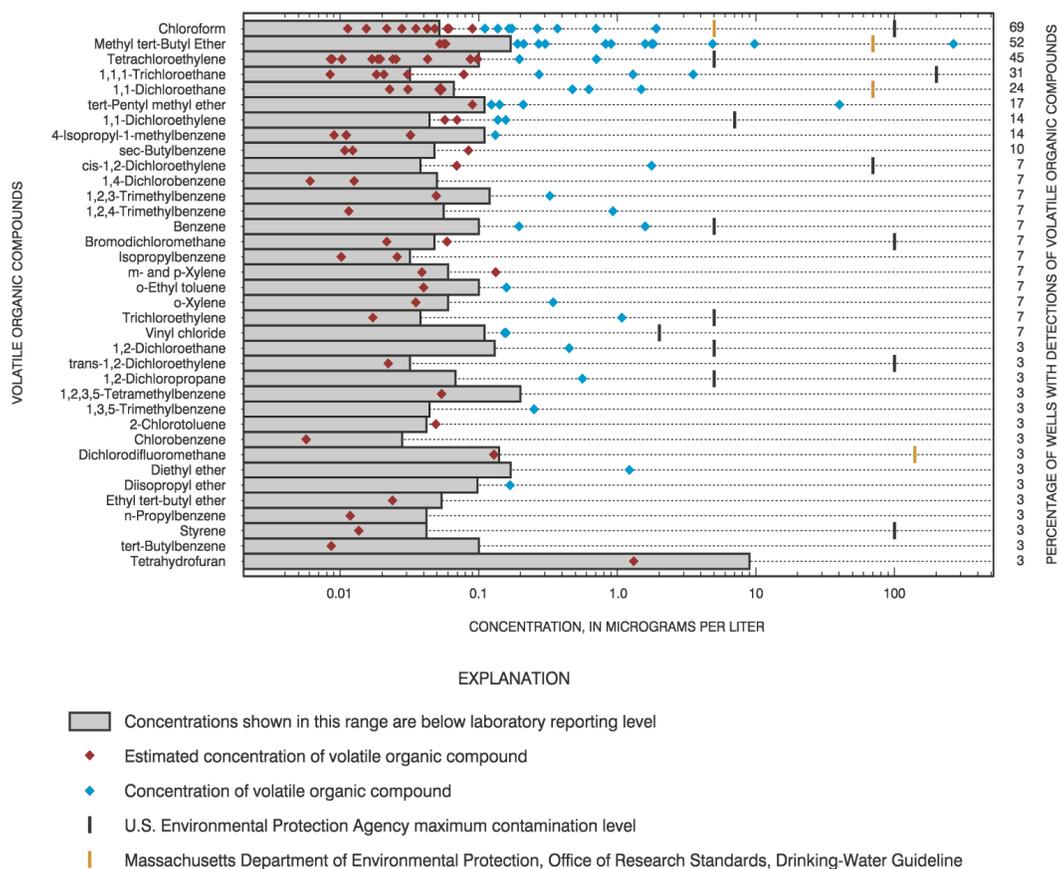
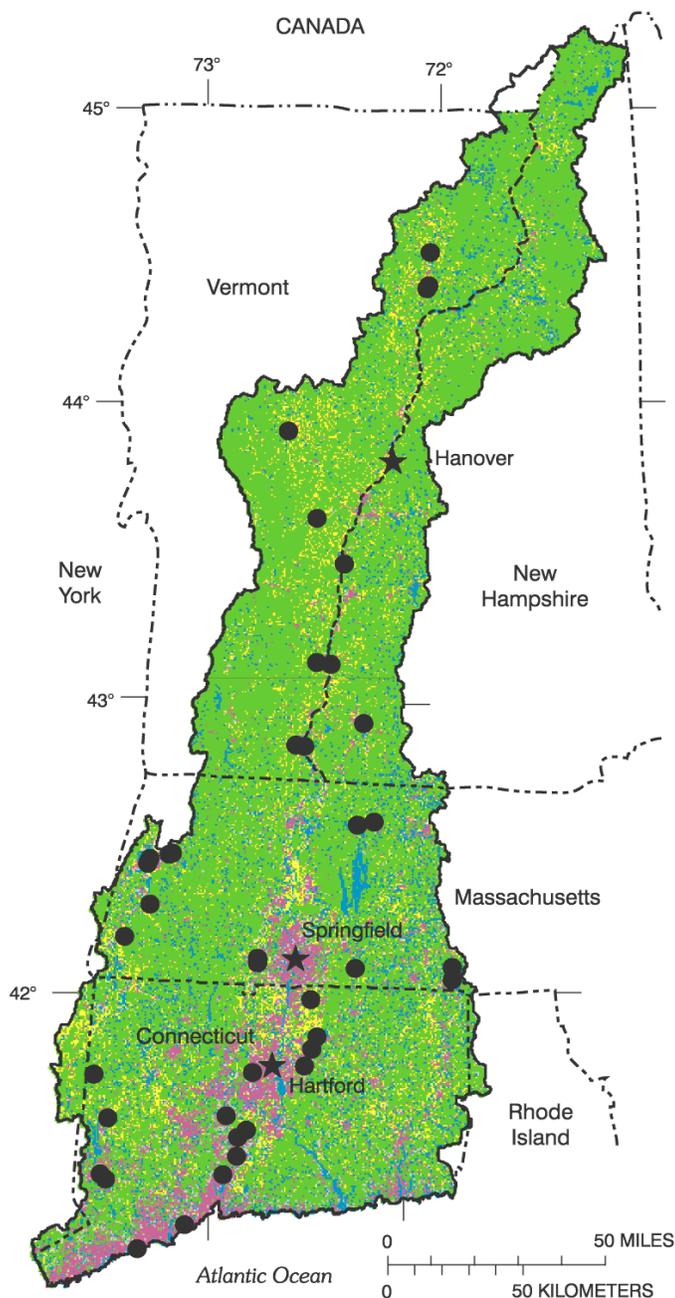


