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A National Survey of Methyl *tert*-Butyl Ether and Other Volatile Organic Compounds in Drinking-Water Sources: Results of the Random Survey

Water-Resources Investigations Report 02-4079

Prepared in cooperation with the Metropolitan Water District of Southern California,
the Oregon Health & Science University, and the
American Water Works Association Research Foundation

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FOREWORD

The U.S. Geological Survey (USGS) is committed to providing the Nation with accurate and timely scientific information that helps 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 quality of the Nation's water resources is critical to assuring the long-term availability of water that is safe for drinking and recreation and suitable for industry, irrigation, and habitat for fish and wildlife. Population growth and increasing demands for multiple water uses make water availability, now 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, and local information needs and decisions related to water-quality management and policy (http://water.usgs.gov/nawqa). Shaped by and coordinated with ongoing efforts of other Federal, State, and local agencies, the NAWQA Program is designed to answer: What is the condition of our Nation's streams and ground water? How are the conditions changing over time? How do natural features and human activities affect the quality of streams and ground water, 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 1991-2001, the NAWQA Program completed interdisciplinary assessments in 51 of the Nation's major river basins and aquifer systems, referred to as Study Units (http://water.usgs.gov/nawqa/studyu.html). Baseline conditions were established for comparison to future assessments, and long-term monitoring was initiated in many of the basins. During the next decade, 42 of the 51 Study Units will be reassessed so that 10 years of comparable monitoring data will be available to determine trends at many of the Nation's streams and aquifers. The next 10 years of study also will fill in critical gaps in characterizing water-quality conditions, enhance understanding of factors that affect water quality, and establish links between sources of contaminants, the transport of those contaminants through the hydrologic system, and the potential effects of contaminants on humans and aquatic ecosystems.

The USGS aims to disseminate credible, timely, and relevant science information to inform 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 a fully integrated understanding of watersheds and 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, interstate, Tribal, and local—as well as nongovernmental organizations, industry, academia, and other stakeholder groups. Your assistance and suggestions are greatly appreciated.

Robert M. Hirsch
Associate Director for Water

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CONVERSION FACTORS AND ABBREVIATIONS

Multiply	By	To obtain
acre	0.4047	hectare
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
million gallons per day (Mgal/d)	0.04381	cubic meter per second

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

$$°F = (1.8 \times °C) + 32$$

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

$$°C = (°F - 32) / 1.8$$

Concentrations of chemical constituents in water are given in micrograms per liter (µg/L).

Other abbreviations used:

AWWARF, American Water Works Association Research Foundation
BTEX, benzene, toluene, ethylbenzene, and xylenes
CWS, community water system
DIPE, diisopropyl ether
DWCCL, Drinking-Water Candidate Contaminant List
ETBE, ethyl tertiary butyl ether
FRB, field reagent blank
GIS, geographic information system
HA, Health Advisory
km, kilometer
mL, milliliter
MCL, Maximum Contaminant Level
MDL, minimum detection limit
MRL, minimum reporting level
MTBE, methyl *tert*-butyl ether
MWDSC, Metropolitan Water District of Southern California
NAWQA, National Water-Quality Assessment
NTNCWS, non-transient non-community water system
OHSU, Oregon Health and Science University
OXY, oxygenated gasoline
PWS, public water system
QC, quality control
RFG, reformulated gasoline
SDWIS, Safe Drinking Water Information System
TAME, *tert*-amyl methyl ether
THM, trihalomethane
TRB, travel reagent blank
TTHM, total trihalomethane
USEPA, U.S. Environmental Protection Agency
USGS, U.S. Geological Survey
VOC, volatile organic compound

A National Survey of Methyl *tert*-Butyl Ether and Other Volatile Organic Compounds in Drinking-Water Sources: Results of the Random Survey

By Stephen J. Grady

ABSTRACT

Methyl *tert*-butyl ether (MTBE) was detected in source water used by 8.7 percent of randomly selected community water systems (CWSs) in the United States at concentrations that ranged from 0.2 to 20 micrograms per liter (µg/L). The Random Survey conducted by the U.S. Geological Survey, in cooperation with the Metropolitan Water District of Southern California and the Oregon Health & Science University, was designed to provide an assessment of the frequency of detection, concentration, and distribution of MTBE, three other ether gasoline oxygenates, and 62 other volatile organic compounds (VOCs) in ground- and surface-water sources used for drinking-water supplies. The Random Survey was the first of two components of a national assessment of the quality of source water supplying CWSs sponsored by the American Water Works Association Research Foundation. A total of 954 CWSs were selected for VOC sampling from the population of nearly 47,000 active, self-supplied CWSs in all 50 States, Native American Lands, and Puerto Rico based on a statistical design that stratified on CWS size (population served), type of source water (ground and surface water), and geographic distribution (State).

At a reporting level of 0.2 µg/L, VOCs were detected in 27 percent of source-water samples collected from May 3, 1999 through October 23, 2000. Chloroform (in 13 percent of samples) was the most frequently detected of 42 VOCs present in the source-water samples, followed by MTBE. VOC concentrations were generally less than 10 µg/L—95 percent of the 530 detections—and 63 percent were less than 1.0 µg/L. Concentrations of 1,1-dichloroethene, tetrachloroethene, trichloroethene, vinyl chloride, and total trihalomethanes (TTHMs), however, exceeded drinking-water regulations in eight samples.

Detections of most VOCs were more frequent in surface-water sources than in groundwater sources, with gasoline compounds collectively and MTBE individually detected significantly more often in surface water. Use of personal and commercial motorized watercraft on surface-water bodies that are drinking-water sources is probably the reason for the elevated detections of gasoline contaminants relative to ground water. MTBE detections demonstrated a seasonal pattern with more frequent detections in surface water in summer months, which is consistent with seasonal watercraft use.

The detection frequency of most VOCs was significantly related to urban land use and population density. Detections of any VOC, non-trihalomethane compounds, gasoline compounds collectively, the specific gasoline compounds benzene, toluene, ethylbenzene, and xylenes (BTEX), MTBE, solvents, and refrigerants were significantly greater in areas with more than 60 percent urban land use and (or) population density greater than 1,000 people per square mile than in source waters from less urbanized or lower population-

density areas. MTBE detections were five times more frequent in source waters from areas with high MTBE use than in source waters from low or no MTBE use, but, unlike other gasoline compounds, MTBE detections were not significantly related to the density of gasoline storage tanks near drinking-water sources.

INTRODUCTION

The chemical methyl *tert*-butyl ether (MTBE) has been added to gasoline in some areas of the United States to control air pollution and to enhance octane levels. With the phaseout of tetraethyl lead, MTBE has been used nationwide at low concentrations in conventional gasoline since 1979 to enhance octane levels. The 1990 Clean Air Act Amendments mandated the use of special blends of gasoline that contain oxygenates to reduce summer ozone and winter carbon monoxide levels in nonattainment areas. MTBE is the most commonly used gasoline oxygenate in the United States. Much of the MTBE used is in reformulated gasoline (RFG) program areas where the concentration of MTBE in gasoline is 11-percent by volume and it is used year round. When used in oxygenated gasoline (OXY) areas, the concentration of MTBE is as much as 15-percent by volume during the winter months; however, ethanol is the more commonly used oxygenate in OXY gasoline.

MTBE may be released into ground water and surface water from point sources, such as leaks or spills, especially during the distribution, storage, and use of the blended gasoline (Zogorski and others, 1997; Hitzig and others, 1998; Hunter, 1999; Moran, Zogorski, and others, 1999), and nonpoint sources, such as automobile and water-craft emissions and evaporative losses, urban precipitation and stormwater runoff (Pankow and others, 1997; Baehr and others, 1999; Moran, Zogorski, and others, 1999). MTBE also has been found in spills of home heating oil in Northeastern States, where it may occur as a contaminant in the fuel oil as a result of mixing with residual amounts of gasoline containing MTBE in the bulk storage, distribution, or delivery of the oil (Robbins and others, 1999).

The combination of MTBE's widespread use and frequent release to the environment through leaks and spills, together with chemical characteristics such as high solubility in water, low soil adsorption, and limited biodegradability, has caused extensive contamination of private and public drinking-water supplies. Some cities, especially in California, have already lost a substantial number of drinking-water sources. In Santa Monica, 75 percent of the drinking-water wells are unusable due to the presence of MTBE (City of Santa Monica, 1999). In South Lake Tahoe, one-third of the city's 34 drinking-water wells have been lost to MTBE contamination (Bourelle, 1998). Los Angeles, San Francisco, Santa Clara Valley, and Sacramento all have wells affected by MTBE (California Department of Health Services, 2001). Other cities with affected drinking-water supplies include LaCrosse, Kansas (Hatten, 2000), and Windham, Maine (State of Maine, 1998), where officials have taken steps to remediate the problem or remove the wells from service. The Interagency Assessment of Oxygenated Fuels (Zogorski and others, 1997) concluded that the full extent of MTBE occurrence in the Nation's drinking-water supplies could not be described due to limited data and recommended that additional data be collected. In response to that need, Grady and Casey (2001) assembled finished drinking-water data for a representative sample of community water systems (CWSs) in the Northeast and Mid-Atlantic regions of the United States and reported that MTBE had been found in drinking water provided by 106 CWSs that collectively serve 2.3 million people. A literature review on MTBE in drinking water conducted as part of this assessment (Delzer, 2002) found that MTBE has been reported in public and (or) private drinking-water supplies in 36 States.

The U.S. Environmental Protection Agency (USEPA) has tentatively classified MTBE as a possible human carcinogen, but no Federal drinking-water standard has been established for MTBE. The USEPA, however, has issued a drinking-water advisory that MTBE concentrations not exceed 20 to 40 µg/L to avert unpleasant taste and odor effects (U.S. Environmental Protection Agency, 1997a). The State of California has issued a taste and odor limit of 5 µg/L and a Maximum Contaminant Level (MCL) of 13 µg/L (California Department of Health Services, 2001). The USEPA also has required that monitoring for MTBE be conducted by selected CWSs under the Unregulated Contaminant Monitoring Rule (U.S. Environmental Protection Agency, 1999a).

Source water is defined by the American Water Works Association as "the supply of water for a water utility [that] is usually treated before distribution to

consumers." A source water can be a river, brook, stream, lake, reservoir, impoundment, spring, or aquifer from which a supply of water is obtained. Approximately 180,000 public water systems (PWSs) provide drinking water, at least some of the time, to about 252 million people in the 50 States, the District of Columbia, Native American Lands, and Puerto Rico (U.S. Environmental Protection Agency, 1997b), and about 54,300 of the PWSs are considered CWSs that supply water to the same population year round. Solley and others (1998) reported that the number of people using public-supplied water year round is expected to increase; therefore, the potential number of people currently being served by a CWS that contains MTBE in the source waters could be substantial and could increase in the future.

The U.S. Geological Survey's (USGS) National Water Quality Assessment (NAWQA) Program, in cooperation with the Metropolitan Water District of Southern California (MWDSC) in LaVerne, California, and the Oregon Health & Science University (OHSU) in Beaverton, Oregon, conducted a nationwide assessment to determine the occurrence and distribution of MTBE and other volatile organic compounds (VOCs) in ground waters and surface waters that serve as drinking-water supplies. The investigation was sponsored by the American Water Works Association Research Foundation (AWWARF). One part of the assessment of the extent of MTBE and other VOC contamination of source waters was conducted by a random survey of CWSs throughout the United States that was designed to allow statistical analysis with a high degree of confidence in the findings. In addition, information about the frequency of detection and concentration of MTBE, other gasoline oxygenates, and other VOCs in source water will help accomplish a goal of the NAWQA Program—to complete a national synthesis of information about VOCs by determining the occurrence and distribution of VOCs in ground and surface water that serve as drinking-water supplies.