Figure 4. Concentrations of volatile organic compounds (VOCs) detected in the 29 water samples from shallow wells in the Boston metropolitan area and percentage of samples in which each VOC was detected.



Base from U.S. Geological Survey digital data 1:250,000, 1993; U.S. Environmental Protection Agency satellite imagery, 30-meter-pixel resolution; national land cover dataset, 1992

EXPLANATION

- | | | |
|--|-------|---------------------|
| Land use | ----- | State boundary |
| Urban | ————— | Study area boundary |
| Agricultural | ● | Sampled well |
| Forest | ★ | Major city |
| Water or wetlands | | |

Figure 5. Land uses and sampled wells in the Connecticut, Housatonic, and Thames River Basins (CONN) NAWQA study unit.

monoxide emissions in the air (U.S. Environmental Protection Agency, 1997). One water sample had an MTBE concentration of 267 µg/L, which exceeded the Massachusetts Department of Environmental Protection's (2000) recommended drinking-water guideline of 70 µg/L. Other samples had MTBE concentrations less than 10 µg/L, and in 48 percent of the samples no MTBE was detected.

COMPARISON OF SHALLOW GROUND-WATER QUALITY IN THE BOSTON METROPOLITAN AREA TO NEARBY URBAN AREAS

A similar study of shallow ground-water quality was previously done in an adjacent basin (fig. 5), thus providing a basis against which to compare data from the BMA study. During 1993-95, 40 water samples were collected from similarly constructed shallow monitoring wells in urban areas in the Connecticut, Housatonic, and Thames River Basins (CONN) NAWQA study unit (Grady and Mullaney, 1998) (figs. 1 and 5). In that study, many wells sampled were in urban areas developed before 1970, compared to wells sampled in the more recently developed areas in the BMA study. The Wilcoxon rank-sum test, also known as the Mann-Whitney test, was used to compare differences in population density and water quality data between the two study units. The median population density near the wells in the CONN study (683 persons per square kilometer, or p/km²) was significantly higher (p = less than 0.01) than the population density near the wells in the BMA study (261 p/km²).

All VOC analytical results for the 40 wells in the CONN study area were censored by the NWQL to a reporting level of 0.2 µg/L. Since then, analytical methods have improved, resulting in differences in laboratory reporting levels between the two studies. To make detection rates comparable, the VOC analytical results for the 29 wells in the BMA study area also were censored to 0.2 µg/L in this section of the report. This resulted in significantly reducing the rates of detection for many of the VOCs in the BMA samples. For example, chloroform was detected in 69 percent of the BMA samples when including concentrations that ranged from 0.011 to 1.92 µg/L, but the detection rate was reduced to 13 percent when the samples were censored at 0.2 µg/L. Laboratory reporting levels for nutrients and pesticides were the same for the two studies.