Purpose and Scope

This report presents the findings of the Random Survey, the first of two surveys cooperatively conducted by the USGS, MWDSC, and OHSU as part of a national assessment of MTBE, other fuel oxygenates, and other VOCs in drinking-water sources for CWSs, that was sponsored by the AWWARF. The Random Survey was designed to provide representative information on the occurrence (frequency of detection and concentration) and distribution of MTBE, three other gasoline oxygenates, and 62 other VOCs in untreated, ground- and surface-water sources of drinking water used by CWSs in the United States. The statistical design of the Random Survey also was intended to allow hypothesis testing of factors that may be related to more frequent detection of MTBE and other VOCs in drinking-water sources.

Information was collected on the quality of water from 954 drinking-water sources in all 50 States, Native American lands, and Puerto Rico for the Random Survey. The source-water samples were collected by participating CWSs from May 3, 1999 to October 23, 2000. This report describes the results of the chemical analyses of the source-water samples and also presents results of statistical analysis used to identify differences in the occurrence and distribution of MTBE and other VOCs that relate to the type of source water, size of systems, and other characteristics of the CWS drinking-water sources sampled for this study.

Acknowledgments

This study and assessment would not have been possible without the cooperation and assistance of the owners, operators, and staff of the 954 water systems that provided information on the characteristics of their water sources and the operation of their water system, and who conscientiously collected and submitted the necessary water samples. All chemical analyses for VOCs in source-water samples were conducted at the MWDSC laboratory in LaVerne, California, under the direction of Bart Koch and Melissa Dale. The author would like to thank George D. Casey, Rick Clawges, Tammy Ivahnenko, and Erika Schoen of the USGS for their efforts in compiling and analyzing the electronic data provided by the USEPA, the participating CWSs, the MWDSC, and other sources that was fundamental to the successful completion of the Random Survey. Finally, the author also would like to thank Bart Koch of the MWDSC, Paul Tratnyek of OHSU, John Zogorski and Gregory Delzer of the USGS, and members of the AWWARF project advisory committee for their technical questions, comments, and suggestions during the design and implementation of this study, and Lori Apodaca and Gregory Delzer of the USGS for their technical review of this report.

IMPLEMENTATION OF THE RANDOM SURVEY

The Random Survey was designed to ensure an unbiased distribution of CWSs by State, type of source water (ground water or surface water), and population served (Ivahnenko and others, 2001). A statistical sampling of a subset of CWSs would allow information on the frequency of occurrence and concentration of MTBE and other VOCs in drinking-water sources for randomly selected CWSs to represent, in aggregate, the overall population of CWSs.

Data on the distribution of the nearly 47,000 active, self-supplied CWSs that serve more than 250 million people (table 1) were obtained from the USEPA's Safe Drinking Water Information System (SDWIS) on November 5, 1998 (U.S. Environmental Protection Agency, 1998b). By design, the Random Survey would distribute 1,000 samples among 10 source-size categories (5 for ground water, 5 for surface water) stratified to reflect the national distribution of the self-supplied systems and the total number of people served by CWSs within each category (Ivahnenko and others, 2001). Because more than 60 percent of CWSs are very small (serve 25 to 500 people) and are supplied by ground-water sources, but 45 percent of the population served by CWSs are customers of very large (more than 50,000 people served), surface-water supplied systems, population density and source-water type were weighted equally in the design of the Random Survey. Consequently, the distribution of the 1,000 CWSs planned for the Random Survey included 613 mostly very small and small, ground-water-supplied systems and 387 predominantly large and very large, surface-water-supplied systems.

The Random Survey was conducted over a 78-week period that began on May 3, 1999 and ended on October 23, 2000. Selection of participating CWSs was made from randomized lists of the 46,960 active, self-supplied water utilities obtained from the SDWIS database on November 5, 1998, until the requisite number of systems was obtained for each source-size category in each State, Native American Lands, and Puerto Rico. Subsequently, sample-collection kits were distributed to the selected CWSs.

A total of 954 source-water samples were submitted to the MWDSC laboratory by the CWSs randomly selected for participation in the survey. With participation by 95 percent of the CWSs included in the design, the sample size achieved was sufficiently close to the total 1,000 planned systems for the Random Survey to accomplish the designed distribution and to allow valid statistical analysis.

The distribution of the 954 participating CWSs by source-water type and system size is shown in table 2. The percentage of ground-water sources sampled for each of the five size categories ranged from 92 to 100 percent of the number planned in the design, and the percentage of the surface-water sources sampled ranged from 86 to 99 percent of the number planned.

Table 1. Number of self-supplied community water systems and number of people served, by type of source water and size of system, November 5, 1998

[Data from U.S. Environmental Protection Agency's Safe Drinking Water Information System (URL http://www.epa.gov/enviro/html/sdwis/). CWS, community water system. CWS size categories: very small, serving less than 500 people; small, serving 501 to 3,300 people; medium, serving 3,301 to 10,000 people; large, serving 10,001 to 50,000 people; very large, serving more than 50,000 people]

CWS size category	Ground water				Surface water			
	Number of systems	Percent of all systems	Number of people served	Percent of total population served	Number of systems	Percent of all systems	Number of people served	Percent of total population served
Very small	28,324	60.3	4,625,130	1.84	1,228	2.64	616,012	0.24
Small	9,775	20.8	14,178,037	5.63	1,562	3.33	5,739,217	2.28
Medium	2,399	5.11	14,219,831	5.65	971	2.07	11,045,463	4.39
Large	1,194	2.54	25,342,137	10.1	928	1.98	36,525,585	14.5
Very large	182	.39	25,696,338	10.2	397	.85	113,671,630	45.2
Total	41,874	89.1	84,061,473	33.4	5,086	10.9	167,597,907	66.6

Table 2. Number of community water systems planned and sampled for the Random Survey, by type of source water and size of system

[CWS, community water system; CWS size categories: very small, serving fewer than 500 people; small, serving 501 to 3,300 people; medium, serving 3,301 to 10,000 people; large, serving 10,001 to 50,000 people; very large, serving more than 50,000 people]

CWS size category	Type of source water and number of systems planned			Type of source water and number of systems sampled			Type of source water and percent of planned systems sampled		
	Ground water	Surface water	Total	Ground water	Surface water	Total	Ground water	Surface water	Total
Very small	311	14	325	292	12	304	94	86	94
Small	132	28	160	121	26	147	92	93	92
Medium	54	32	86	50	30	80	93	94	93
Large	63	83	146	63	79	142	100	95	97
Very large	53	230	283	53	228	281	100	99	99
Total	613	387	1,000	579	375	954	94	97	95

Geographic Distribution of Participating Community Water Systems

The geographic distribution of systems sampled is within 90 percent of the target proportion for 45 of the 52 States or other geographic entities (table 3). The only substantial difference in the achieved distribution of CWSs from the design was the selection of only 14 of 22 planned systems in U.S. Territories, and that all 14 of these are in Puerto Rico. The logistical difficulties of locating and contacting potential participating CWSs in other U.S. Territories required this modification in design. Overall, the achieved distribution has a slight deficit in the number of smaller systems for both surface- and ground-water-supplied CWSs. Generally, it was considerably more difficult to obtain participants from the smallest size categories, and the total population of very small surface-water supplied systems is limited. For some States, failure by the one or two systems in these categories to participate in the survey provided no alternative selections.

The percentage of planned systems sampled in each State ranged from 67 to 100 percent for ground-water supplied systems and from 59 to 100 percent for surface-water supplied systems. A small deficit in participating ground-water systems occurred in almost half the States, mostly for the very small and small systems. The very small systems typically have part-time operators and management, and often there were difficulties in making contact with or obtaining the samples from very small ground-water supplied systems.

The geographic distribution of the 579 ground-water sources and 375 surface-water sources in the 50 States, Native American lands, and Puerto Rico sampled for the Random Survey are shown in figure 1. Nearly all (98 percent) of the ground-water sources were wells (2 percent were springs). Surface-water sources included 204 lakes and (or) reservoirs (54 percent), and 171 rivers, streams, aqueducts, or canals (46 percent). Fifty-five percent of the drinking-water sources sampled in the Random Survey are east of the Mississippi River. Proportionally, more CWSs in the east have surface-water sources than those in the west, where ground-water sources make up two-thirds of source waters sampled. The distribution of source waters also reflects regional physiographic and hydrogeologic characteristics. Ground-water sources are predominant in much of the southeastern Atlantic and Gulf of Mexico coastal plain in Georgia, Florida, Mississippi, and Louisiana, and in the High Plains that are underlain by productive aquifers. Surface-water sources are more dominant in the humid Appalachian and Ozark Mountain areas and along the shores of the Great Lakes.

Table 3. Number of community water systems sampled and planned for the Random Survey, by source-size category and State

[GW, ground water; SW, surface water; VSM, very small; SM, small; MED, medium; LRG, large; VLRG, very large]

State or other entity	Number of CWSs sampled/number of CWSs planned											Percentage of planned
	Source-size category										Total	
	GW-VSM	GW-SM	GW-MED	GW-LRG	GW-VLRG	SW-VSM	SW-SM	SW-MED	SW-LRG	SW-VLRG		
AK	4/4	1/1	0	0	0	1/1	0	0	0	1/1	7/7	100
AL	0/0	2/2	2/2	1/1	0	0	0	1/1	3/3	5/5	14/14	100
AR	2/2	2/2	1/1	0	0	0	0/1	1/1	1/1	1/1	8/9	89
AZ	5/5	2/2	1/1	2/2	1/1	0	0	0	0	6/6	17/17	100
CA	19/20	5/5	4/3	7/7	11/11	2/2	2/2	2/2	5/5	30/30	87/87	100
CO	4/5	1/1	0	0	0	1/1	1/1	0/1	2/2	6/6	15/17	88
CT	5/5	1/1	0	0	0	0	0	0	2/2	5/5	13/13	100
DE	2/2	1/1	0	0	0	0	0	0	0	1/1	4/4	100
FL	13/13	5/6	3/3	7/7	17/17	0	0	0	1/1	3/3	49/50	98
GA	11/12	2/3	1/1	1/1	1/1	0	1/1	1/1	3/3	8/8	29/31	94
HI	0	1/1	0	0	1/1	0	0	0	0	0	2/2	100
IA	7/7	4/4	1/1	1/1	1/1	0	0	0	0	2/2	16/16	100
ID	5/5	1/1	1/1	1/1	0	1/1	0	0	0	1/1	10/10	100
IL	7/7	4/5	2/2	2/2	1/1	0	1/1	1/1	3/3	8/8	29/30	97
IN	4/4	4/4	2/2	2/2	1/1	0	0	1/1	1/1	4/4	19/19	100
KS	4/4	3/3	0	1/1	0	0	1/1	1/1	1/1	3/3	14/14	100
KY	1/1	0	0	0	0	0	1/1	2/2	4/5	2/2	10/11	91
LA	8/8	5/5	1/3	2/2	1/2	0	0	1/1	1/1	5/5	24/27	89
MA	2/2	0/1	2/2	3/3	1/1	0	0	1/1	4/4	8/8	21/22	95
MD	3/4	1/1	1/1	1/1	0	0	0	0	1/1	5/5	12/13	92
ME	2/2	1/1	0	0	0	0	1/1	0	1/1	0	5/5	100
MI	8/9	4/4	1/1	1/1	1/1	0	0	1/1	2/2	4/4	22/23	96
MN	5/6	4/4	1/1	3/3	0	0	0	0	1/1	2/2	16/17	94
MO	8/8	4/4	2/2	1/1	1/1	0	1/1	1/1	1/1	4/4	23/23	100
MS	5/5	8/9	3/3	2/2	0	0	0	0	0	0	18/19	95
MT	4/5	1/1	0	0	0	0	0	0	0	1/1	6/7	86
NC	15/16	3/3	1/1	1/1	0	0	1/1	2/2	4/4	7/7	34/35	97
ND	1/1	1/1	0	0	0	0	0	0	1/1	0	3/3	100
NE	5/5	2/2	1/1	1/1	0	0	0	0	0	1/1	10/10	100
NH	5/5	1/1	0	0	0	0	0	0	1/1	1/1	8/8	100
NJ	3/3	2/2	2/2	4/4	1/1	0	0	0	1/1	8/8	21/21	100
NM	5/5	1/1	1/1	1/1	1/1	0	0	0	0	0	9/9	100
NV	2/2	1/1	0	0	0	0	0	0	0	1/1	4/4	100
NY	12/15	3/4	1/1	3/3	4/4	1/1	2/2	2/2	4/4	16/16	48/52	92
OH	7/7	4/4	2/2	3/3	2/2	0	1/1	1/1	4/4	10/10	34/34	100

Table 3. Number of community water systems sampled and planned for the Random Survey, by source-size category and State–Continued

[GW, ground water; SW, surface water; VSM, very small; SM, small; MED, medium; LRG, large; VLRG, very large]

State or other entity	Number of CWSs sampled/number of CWSs planned											Percentage of planned
	Source-size category										Total	
	GW-VSM	GW-SM	GW-MED	GW-LRG	GW-VLRG	SW-VSM	SW-SM	SW-MED	SW-LRG	SW-VLRG		
OK	3/3	1/2	1/1	1/1	0	1/1	2/2	2/2	2/2	4/4	17/18	94
OR	5/6	1/1	0	1/1	0	1/1	1/1	1/1	2/2	2/2	14/15	93
PA	11/14	4/5	2/2	1/1	0	1/1	1/1	2/2	6/6	15/15	43/47	92
RI	0	0	0	0	0	0	0	0	0	1/1	1/1	100
SC	3/4	1/1	1/1	0	0	0	0	0	2/2	3/3	10/11	91
SD	2/2	1/1	0	0	0	0	0	0	0	1/1	4/4	100
TN	1/1	1/1	1/1	1/1	1/1	0	1/1	2/2	4/4	4/4	16/16	100
TX	25/24	12/14	3/6	3/3	3/3	0/1	1/2	2/2	5/5	17/17	71/77	92
UT	3/3	1/1	1/1	1/1	0	0	0	0	0	4/4	10/10	100
VA	11/11	2/2	0	0	0	0	1/1	1/1	2/2	6/6	23/23	100
VT	2/3	1/1	0	0	0	0	1/1	0	0	0	4/5	80
WA	15/17	4/4	1/1	2/2	1/1	1/1	1/1	0	1/1	2/2	28/30	93
WI	7/7	4/4	2/2	1/1	1/1	0	0	0	1/1	3/3	19/19	100
WV	2/2	0/1	0	0	0	0	2/2	1/1	1/1	1/1	7/8	88
WY	2/2	0	0	0	0	0	0	0	0	0	2/2	100
NA[1]	6/6	2/2	0	0	0	1/1	0	0	0	0	9/9	100
PR[2]	1/2	1/1	1/1	1/1	0	1/2	2/2	0/1	1/4	6/8	14/22	64
Total	292/311	121/132	50/54	63/63	53/53	12/14	26/28	30/32	79/83	228/230	954/1,000	95
Percentage of planned	94	92	93	100	100	86	93	94	95	99	95	

[1]Native Americans Lands.
[2]Puerto Rico.

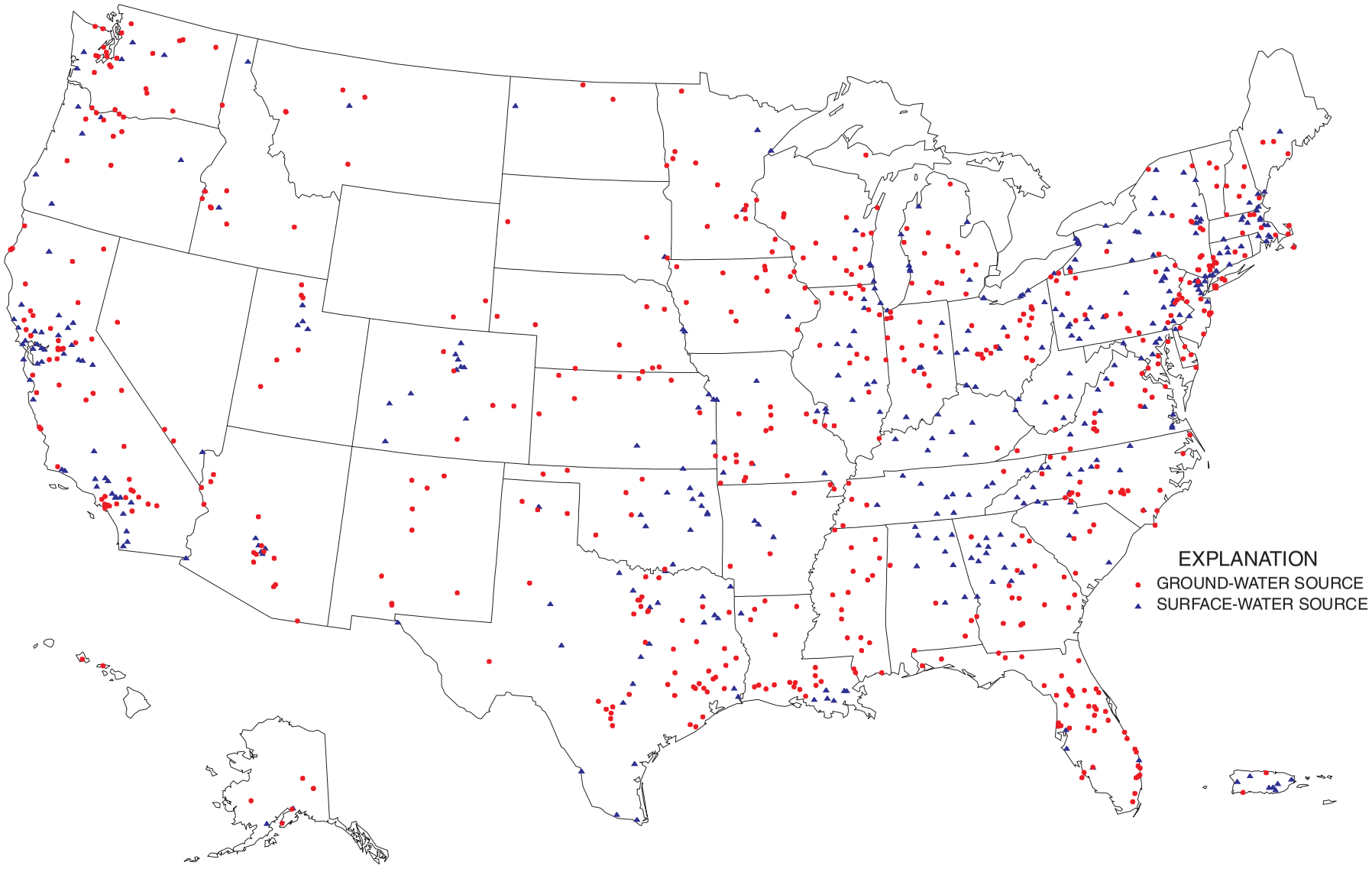

Figure 1. Distribution of drinking-water sources for community water systems in the United States and Puerto Rico sampled for the Random Survey.

Temporal Distribution of Source-Water Samples

Sample collection for the Random Survey was designed to provide an even distribution of the number of samples collected in any particular month or season. The temporal distribution of the 1,000 source-water samples planned for in the design of the Random Survey was to spread the sample collection over a 64-week period in such a way as to preclude seasonal bias in the data (Ivahnenko and others, 2001). To achieve an equal number of samples on a monthly basis for a calendar year, about 83 samples (or 8 percent of the samples) should be collected each month. Because the sampling was planned to extend beyond a calendar year, only about one-half as many samples would be collected each week during the initial and final 12 weeks of the survey (collectively) as were scheduled during the intervening 40 weeks (fig. 2). The actual sampling period, however, extended for 78 weeks (from May 3, 1999 through October 23, 2000) as logistical considerations (such as holiday work schedules) and the need to reselect and (or) reschedule some participating CWSs caused deviation from the designed sample frequency. Because of the difficulties experienced in locating the requisite number of small CWSs to participate in the Random Survey, the sample period (fig. 2) was extended to allow for participation by as many CWSs as could be arranged. The modifications in the sampling schedule did skew the temporal pattern of the samples from the even distribution planned. The percentage of all samples collected during any particular month of the year exceeded the planned 8 percent per month during the summer months (fig. 3). In particular, the number of samples submitted during August was almost 150 percent of the target, whereas a deficit occurred during the fall and early winter months, especially November and December. The geographic distribution of drinking-water sources sampled in any month was random, however, and it is considered unlikely that the occurrence of MTBE or other VOCs determined during the Random Survey was affected by the temporal variations in sample allocation.

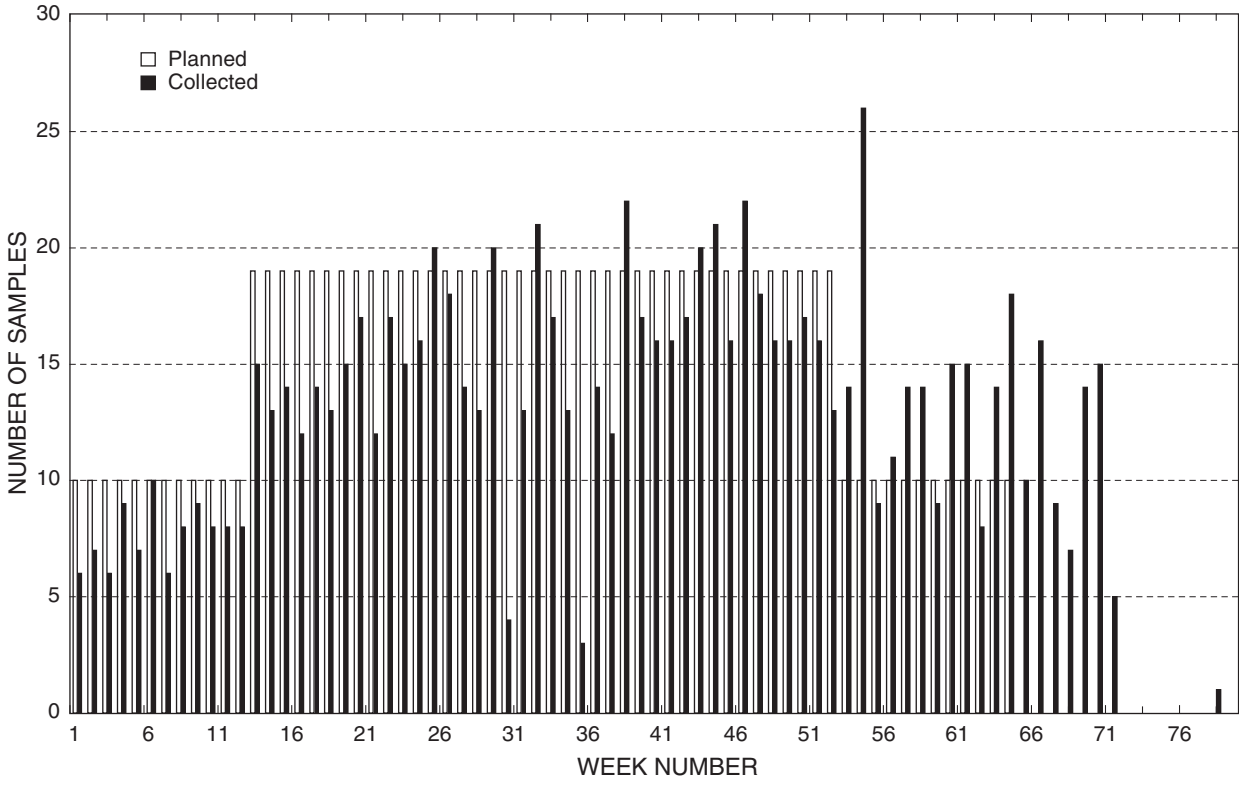

Figure 2. Number of source-water samples planned and the number of samples collected per week for the Random Survey.