The median concentrations of nitrate in waters from the two study areas were not statistically different (p = 0.60) (fig. 6). Grady (1994) noted that multiple factors related to nitrogen found in ground water in urban settings, such as leakage from sewer lines and heavy use of lawn fertilizer in residential areas.

The most frequently detected VOC in both study areas at the censored level of 0.2 µg/L was MTBE (fig. 7). Despite the difference in population density between the two study areas, the median concentrations of MTBE in samples were not statistically different (p = 0.32) (fig. 8). The detection rates for MTBE were nearly identical (38 and 40 percent, respectively) in the BMA and CONN studies (fig. 7). The similarity in concentrations and detection rates of MTBE reflects that MTBE has been widely used throughout New England.

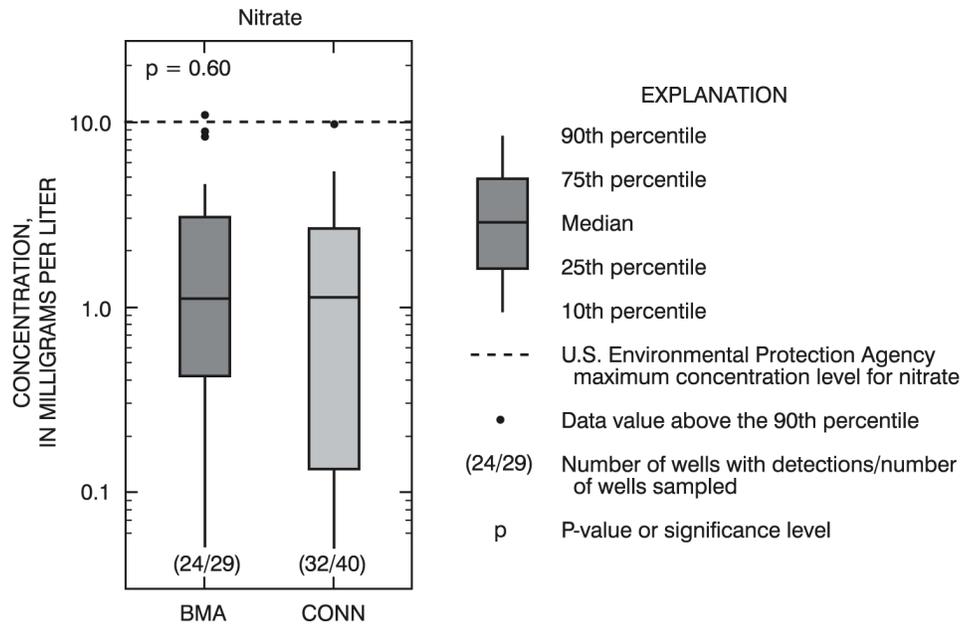


Figure 6. Distribution of nitrate concentrations in water samples from 29 shallow wells in the Boston metropolitan area (BMA) and 40 shallow wells in the Connecticut, Housatonic, and Thames River Basins (CONN) NAWQA study unit. A p-value above 0.05 indicates no statistical difference between the two study areas.