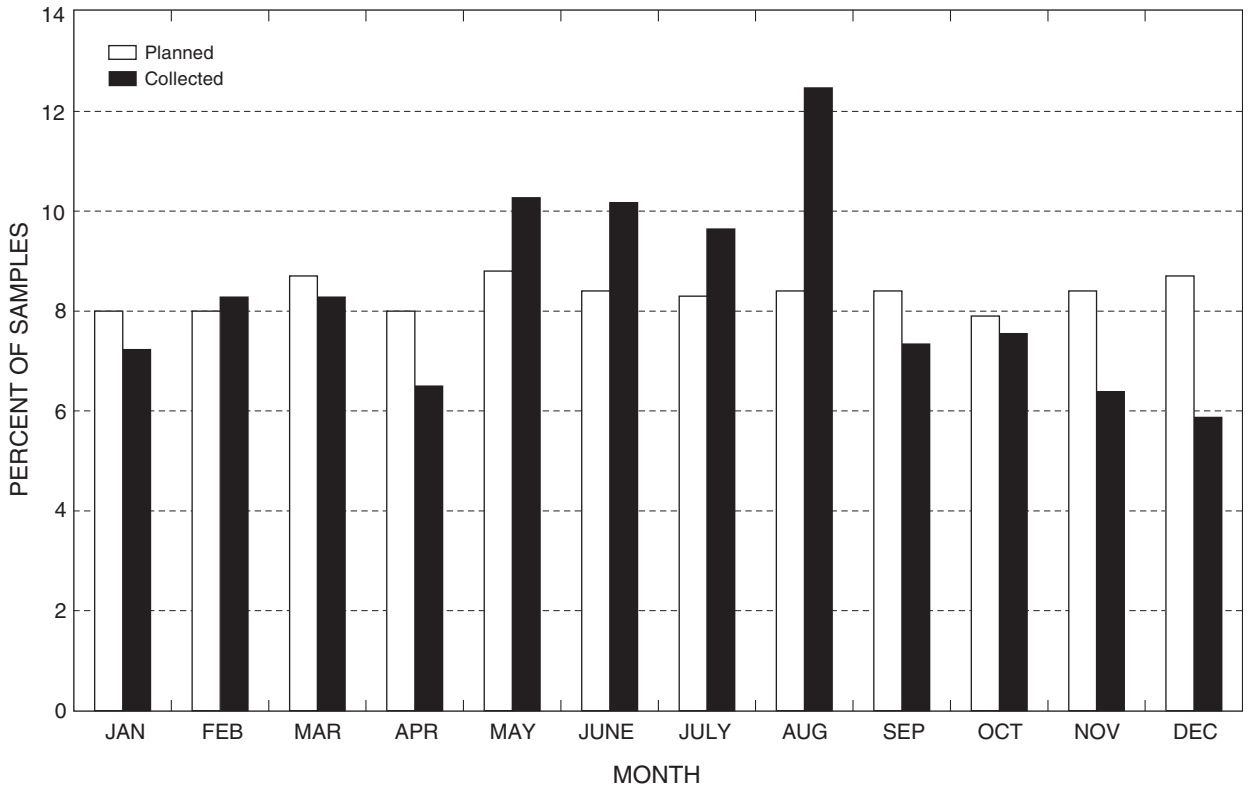

Figure 3. Percentage of source-water samples planned and the percentage of samples collected per month for the Random Survey.

DATA COLLECTION AND ANALYSIS

The findings of the Random Survey are based on information obtained and reviewed as part of four data collection and analysis activities described in the following sections of the report: (1) collection and laboratory chemical analysis of source-water and companion field, quality-control samples, (2) application of appropriate data analysis and interpretation methods, (3) review of the quality-control data to assure that data-quality objectives were met, and (4) collection and compilation of ancillary information on the drinking-water sources and other geospatial data that may contribute to a better understanding of the occurrence and distribution of MTBE and other VOCs in source water. While the overall design for this assessment has been previously documented (Ivahnenko and others, 2001) and is not be repeated here, additional information on the data collection, review, documentation, and analysis are described below for the reader's convenience.

Collection of Source-Water and Quality-Control Samples

All source-water samples for the Random Survey were collected by CWS personnel. Sample kits with baked-glass vials, VOC-free reagent water for field blanks, and instructions for collecting the VOC samples were provided by MWDSC to CWS personnel, with emphasis on collecting a raw (untreated) source-water sample. Two drops of 50-percent dilute hydrochloric acid were added to 40-mL (milliliter) baked-glass vials prior to shipment to the CWS. Samples for the Random Survey were analyzed for MTBE, three other gasoline oxygenates—ethyl *tert*-butyl ether (ETBE), diisopropyl ether (DIPE), and *tert*-amyl methyl ether (TAME)—plus 62 additional VOCs (table 4) at the MWDSC laboratory using the USEPA-approved method 524.2 (U.S. Environmental Protection Agency, 1995).

Most source-water samples submitted to the MWDSC laboratory were accompanied by one or more

reagent-water blanks. Commercially produced, VOC-free reagent water was routinely tested at the MWDSC laboratory to ensure purity and sent to the CWSs to be used for collecting field reagent blanks (FRBs). Instructions were given to fill the empty glass vials labeled "Field Blank" at each sample site with the VOC-free water provided in the sample kit, at the same time the source-water sample was collected. FRBs were collected and processed in the same location as the source-water sample, thereby exposing the blank water to sampling conditions. FRBs also were preserved with one or two drops of 50-percent dilute hydrochloric acid, but in general, were analyzed only if VOCs were detected in the corresponding environmental sample. Travel reagent blanks (TRBs) also accompanied most environmental samples. TRB vials were prepared at the MWDSC laboratory by filling 40-mL baked-glass vials with VOC-free water. TRBs were never uncapped by the samplers, and like the FRBs, were generally analyzed only if VOCs were detected in the environmental sample.

A total of 956 source-water samples and 402 quality-control (QC) samples were submitted to the MWDSC laboratory in LaVerne, California during the 78-week sample-collection period. Except for two CWSs, samples were collected only once by each of 954 CWSs that participated in the survey. The extra two samples were kept in the database for a data-quality review, but they were not included in the data analysis for occurrence and distribution of VOCs.

Analysis of Data

Statistical summaries of the data, presented in tabular and graphical formats in this report, are used to describe the occurrence and distribution of MTBE and VOCs in drinking-water sources. Descriptive statistics include number of samples, number of detections, the frequency of detection (percentage of samples with detections), detectable concentration range, and medians of detected VOC concentrations. Because the data for all VOCs reported by the MWDSC laboratory are highly censored, that is, 50 percent or more (and commonly 90 percent or more) of concentrations are below the minimum reporting level (MRL), median concentrations or other statistical measures of central tendency (mean) or spread (standard deviation, interquartile range, or most other percentiles of the sample-population distribution) cannot be determined. Medians of the concentrations above the MRL, although a positively biased indication of the median VOC concentration for sample populations, are provided because this statistic affords the only comparison of concentrations among such highly censored analytes.

Descriptive and nonparametric statistics, histograms, cumulative frequency plots, and scatter plots (Helsel and Hirsch, 1992) are used in this report to describe the frequency of detection and concentration of MTBE and other VOCs in drinking-water sources. The data are summarized to show the occurrence and distribution in relation to the type of source water (ground water, surface water, reservoirs and rivers) and to the size of the CWSs (five categories based on population served). Maps show the location of drinking-water sources (wells, springs, and surface-water intakes) where samples were collected for analyses of MTBE and selected other VOCs, and the location of drinking-water sources where these compounds were detected. Where appropriate, a variety of hypothesis tests including contingency-table tests (Pearson's chi-square test with Yates' continuity correction), Kruskal-Wallis tests, and the Wilcoxon signed rank test (Iman and Conover, 1983; Helsel and Hirsch, 1992), were used to test for relations between the frequency of detection or concentrations of VOCs and anthropogenic factors such as land use, population density, and the distribution of high MTBE-use areas.

Contingency-table tests are used in this report because the highly censored VOC analytical data largely precludes analysis by hypothesis tests that evaluate continuous variables. Contingency tables measure the association between two discrete, categorical variables. For example, is the probability of detecting a VOC (compared to the probability of non-detection) related to a type of source water, the size of CWSs, land use, or the presence or absence of some other anthropogenic factor? The data are arranged into a matrix of rows and columns—with no natural ordering—and the distribution of data among the categories is tested to determine if the row classification is independent of the column using the chi-square distribution (Helsel and Hirsch, 1992). As with other statistical tests used in this report, the results of the contingency-table tests are expressed by the "p-value" or the significance level attained by the data; for this report, the null hypothesis is rejected and the two variables are determined to be significantly related at p-values less than 0.05 (95-percent confidence level). When the variables are found to be dependent or related, however, it is not necessarily implied that one variable causes the observed response in the second variable.

Table 4. Volatile organic compounds analyzed for the Random Survey

[MDL, method detection limit; MRL, minimum reporting level; USEPA, U.S. Environmental Protection Agency; MCL, USEPA Maximum Contaminant Level; HA, USEPA Health Advisory; DWCCL, USEPA Drinking-Water Contaminant Candidate List; µg/L, microgram per liter; --, not applicable]

Volatile organic compound (abbreviation)	MDL (µg/L)	MRL (µg/L)	MCL[1] (µg/L)	HA[1] (µg/L)	DWCCL[2]
Gasoline Oxygenates					
Ethyl *tert*-butyl ether (ETBE)	0.034	0.2	--	--	--
Diisopropyl ether (DIPE)	.073	.2	--	--	--
tert-Amyl methyl ether (TAME)	.025	.2	--	--	--
Methyl *tert*-butyl ether (MTBE)	.039	.2	--	20-40	Yes
Other Gasoline Compounds					
Benzene	.029	.2	5	--	--
n-Butylbenzene	.047	.2	--	--	--
sec-Butylbenzene	.044	.2	--	--	--
tert-Butylbenzene	.037	.2	--	--	--
Ethylbenzene	.033	.2	700	700	--
Naphthalene	.055	.2	--	100	Yes
Toluene	.025	.2	1,000	1,000	--
1,3,5-Trimethylbenzene	.026	.2	--	--	--
m-, *p*-Xylene	.065	.2	10,000	10,000	--
o-Xylene	.028	.2	10,000	10,000	--
Trihalomethane Disinfectant By-Products					
Bromodichloromethane	.018	.2	([3])	--	--
Bromoform	.022	.2	([3])	--	--
Chloroform	.024	.2	([3])	--	--
Chlorodibromomethane	.016	.2	([3])	60	--
Solvents					
Bromobenzene	.029	.2	--	--	Yes
Methyl ethyl ketone	.645	2.0	--	--	--
Carbon tetrachloride	.049	.2	5	--	--
Chlorobenzene	.032	.2	100	100	--
Chloroethane	.095	.2	--	--	--
2-Chlorotoluene	.033	.2	--	100	--
4-Chlorotoluene	.030	.2	--	100	--
Dibromomethane	.028	.2	--	--	--
1,2-Dichlorobenzene	.037	.2	600	600	--
1,3-Dichlorobenzene	.029	.2	--	600	--
1,1-Dichloroethane	.036	.2	--	--	Yes
1,2-Dichloroethane	.029	.2	5	--	--
1,1-Dichloroethene	.082	.2	7	7	--
cis-1,2-Dichloroethene	.024	.2	70	70	--
trans-1,2-Dichloroethene	.040	.2	100	100	--
1,2-Dichloropropane	.028	.2	5	--	--
1,1,1,2,2,2-Hexachloroethane	.086	.2	--	1	--
Methylene chloride	.021	.2	5	--	--
n-Propylbenzene	.043	.2	--	--	--

Table 4. Volatile organic compounds analyzed for the Random Survey–Continued

[MDL, method detection limit; MRL, minimum reporting level; USEPA, U.S. Environmental Protection Agency; MCL, USEPA Maximum Contaminant Level; HA, USEPA Health Advisory; DWCCL, USEPA Drinking-Water Contaminant Candidate List; µg/L, microgram per liter; --, not applicable]

Volatile organic compound (abbreviation)	MDL (µg/L)	MRL (µg/L)	MCL[1] (µg/L)	HA[1] (µg/L)	DWCCL[2]
Solvents—Continued					
1,1,1,2-Tetrachloroethane	0.020	0.2	--	70	--
1,1,2,2-Tetrachloroethane	.026	.2	--	--	Yes
Tetrachloroethene (PCE)	.049	.2	5	--	--
1,2,4-Trichlorobenzene	.042	.2	70	70	--
1,1,1-Trichloroethane	.045	.2	200	200	--
1,1,2-Trichloroethane	.014	.2	5	3	--
Trichloroethene (TCE)	.034	.2	5	--	--
1,2,3-Trichloropropane	.027	.2	--	40	--
Fumigants					
Bromomethane	.084	.2	--	10	Yes
1,4-Dichlorobenzene	.033	.2	75	75	--
cis-1,3-Dichloropropene	.024	.2	--	--	Yes
trans-1,3-Dichloropropene	.026	.2	--	--	Yes
Refrigerants					
Chloromethane	.105	.2	--	3	--
Dichlorodifluoromethane	.121	.2	--	1,000	--
Trichlorofluoromethane	.096	.2	--	2,000	--
1,1,2-Trichloro-1,2,2-trifluoroethane	.099	.2	--	--	--
Organic Synthesis Compounds					
Acrylonitrile	.098	.2	--	--	--
Bromochloromethane	.036	.2	--	90	--
1,3-Dichloropropane	.029	.2	--	--	Yes
2,2-Dichloropropane	.056	.2	--	--	Yes
1,1-Dichloropropene	.060	.2	--	--	Yes
Hexachlorobutadiene	.057	.2	--	1	Yes
Isopropylbenzene	.040	.2	--	--	--
p-Isopropyltoluene	.037	.2	--	--	Yes
Styrene	.026	.2	100	100	--
1,2,3-Trichlorobenzene	.042	.2	--	--	--
1,2,4-Trimethylbenzene	.022	.2	--	--	Yes
Vinyl bromide	.084	.2	--	--	--
Vinyl chloride	.082	.2	2	--	--

[1]U.S. Environmental Protection Agency, 2000.
[2]U.S. Environmental Protection Agency, 1998a.
[3]Maximum Contaminant Level for total trihalomethanes is 80 µg/L.

Review of Field Quality-Control Data

The field quality-control (QC) data collected in conjunction with the Random Survey were reviewed and the results are presented here. Field reagent (FRB) and trip reagent (TRB) blanks were used to measure any systematic or random contamination from the environment around the sample site and during the sample shipment. In addition to data for 956 source-water samples, the MWDSC laboratory reported VOC analyses for 290 FRBs and 112 TRBs. Although field blank vials and VOC-free reagent water were provided to all CWSs, not all FRBs were received or analyzed. A small number (21) of CWSs omitted processing and returning the field blank with their sample vials (or their FRBs were broken in transit), and the FRBs and TRBs generally were not analyzed unless VOCs were detected in the companion source-water samples. TRBs were not included in the sample kits provided to the CWSs until week 16 of the Random Survey.

The QC data indicate that some samples may have been contaminated because 93 percent of the FRBs and 92 percent of the TRBs analyzed contained one or more VOCs at concentrations equal to or greater than the method detection limit (MDL). Forty-three of the 56 VOCs detected in source-water samples were reported in 1 or more of the 290 FRBs at concentrations equal to or greater than the MDL, and 20 of these compounds were detected in 1 or more of the 112 TRBs (table 5). Toluene and methylene chloride were the most frequently detected VOCs, reported at concentrations equal to or above their MDLs in nearly three-quarters of the FRB and TRBs, but nine additional VOCs, including MTBE, were reported in more than 10 percent of the FRBs and TRBs (table 5). The contamination was largely low-level, however, and most (80 percent) VOC concentrations in the field and trip blanks were less than the MRL (equal to 0.2 µg/L for all VOCs except for methyl ethyl ketone, which has an MRL of 2.0 µg/L). Still, 25 of the VOCs detected in FRBs and 8 of the VOCs detected in TRBs were measured in some QC samples at concentrations equal to or above the MRL.

The extensive low-level contamination evident in the field QC data prevented reporting the occurrence of VOCs in source water at concentrations below the MRL; however, because contamination was measured in 108 FRBs (37 percent) and 10 TRBs (8.9 percent) at concentrations at or above the MRL, the field QC data were analyzed further to determine the level of uncertainty associated with VOC detection frequencies in source water reported at the MRL. The procedures used to evaluate and quantify the extent of external sample contamination and the implications for the source-water findings are described below.

The additional analysis of field QC data included the following steps. First, the concentrations of VOCs in all source-water and QC-samples were plotted in relation to the sequence in time when each sample was analyzed by the MWDSC laboratory. Such plots can demonstrate the occurrence of temporal anomalies in VOC detections that may represent a systematic bias or periodic contamination that may be related to field and (or) laboratory methods and performance. The results of all source-water and field-QC sample analyses for MTBE and naphthalene, respectively, ordered sequentially by date and time of analysis during the 78-week duration of the Random Survey, are shown in figures 4 and 5. The plots show that although detections of MTBE were measured throughout the period without any apparent bias associated with any particular time increment, the naphthalene detections were more frequent at certain times during the analytical time span. Periods when naphthalene detections were disproportional may correspond to some phenomenon in the laboratory analytical procedure or environment that produced systematic naphthalene contamination of the samples during those periods. Low-level detects (<MRL) of high molecular weight analytes such as naphthalene have been observed to occur after the analysis of a spiked sample and have been attributed to "carry over" of the analyte on the sorbent purge trap (B. Koch, Metropolitan Water District of Southern California, written commun., 2002). Nearly all the naphthalene concentrations were below the MRL of 0.2 µg/L, however, and consequently, any apparent systematic naphthalene contamination would be nullified by conducting the data analysis at that level. Three other analytes—1,2,3-trichlorobenzene, 1,2,4-trichlorobenzene, and *p*-isopropyltoluene—demonstrated similar temporal patterns of clustered detections within specific time periods of the analytical time span, but all detections of the three compounds were below their MRLs and, consequently, are not problematic for interpretations of the source-water data at the MRL.

Table 5. Volatile organic compounds detected in field and trip blanks

[MDL, method detection limit; MRL, minimum reporting level, µg/L, microgram per liter]

Volatile organic compound	Blank		Number of detections		Range of concentration (µg/L)	Frequency of detection (percent)	
	Type	Number	At or above MDL	At or above MRL		At or above the MDL	At or above the MRL
Benzene	field	290	44	2	0.03 - 0.23	15	0.7
Benzene	trip	112	2	0	.03 - .06	1.8	0
Bromobenzene	field	290	1	0	.05	.3	0
Bromobenzene	trip	112	1	0	.04	.9	0
Bromochloromethane	field	290	1	0	.06	.3	0
Bromochloromethane	trip	112	0	0	not detected	0	0
Bromodichloromethane	field	290	9	1	.02 - 5.3	3.1	.3
Bromodichloromethane	trip	112	0	0	not detected	0	0
Bromoform	field	290	2	2	.02 - 1.2	.7	.7
Bromoform	trip	112	0	0	not detected	0	0
Bromomethane	field	290	1	0	.11	.3	0
Bromomethane	trip	112	0	0	not detected	0	0
Chlorodibromomethane	field	290	4	1	.03 - 1.6	1.4	.3
Chlorodibromomethane	trip	112	0	0	not detected	0	0
Chloroform	field	290	61	5	.03 - 12.	21	1.7
Chloroform	trip	112	17	0	.03- .07	15	0
Chloromethane	field	290	2	2	.60 - 1.2	.7	.7
Chloromethane	trip	112	0	0	not detected	0	0
2-Chlorotoluene	field	290	1	0	.05	0.3	0
2-Chlorotoluene	trip	112	0	0	not detected	0	0
1,4-Dichlorobenzene	field	290	8	3	.04 - 3.7	2.8	1.0
1,4-Dichlorobenzene	trip	112	1	0	.08	0	0
1,1-Dichloroethane	field	290	1	0	.12	.3	0
1,1-Dichloroethane	trip	112	0	0	not detected	0	0
1,1-Dichloroethene	field	290	1	0	.09	0.3	0
1,1-Dichloroethene	trip	112	0	0	not detected	0	0
cis-1,2-Dichloroethene	field	290	1	0	.15	.3	0
cis-1,2-Dichloroethene	trip	112	0	0	not detected	0	0
Dibromomethane	field	278	1	0	.07	.4	0
Dibromomethane	trip	112	0	0	not detected	0	0
Dichlorodifluoromethane	field	290	3	2	.13 - .21	1.0	.7
Dichlorodifluoromethane	trip	112	0	0	not detected	0	0

Table 5. Volatile organic compounds detected in field and trip blanks–Continued

[MDL, method detection limit; MRL, minimum reporting level, µg/L, microgram per liter]

Volatile organic compound	Blank		Number of detections		Range of concentration (µg/L)	Frequency of detection (percent)	
	Type	Number	At or above MDL	At or above MRL		At or above the MDL	At or above the MRL
1,2-Dichloropropane	field	278	1	0	0.09	0.4	0
1,2-Dichloropropane	trip	112	0	0	not detected	0	0
1,3-Dichloropropane	field	282	3	0	.03 - .09	1.1	0
1,3-Dichloropropane	trip	112	1	0	.03	.9	0
Ethylbenzene	field	290	104	34	.04 - 1.6	36	12
Ethylbenzene	trip	112	9	1	.04 - 1.1	8.0	.9
Ethyl *tert*-butyl ether	field	290	2	0	.16 - .19	.7	0
Ethyl *tert*-butyl ether	trip	112	0	0	not detected	0	0
Isopropylbenzene	field	290	31	11	.04 - .53	11	3.8
Isopropylbenzene	trip	112	2	1	.04 - .27	1.8	.9
p-Isopropyltoluene	field	290	3	0	.04 - .05	1.0	0
p-Isopropyltoluene	trip	112	1	0	.05	.9	0
Methyl ethyl ketone	field	290	15	4	.81 - 4.0	5.5	1.4
Methyl ethyl ketone	trip	112	0	0	not detected	0	0
Methyl *tert*-butyl ether	field	290	114	10	.04 - .61	39	3.4
Methyl *tert*-butyl ether	trip	112	52	3	.04 - .29	46	2.7
Methylene chloride	field	290	192	19	.02 - 13	69	6.6
Methylene chloride	trip	112	78	0	.03 - .14	70	0
Naphthalene	field	290	38	1	.06 - .21	17	.3
Naphthalene	trip	112	10	0	.06 - .13	13	0
n-Propylbenzene	field	290	33	4	.05 - .32	11	1.4
n-Propylbenzene	trip	112	2	1	.07 - .28	1.8	.9
Styrene	field	290	169	58	.03 - 7.9	58	20
Styrene	trip	112	48	6	.03 - 1.5	43	5.4
tert-Amyl methyl ether	field	287	4	0	.04 - .07	1.4	0
tert-Amyl methyl ether	trip	112	1	0	.04	0.9	0
1,1,2,2-Tetrachloroethane	field	290	2	0	.06 - .09	0.7	0
1,1,2,2-Tetrachloroethane	trip	112	0	0	not detected	0	0
Tetrachloroethene	field	290	9	2	.05 - 12	3.1	.7
Tetrachloroethene	trip	112	0	0	not detected	0	0

Table 5. Volatile organic compounds detected in field and trip blanks–Continued

[MDL, method detection limit; MRL, minimum reporting level, µg/L, microgram per liter]