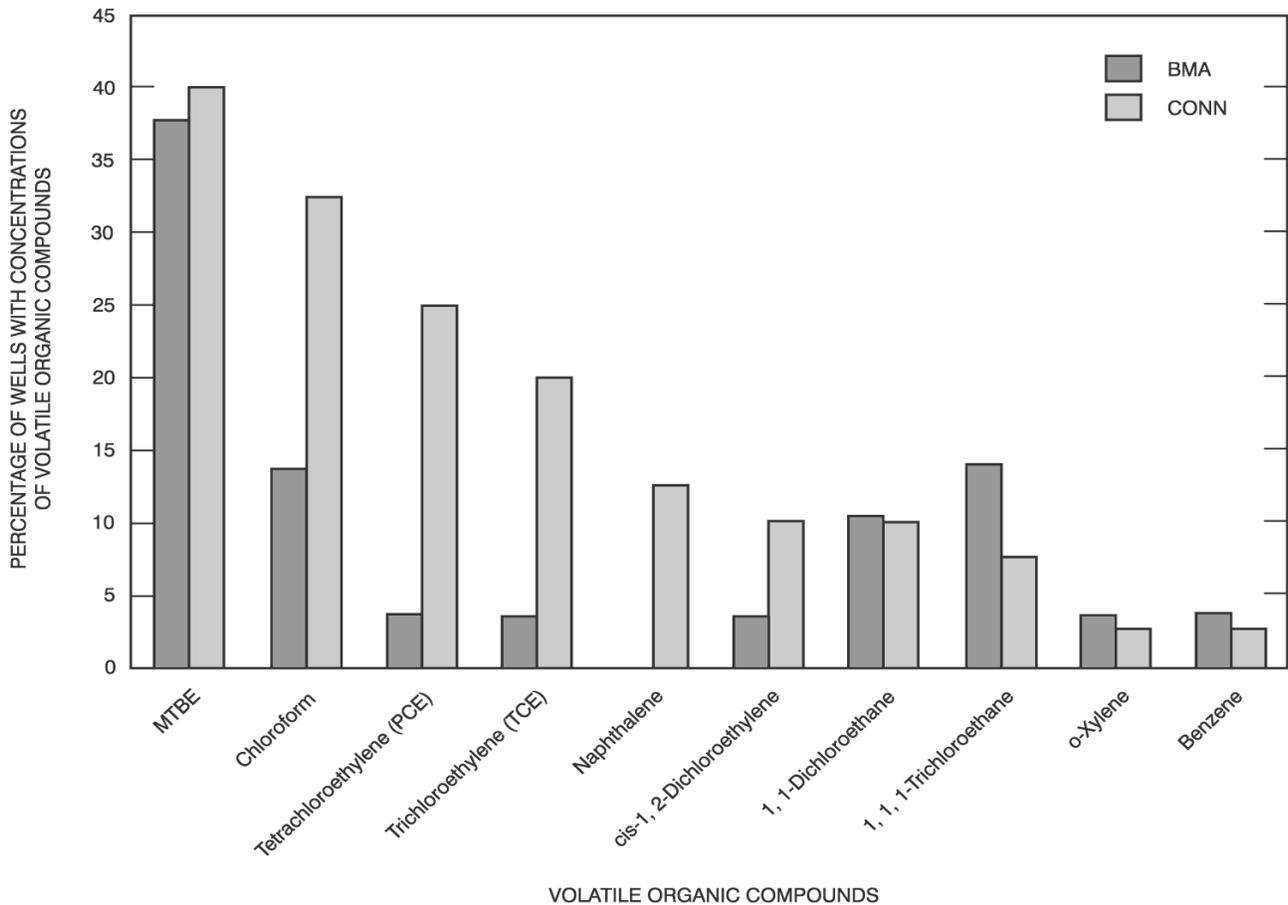


Figure 7. Percentage of wells with detections for 6 volatile organic compounds in water samples from 29 shallow wells in the Boston metropolitan area (BMA) and 40 shallow wells in the Connecticut, Housatonic, and Thames River Basins (CONN) NAWQA study unit.