Volatile organic compound	Blank		Number of detections		Range of concentration (µg/L)	Frequency of detection (percent)	
	Type	Number	At or above MDL	At or above MRL		At or above the MDL	At or above the MRL
Toluene	field	290	208	36	0.03 - 3.4	74	12
Toluene	trip	112	57	2	.03 - 1.7	51	1.8
1,2,3-Trichlorobenzene	field	290	12	0	.05 - .11	4.8	0
1,2,3-Trichlorobenzene	trip	112	1	0	.07	1.8	0
1,2,4-Trichlorobenzene	field	290	14	0	.04 - .16	4.8	0
1,2,4-Trichlorobenzene	trip	112	5	0	.06 - .12	4.5	0
1,1,1-Trichloroethane	field	290	2	1	.15 - .52	.7	.3
1,1,1-Trichloroethane	trip	112	0	0	not detected	0	0
1,1,2-Trichloroethane	field	290	5	0	.02 - .07	1.7	0
1,1,2-Trichloroethane	trip	112	0	0	not detected	0	0
Trichloroethene	field	290	7	3	.04 - 2.9	2.4	1.0
Trichloroethene	trip	112	0	0	not detected	0	0
Trichlorofluoromethane	field	290	5	3	.15 - .28	1.7	1.0
Trichlorofluoromethane	trip	112	0	0	not detected	0	0
1,2,4-Trimethylbenzene	field	290	32	13	.03 - .58	11	4.5
1,2,4-Trimethylbenzene	trip	112	1	0	.03	.9	0
1,3,5-Trimethylbenzene	field	290	12	0	.03 - .13	4.1	0
1,3,5-Trimethylbenzene	trip	112	0	0	not detected	0	0
Vinyl chloride	field	290	1	1	.2	.3	.3
Vinyl chloride	trip	112	0	0	not detected	0	0
m-, *p*-Xylene	field	290	119	63	.07 - 4.0	41	22
m-, *p*-Xylene	trip	112	12	3	.07 - 2.3	11	2.7
o-Xylene	field	290	93	31	.03 - 2.1	32	11
o-Xylene	trip	112	7	1	.03 - 1.5	6.2	.9

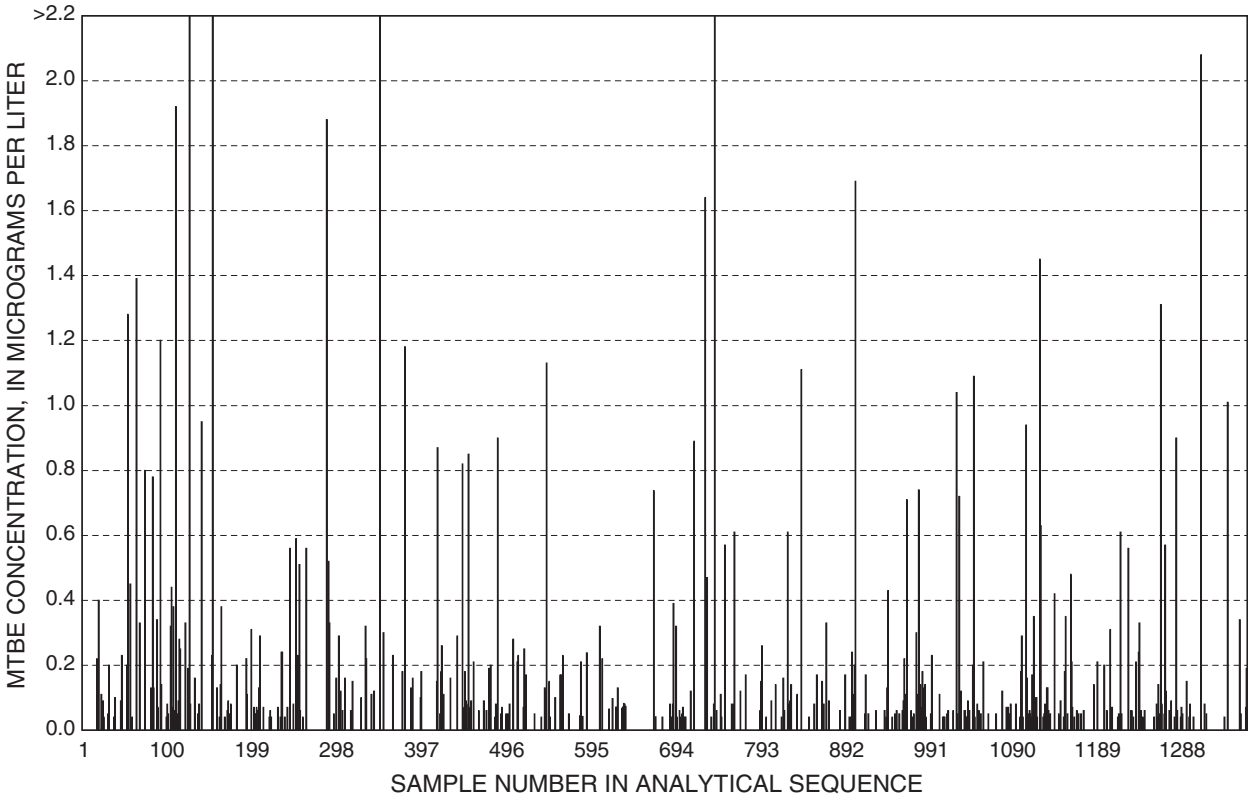

Figure 4. Concentrations of methyl *tert*-butyl ether (MTBE) in all source-water and field quality-control samples analyzed for the Random Survey, plotted sequentially by date and time of analysis.

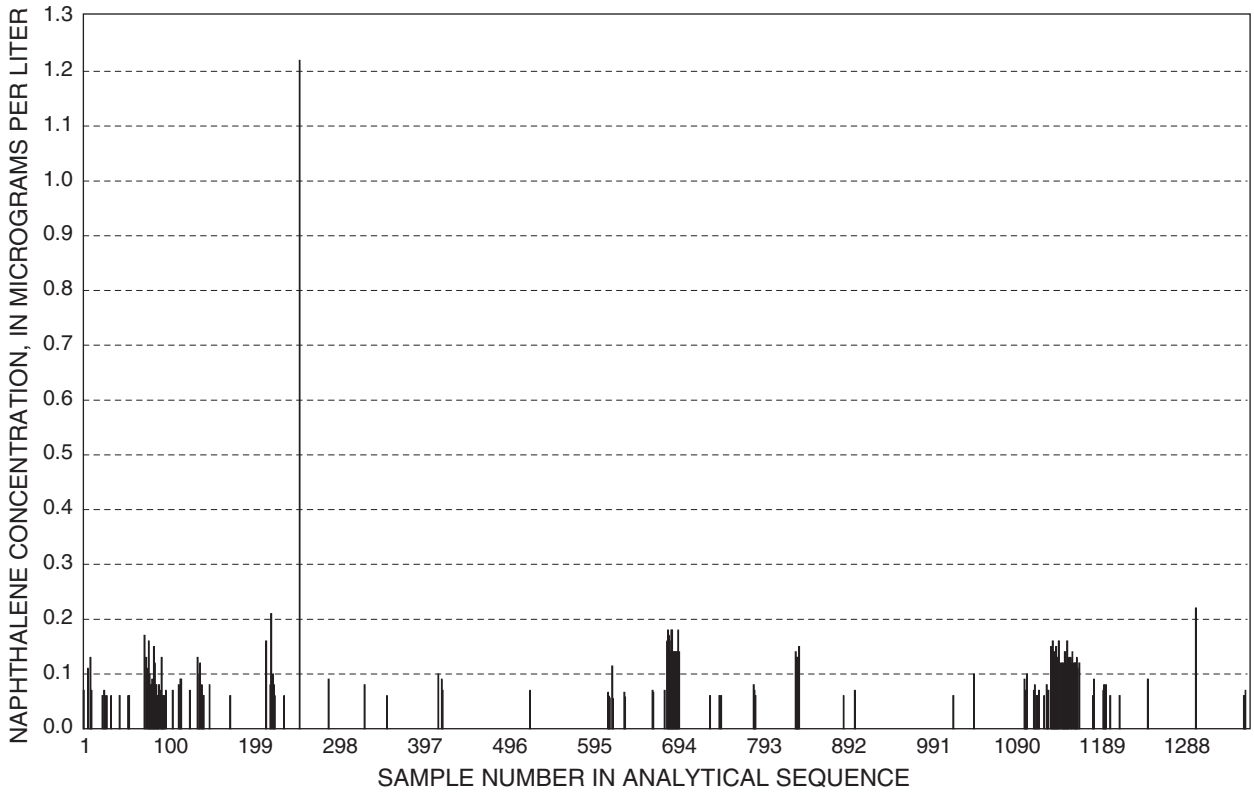

Figure 5. Concentrations of naphthalene in all source-water and field quality-control samples analyzed for the Random Survey, plotted sequentially by date and time of analysis.

Next, the concentration of all VOCs detected in source-water samples were plotted against the concentration of these VOCs in companion FRBs. An example of these plots for *m-, p*-xylene is shown in figure 6. The x-y plots readily identify samples that contain similar concentrations of the same analyte in both source water and FRBs. Nearly equal concentrations in the source-water sample and the field blank may result from simultaneous contamination of the sample and the blank from an external source. For example, figure 6 shows 18 pairs of source-water samples and FRBs containing concentrations of *m-, p*-xylene that plot on or close to a 1:1-ratio line. Because the data do not demonstrate a constant bias in one direction, that is, the source-water concentrations are not always greater than the FRBs, the process that caused contamination of the samples must have been random rather than systematic. Consequently, it is impossible to develop an algorithm to "correct" sample concentrations back to "original" concentrations, but it is necessary to quantify the maximum potential extent of random contamination with respect to reporting the frequency of VOC detection in source water.

An analysis of source-water detections, together with the QC data, can be used to identify and adjust the frequency of detection for the possibility of random sample contamination. First, the data for the source-water samples are subdivided into seven categories (lettered A-D, E1, E2, and F in fig. 7) that relate to the level of uncertainty associated with the validity of VOC detections. Five of the seven categories (A-D and E1) reflect valid results with no random contamination uncertainty (see fig. 7); however, two groups (E2 and F) include measurable and undeterminable (estimated) levels of uncertainty, with regard to random contamination. The lack of VOC detections clearly demonstrates the absence of sample contamination at the MRL. Conditions A, B, and C showed no VOC detections above the MRL, and although detections were noted in the FRBs for condition B, the results from these groups

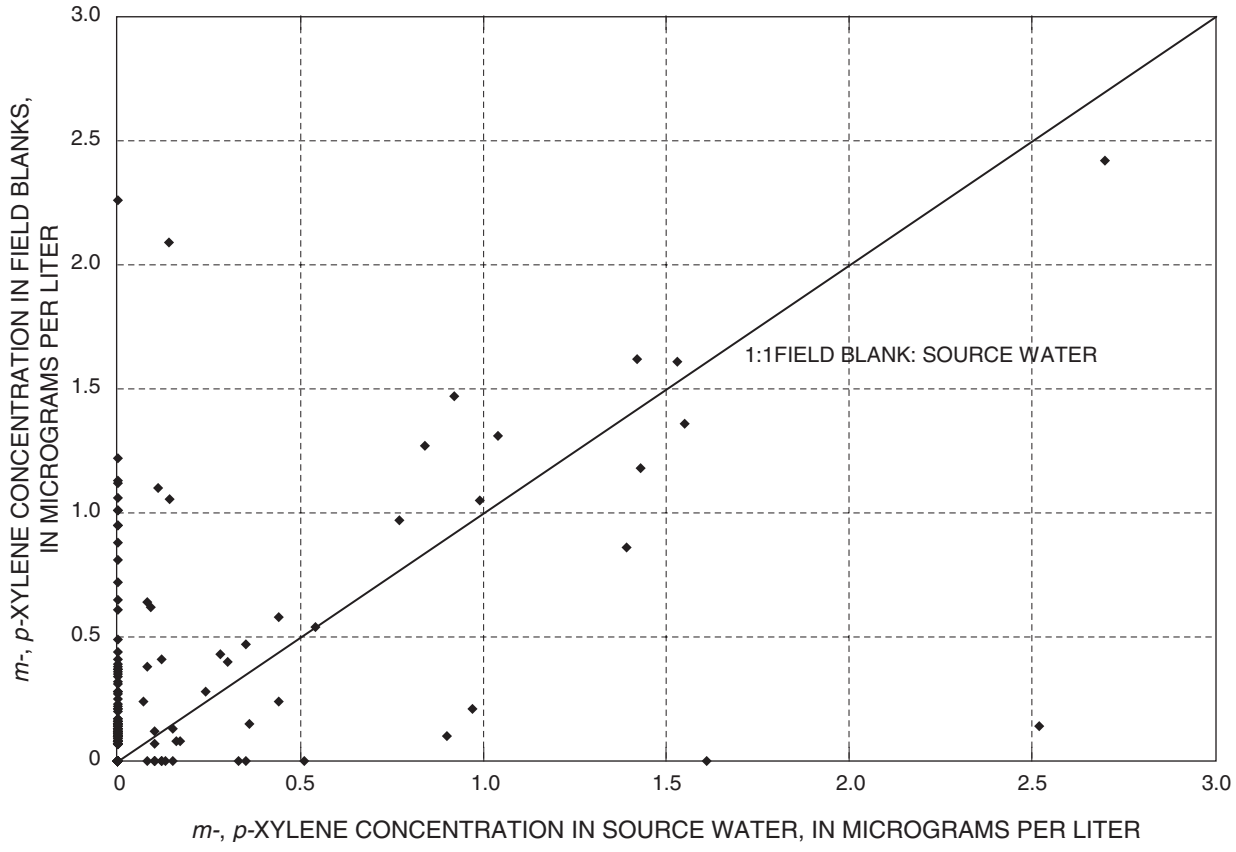

Figure 6. Comparison of concentrations of *m*-, *p*-xylenes in source-water samples and companion field blanks.

were considered to accurately represent the source-water conditions. Similarly, the results for condition D, in which VOCs were detected in the source water and the corresponding FRBs were clean (that is, no VOCs detected), also are considered valid VOC detections because there is no indication of contamination in the FRBs. The validity of two groups of data remain in question: (1) samples that have the same VOCs in the source water and companion field blanks (conditions E1 and E2), and (2) those source-water samples with concentrations of VOC analytes that do not have corresponding FRBs (condition F).

POSSIBILITY OF RANDOM CONTAMINATION OF SOURCE-WATER SAMPLES	CONDITION (MTBE, methyl *tert*-butyl ether)
No random sample contamination	Condition A: Source water = no VOCs detected Field reagent blank = no VOCs detected For MTBE = 189 samples
No random sample contamination	Condition B: Source water = no VOCs detected Field reagent blank = VOCs detected For MTBE = 4 samples
No random sample contamination	Condition C: Source water = no VOCs detected Field reagent blank = not analyzed For MTBE = 662 samples
No random sample contamination	Condition D: Source water = VOCs detected Field reagent blank = no VOCs detected For MTBE = 77 samples
No random sample contamination	Condition E1: Source water = VOCs detected Field reagent blank = same VOCs detected, and source-water concentrations are >5 times field reagent-blank concentrations For MTBE = 0 samples
Random sample contamination suspected	Condition E2: Source water = VOCs detected Field reagent blank = same VOCs detected, and source-water concentrations are < 5 times field reagent-blank concentrations For MTBE = 20 samples
Undetermined possibility of random sample contamination	Condition F: Source water = VOCs detected Field reagent blank = not analyzed For MTBE = 4 samples
Frequency of detection, unadjusted = D+E1+E2+F/A+B+C+D+E1+E2+F for MTBE = (77+0+20+4)/(189+4+662+77+0+20+4) = 101/956 = 10.6 percent	
Frequency of detection, adjusted = C+E1+F/A+B+C+D+E1+F for MTBE = (77+0+4)/(189+4+662+77+0+4) = 81/936 = 8.7 percent	
Estimated frequency of detection that may be attributed to random contamination of source-water samples = frequency of detection, unadjusted - frequency of detection, adjusted for MTBE = 10.6 percent - 8.7 percent = 1.9 percent	

Figure 7. Schematic diagram for adjusting the frequency of detection of volatile organic compounds (VOCs) in source-water samples to reflect possible random sample contamination.

The data for samples with detections of the same VOCs in both the source-water sample and the companion FRB (condition E) were examined and divided into two subcategories—source-water detections that were greater than (condition E1) or less than (condition E2) five times the concentration in the FRB (table 6). Source-water samples with five or more times the concentrations of VOCs measured in FRBs were judged to have virtually no possibility that the source-water concentration was an artifact of random contamination. These samples were rare—only one source-water detection for chloroform, bromodichloro-methane, and bromoform met this criteria. For samples with VOCs at concentrations less than five times the FRB concentration, there was clear possibility that the source-water detection was due to random contamination, particularly when concentrations approached a 1:1 ratio for one or more contaminant. Accordingly, 153 source-water VOC detections that fell under condition E2 were removed from the source-water dataset and are not included in the occurrence of VOCs in source water provided in this report. This is a conservative approach to reporting VOC occurrence, and the author recognizes that the occurrence of the same VOCs in a source-water sample and its companion field blank does not indicate definitively that random contamination of the source-water sample has occurred, but rather only that contamination cannot definitively be ruled out.

Detection of VOCs in FRBs and TRBs confirms contamination of the blank water at some time subsequent to shipment from the MWDSC laboratory. Such contamination has been observed in FRBs without contamination of companion source-water samples (condition B). It is for this reason that the source-water samples with VOC detections but without companion FRBs (condition F) are considered to have some uncertainty associated with the validity of these detections but are not censored from the source-water data in subsequent analysis of the occurrence of VOCs.

The process used to identify source-water samples that may have been affected by random VOC contamination is summarized in figure 7, and VOC-detection frequencies are adjusted accordingly. The adjusted detection frequency is equal to the total number of times a VOC was detected at the MRL minus the number of condition E2 samples (samples with VOC concentrations less than 5 times those in the corresponding FRBs), divided by the total number of samples minus the number of condition E2 samples. The difference between the adjusted detection frequency and the unadjusted detection frequency represents the possible extent of random contamination of source-water samples. The frequency of detection was adjusted downward for 20 of the 42 VOCs detected in source-water samples because some of the VOC detections may be from random contamination.

Differences between the unadjusted frequency of detection in source-water samples and the frequency of detection adjusted for possible random contamination range from 2.3 percent for toluene to 0.1 percent for several VOCs, but are zero for more than half of the 42 VOCs detected in source water (table 7). Random contamination may account for 1 percent or more of the unadjusted detection frequency for seven VOCs including toluene, styrene, *m-, p*-xylene, MTBE, *o*-xylene, ethylbenzene, and 1,2,4-trimethylbenzene. Consequently, for this report, the detection frequency of VOCs at concentrations equal to or exceeding the MRL in source water can be most confidently and conservatively reported to be equal to the adjusted detection frequency. Accordingly, for example, it is reported that 8.7 percent of the source-water samples contained the gasoline additive MTBE at concentrations equal to or exceeding 0.2 µg/L, even though as many as 10.6 percent of sources may have contained MTBE.

Finally, a review of data for the TRBs was conducted to determine if there was a relation between the frequency and concentration of VOC detections in the TRBs and the FRBs for sites where each of these field QC samples were collected. Most of the time (83 percent of all TRB detections) when VOCs were detected in the trip blanks, they also were detected in the field blanks. Among the 105 companion trip and field blanks that were analyzed by the MWDSC, 94 percent of the TRB detections were at concentrations less than the MRL. Two-thirds of the time when the same compound was detected in both blanks, the concentration in the TRB was less than in the FRB. A statistical analysis (Wilcoxon signed-rank test) of the relation between TRB and FRB concentrations indicated that concentrations of 10 of the 20 VOCs detected in both blanks were significantly greater (at the 95-percent confidence level) in FRBs (table 8).

Table 6. Number of source-water samples that meet specified conditions with respect to the possibility of random contamination

Volatile organic compound	Condition (see fig. 7) and number of samples						
	A	B	C	D	E1	E2	F
Chloroform	172	2	654	107	1	8	12
Methyl *tert*-butyl ether	189	4	662	77	0	20	4
Bromodichloromethane	233	1	660	54	1	1	6
Chlorodibromomethane	242	1	659	46	0	1	7
Toluene	239	18	666	10	0	23	0
Bromoform	261	1	661	27	1	0	5
Tetrachloroethene	262	0	665	26	0	2	1
m-, *p*-Xylene	220	44	665	6	0	20	1
Styrene	225	40	665	4	0	21	1
Trichloroethene	264	1	666	22	0	2	0
o-Xylene	252	17	665	5	0	16	1
Ethylbenzene	251	20	665	4	0	15	1
1,2,4-Trimethylbenzene	273	4	666	4	0	9	0
cis-1,2-Dichloroethene	278	0	666	12	0	0	0
1,1-Dichloroethane	279	0	666	11	0	0	0
1,1,1-Trichloroethane	280	0	665	9	0	1	1
Isopropylbenzene	276	5	666	2	0	7	0
1,1-Dichloroethene	283	0	665	7	0	0	1
Carbon tetrachloride	283	0	666	7	0	0	0
Methyl ethyl ketone	285	3	666	5	0	1	0
Trichlorofluoromethane	282	3	666	5	0	0	0
Methylene chloride	268	18	665	2	0	2	1
Benzene	284	2	666	3	0	1	0
1,4-Dichlorobenzene	285	2	665	2	0	1	1
Dichlorodifluoromethane	285	2	666	4	0	0	0
Chloromethane	286	2	665	2	0	0	1
1,2-Dichloroethane	287	0	666	3	0	0	0
Dibromomethane	270	0	645	2	0	0	0
1,2-Dichloropropane	275	0	645	1	0	1	0
Naphthalene	287	1	666	2	0	0	0
1,1,2-Trichloro-1,2,2-trifluoroethane	288	0	666	2	0	0	0
Bromomethane	289	0	665	1	0	0	1
n-Propylbenzene	285	3	666	1	0	1	0
tert-Amyl methyl ether	285	0	666	2	0	0	0
Diisopropyl ether	288	0	666	2	0	0	0
1,2,3-Trichloropropane	289	0	666	1	0	0	0
Vinyl chloride	288	1	666	1	0	0	0
n-Butylbenzene	289	0	666	1	0	0	0
Ethyl *tert*-butyl ether	289	0	666	1	0	0	0
Chloroethane	289	0	666	1	0	0	0
Chlorobenzene	289	0	666	1	0	0	0
1,2-Dichlorobenzene	289	0	666	1	0	0	0

Table 7. Frequency of detection of volatile organic compounds in source-water samples at or above the minimum reporting level adjusted for random contamination

Volatile organic compound	Unadjusted			Adjusted			Difference
	Number of detections	Number of samples	Detection frequency	Number of detections	Number of samples	Detection frequency	
Chloroform	128	956	13.4	120	948	12.7	0.7
Methyl *tert*-butyl ether	101	956	10.6	81	936	8.7	1.9
Bromodichloromethane	62	956	6.5	61	955	6.4	0.1
Chlorodibromomethane	54	956	5.7	53	955	5.6	0.1
Bromoform	33	956	3.4	33	956	3.4	0
Tetrachloroethene	29	956	3.0	27	954	2.8	0.2
Trichloroethene	24	955	2.5	22	953	2.3	0.2
cis-1,2-Dichloroethene	12	956	1.3	12	956	1.3	0
1,1-Dichloroethane	11	956	1.2	11	956	1.2	0
Toluene	33	956	3.4	10	933	1.1	2.3
1,1,1-Trichloroethane	11	956	1.2	10	955	1.0	0.2
m-, *p*-Xylene	27	956	2.8	7	936	0.8	2.0
1,1-Dichloroethene	8	956	0.8	8	956	0.8	0
Carbon tetrachloride	7	956	0.7	7	956	0.7	0
o-Xylene	22	956	2.3	6	940	0.6	1.7
Ethylbenzene	20	956	2.1	5	941	0.5	1.6
Methyl ethyl ketone	6	955	0.6	5	954	0.5	0.1
Trichlorofluoromethane	5	956	0.5	5	956	0.5	0
Styrene	26	956	2.7	5	935	0.5	2.2
1,2,4-Trimethylbenzene	13	956	1.4	4	947	0.4	1.0
Dichlorodifluoromethane	4	956	0.4	4	956	0.4	0
Methylene chloride	5	956	0.5	3	954	0.3	0.2
Benzene	4	956	0.4	3	955	0.3	0.1
1,4-Dichlorobenzene	4	956	0.4	3	955	0.3	0.1
Chloromethane	3	956	0.3	3	956	0.3	0
1,2-Dichloroethane	3	956	0.3	3	956	0.3	0
Isopropylbenzene	9	956	0.9	2	949	0.2	0.7
Dibromomethane	2	922	0.2	2	922	0.2	0
Naphthalene	2	956	0.2	2	956	0.2	0
1,1,2-Trichloro-1,1,2-trifluoroethane	2	956	0.2	2	956	0.2	0
Bromomethane	2	956	0.2	2	956	0.2	0
tert-Amyl methyl ether	2	956	0.2	2	956	0.2	0
Diisopropyl ether	2	956	0.2	2	956	0.2	0
n-Propylbenzene	2	956	0.2	1	955	0.1	0.1
1,2-Dichloropropane	2	922	0.2	1	921	0.1	0.1
1,2,3-Trichloropropane	1	956	0.1	1	956	0.1	0
Vinyl chloride	1	956	0.1	1	956	0.1	0
n-Butylbenzene	1	956	0.1	1	956	0.1	0
Ethyl *tert*-butyl ether	1	956	0.1	1	956	0.1	0
Chloroethane	1	956	0.1	1	956	0.1	0
Chlorobenzene	1	956	0.1	1	956	0.1	0
1,2-Dichlorobenzene	1	956	0.1	1	956	0.1	0