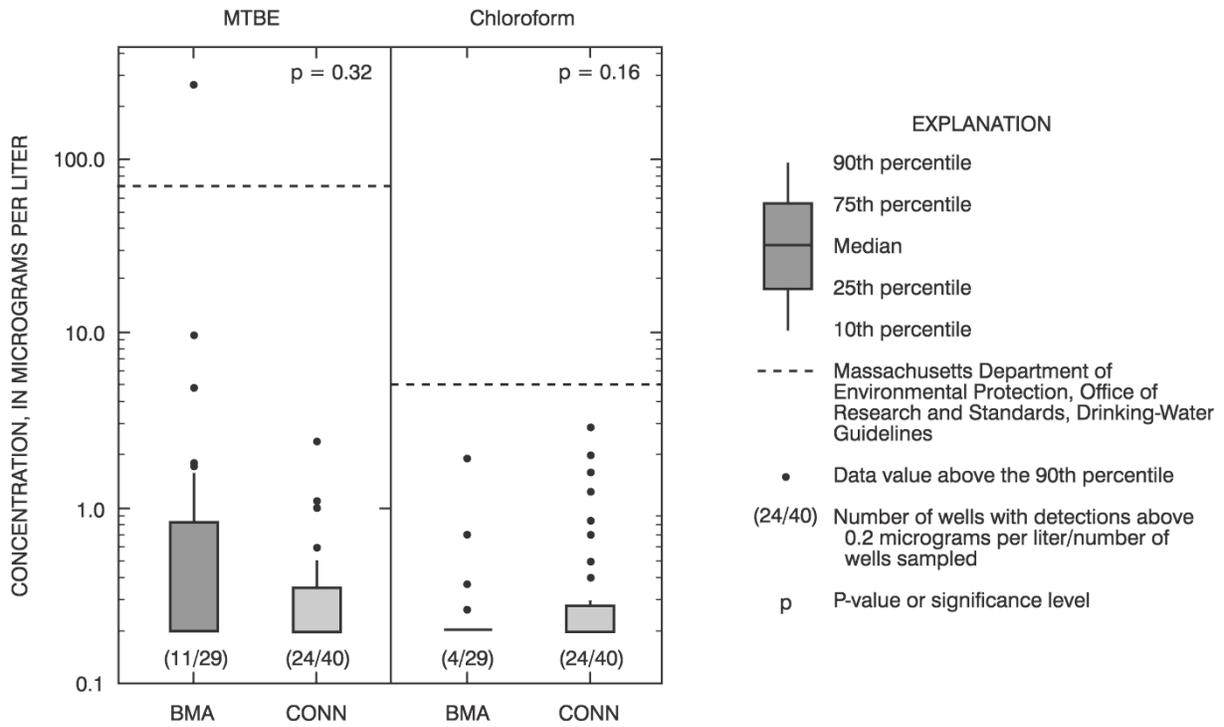


Figure 8. Distributions of MTBE and chloroform concentrations in water samples from 29 shallow wells in the Boston metropolitan area (BMA) and 40 shallow wells in the Connecticut, Housatonic, and Thames River Basins (CONN) NAWQA study unit. A p-value above 0.05 indicates no statistical difference between the two study areas.

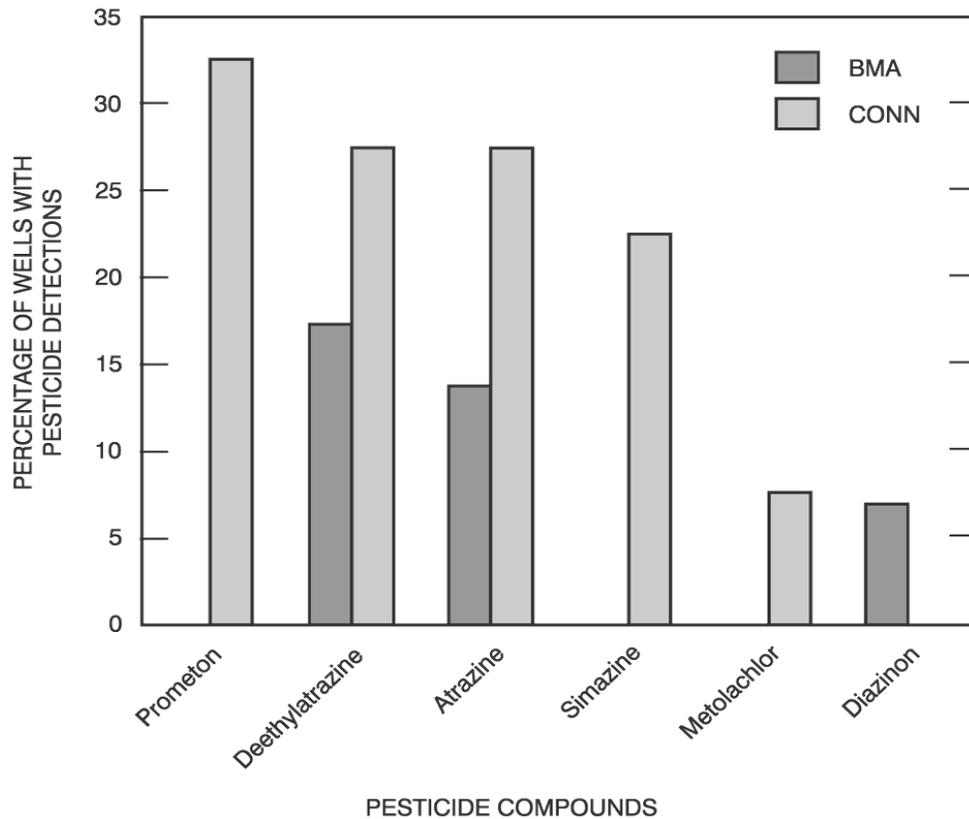


Figure 9. Percentage of wells with detections of 6 pesticides in water samples from 29 shallow wells in the Boston metropolitan area (BMA) and 40 shallow wells in the Connecticut, Housatonic, and Thames River Basins (CONN) NAWQA study unit.

Concentrations of chloroform in water samples from both studies were not statistically different ($p = 0.16$) (fig. 8). However, the rate of detection of chloroform, tetrachloroethylene (PCE), trichloroethylene (TCE), and naphthalene in the two studies does differ (fig. 7). Many of the shallow wells in the CONN study area were installed in older, more densely populated areas than were the wells in the BMA, which could account for the high rate of detection for chloroform and other VOCs in water from wells in the CONN study area.

Fewer pesticides were detected—and at lower frequencies—in water from wells in the BMA than in water from wells in the CONN study area (fig. 9). The highest pesticide concentration in a sampled well from the CONN study area was 2.3 $\mu\text{g/L}$ for atrazine (Grady and Mullaney, 1998). The highest pesticide concentration in a sampled well from the BMA study area was 0.011 $\mu\text{g/L}$ for atrazine. Atrazine and other triazine herbicides are used primarily in agriculture but are also used on rights-of-way in urban areas.

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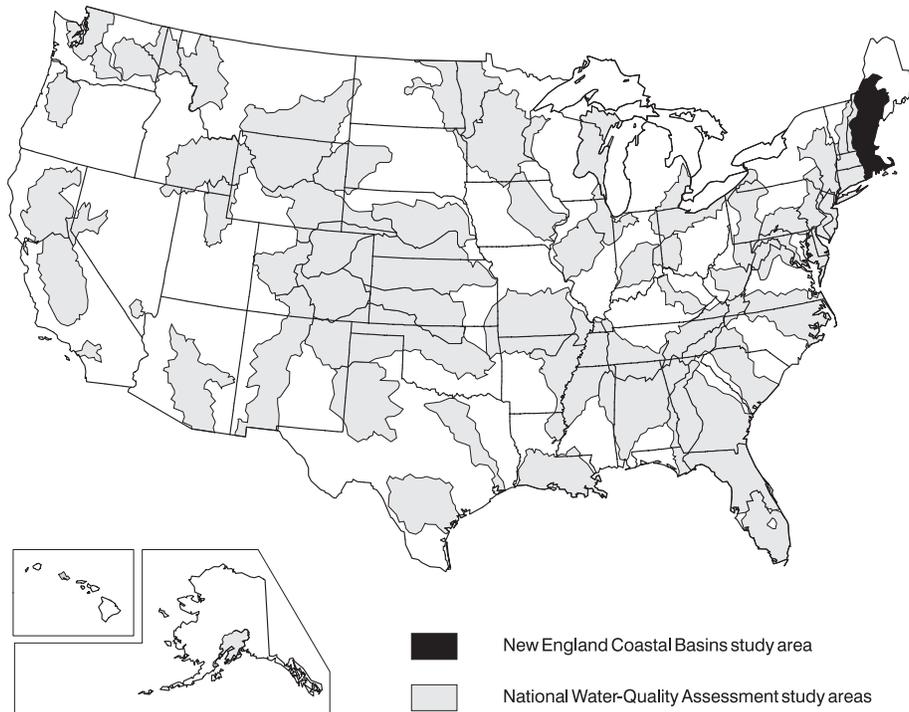
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Charles G. Groat, Director



NAWQA Program Information

The U.S. Geological Survey is conducting an assessment of water quality in the New England Coastal Basins (NECB) study area as part of the National Water-Quality Assessment (NAWQA) Program. The long-term goals of NAWQA are to describe the status of and trends in the quality of a large representative part of the Nation's surface- and ground-water resources and to identify major factors that affect the quality of these resources. A total of 59 hydrologic systems are to be studied that include parts of most major river basins and aquifer systems in the Nation. The assessment activities in the NECB study area began in 1997.