Table 8. Statistical comparison of the concentrations of volatile organic compounds in 105 companion field blanks and trip blanks

[FRB, field reagent blank; TRB, trip reagent blank; Ho, null hypothesis; <, less than; >, more than; p-values <0.05 significant at 95-percent confidence level shown in bold]

Volatile organic compound	Number of detections in field blanks	Number of detections in trip blanks	Null hypothesis tested and p-value		
			Ho: FRB=TRB	Ho: FRB<TRB	Ho: FRB>TRB
Toluene	88	54	**<0.0001**	**<0.0001**	1.0
Styrene	71	44	**<0.0001**	**<0.0001**	1.0
m-, *p*-Xylene	39	10	**<0.0001**	**<0.0001**	1.0
Ethylbenzene	33	8	**<0.0001**	**<0.0001**	1.0
o-Xylene	29	6	**<0.0001**	**<0.0001**	1.0
Chloroform	36	16	**0.0001**	**0.0001**	0.9999
n-Propylbenzene	12	2	**0.0037**	**0.0019**	0.9982
Isopropylbenzene	12	2	**0.0041**	**0.0021**	0.9980
1,2,4-Trimethylbenzene	8	1	**0.0047**	**0.0024**	0.9977
Methylene chloride	71	75	**0.0286**	**0.0143**	0.9858
1,2,3-Trichlorobenzene	3	1	0.0843	0.9589	0.3173
Benzene	6	2	0.1564	0.9228	0.0782
Methyl *tert*-butyl ether	42	48	0.2282	0.8866	0.1141
1,2,4-Trichlorobenzene	4	4	0.3173	0.8437	0.1587
Bromobenzene	0	1	0.3219	0.1610	0.8436
1,4-Dichlorobenzene	1	1	0.3219	0.1610	0.8436
tert-Amyl methyl ether	0	1	0.3219	0.1610	0.8436
Naphthalene	11	9	0.7948	0.2068	0.1564
1,3-Dichloropropane	1	1	1.0	0.5054	0.5000
p-Isopropyltoluene	1	1	1.0	0.5027	0.5027

Larger concentrations of VOCs in FRBs than in TRBs may indicate that the source of contamination for these compounds was present at the source-water site, as the field blanks were opened to the atmosphere only at those locations, whereas the trip blanks were not. There were too few (less than 10) detections for eight VOC analytes (table 8) to discern differences between the FRB and TRB concentrations for these compounds. For MTBE and naphthalene, there were sufficient detections for valid statistical analysis; however, no significant differences were observed in either blank type. Consequently, the low-level contamination evident in field blanks for MTBE and naphthalene may not be field related.

In summary, the review of field QC and source-water data suggests that random contamination of some source-water samples may have occurred for some VOC analytes even at concentrations censored at the MRL. The strategy ultimately selected to calculate the frequency of detection of each analyte in the Random Survey was to exclude detections for source-water samples when evidence of possible random contamination for that analyte existed (condition E2 in table 6 and fig. 7). As such, the occurrence of VOCs in source water reported by the Random Survey has been adjusted downward for the extent of random contamination determined from the field QC samples collected as part of this survey.

Collectively, laboratory and field quality-control data and the above-noted procedures used to calculate VOC detection frequencies provide a high assurance of the validity of reported detections. To be included as a detection in the Random Survey, a compound tentatively identified from the analysis of a source-water sample must have passed all three of the following criteria:

- The compound was positively identified via its fragmentation pattern;
- Detection of the compound was not due to laboratory contamination; and
- Detection of the compound was not due to field contamination.

Collection of Ancillary Information

In addition to source-water and quality-control samples, ancillary information was collected from the participating CWSs and other sources. This information was needed for statistical analysis and to determine possible relations between the occurrence of MTBE or other VOCs in the source-water samples and anthropogenic factors. Ancillary information included location (latitude and longitude) of the drinking-water sources sampled (well or intakes); actual population served by the CWS; source-water characteristics (for example, well depth, yield, aquifer type, surface-water type and size, intake specifics, and any previous water-quality problems); areal patterns of MTBE and other fuel-oxygenate use; land use; population density; and known or potential point-source locations of VOCs (toxic release inventory sites, leaking underground storage tanks, and Resource Conservation and Recovery Act and Comprehensive Environmental Response, and Compensation and Liability Act regulated sites) near the sampled drinking-water sources. This information was obtained from available data bases and (or) collected directly from participating CWSs through their responses to a mail-in questionnaire.

Information on the precise location of drinking-water sources often is missing from the SDWIS data base; therefore, latitude and longitude information was requested from each of the participating CWSs for each drinking-water source sampled (intake or well). If latitude and longitude were not available, the CWSs was asked to locate the well or intake on a topographic map, from which USGS personnel determined the latitude and longitude. To confirm latitude and longitude locations (if provided) or to determine the location of the drinking-water source if not, a follow-up telephone call was made during which the CWS contact was asked to verbally describe the location of the well or intake to USGS personnel. Latitude and longitude was then determined or confirmed using DeLorme Street Atlas/Topo USA software (DeLorme, Yarmouth, Maine), and it was entered into a geographical information system (GIS). The results of the analysis that use the locational information obtained for this study are included in a later section of this report, however, the locations of drinking-water sources are not releaseable under current (2002) USGS Homeland Security policy.

A short questionnaire was filled out during an initial telephone interview with CWS staff when they agreed to participate in the Random Survey. The initial questionnaire was used to verify basic information obtained from the SDWIS data base for the selected utility, obtain some additional information on the source waters to be sampled, and identify the persons and means for further contact. A more detailed written questionnaire (Ivahnenko and others, 2001, appendix A, p. 27-34) was subsequently delivered to the CWS with their sample kit. The written questionnaire requested information about the source water, intake location, filtration and treatment, distribution area, actual population served, and the quality and quantity of water delivered by suppliers. Specific information requested on the questionnaire included well characteristics, aquifer type, vulnerability of ground-water sources, and watershed protection and watercraft-use characteristics of surface-water sources.

Participation in the mail-in questionnaire survey was remarkably high—99 percent of the CWSs participated and 941 responses to the written questionnaire were received. The responses to 70 questions posed by the questionnaire were tabulated and are presented in appendix 1 of this report. This information provides valuable insight into environmental conditions and operational characteristics of drinking-water sources sampled for the Random Survey. To the extent possible, this information will be extrapolated to provide support to observations and conclusions regarding the occurrence and distribution of MTBE and other VOCs in source water. To some degree, however, the utility of the ancillary information from the mail-in questionnaire is constrained by the relatively high number of responses with missing or ambiguous information for some questions (see appendix 1).

National geospatial data on land use (Vogelmann and others, 2001), population density (Price and Clawges, 1999), and point-source locations of VOCs (Vista Information Systems, 1999) were used to augment the ancillary information obtained from the mail-in questionnaire and to provide a consistent coverage for all participating CWSs. Information on MTBE or other fuel-oxygenate use was compiled from USEPA documentation (U.S. Environmental Protection Agency, 1999b; 1999c) and industry surveys. This ancillary information was used to identify important natural and anthropogenic factors associated with the locations of drinking-water sources that relate to the frequency and concentration of MTBE and other VOCs observed in source water.

OCCURRENCE AND DISTRIBUTION OF VOLATILE ORGANIC COMPOUNDS IN DRINKING-WATER SOURCES

The 954 source-water samples collected from May 3, 1999 to October 23, 2000 by the participating CWSs were analyzed for VOCs by the MWDSC laboratory and are the basis for the findings of the Random Survey. The data include analyses for 66 VOCs in 579 ground-water and 375 surface-water samples (table 4). Some samples for six compounds— dibromomethane, 1,2-dichloropropane, 1,3-dichloropropane, bromochloromethane, trichloroethene, and methyl ethyl ketone—did not meet the daily calibration control checks (83 times collectively), and consequently, these analytes were not reported by the MWDSC laboratory. Also, as discussed previously in this report, a review of quality-control data identified 153 VOC detections at the MRL that may have resulted from random contamination of source-water samples (condition E2 samples in table 6), and these analytical determinations were removed from the source-water database. Consequently, 22 analytes were reported in fewer than 954 source-water samples (see appendix 2). A total of 62,728 (99.6 percent) of 62,964 potential VOC analytical determinations of the 66 target analytes are included in this analysis.

Forty-two of the 66 target VOC analytes were detected in at least 1 source-water sample at a concentration equal to or greater than its MRL. Eleven compounds were detected in more than 1.0 percent of source-water samples (fig. 8A), whereas 31 VOCs were detected in fewer than 1.0 percent of the samples (fig. 8B). One or more VOCs were detected in 257 (27 percent) of the 954 source-water samples at concentrations equal to or exceeding the MRL. The number of detections at or above the MRL, the frequency of detection at the MRL, and the range of concentrations of all VOCs detected in the source-water samples is tabulated by type of source water and size of CWS in appendix 2.

Chloroform was the most frequently detected VOC, reported at concentrations equal to or greater than 0.2 µg/L in 120 (nearly 13 percent) of the source-water samples (fig. 8A). MTBE was the second most frequently detected VOC, reported in 81 (8.7 percent) of the source waters sampled (fig. 8A). Other VOCs detected in 10 or more source-water samples (fig. 8A) include three additional trihalomethanes—bromodichloromethane, chlorodibromomethane, and bromoform—several commonly used solvents or their degradation by-products— tetrachloroethene, trichloroethene, *cis*-1,2-dichloroethene, 1,1-dichloroethane, and 1,1,1-trichloroethane—and one other gasoline compound, toluene. All other VOCs detected in source waters (fig. 8B) were detected rarely (in fewer than 10 source-water samples).

Although VOCs were detected in about one-quarter of the source waters sampled, VOC concentrations were small. About 95 percent of the total 530 VOC detections reported by the MWDSC laboratory were at concentrations less than 10 µg/L, and nearly two-thirds of all detections (63 percent) were less than 1.0 µg/L. However, eight source-water samples contained concentrations of 1,1-dichloroethene, tetrachloroethene, trichloroethene, and (or) vinyl chloride that would exceed USEPA's MCLs if the samples represented finished drinking water. All but one of these elevated concentrations were in samples from ground-water sources (one surface-water sample contained slightly more than 5 µg/L of tetrachloroethene and one other surface-water sample exceeded the total trihalomethane (TTHM) MCL of 80 µg/L. The cumulative distribution of the concentrations of VOCs detected in source-water samples (fig. 9) shows that concentrations were similar in ground water and surface water.

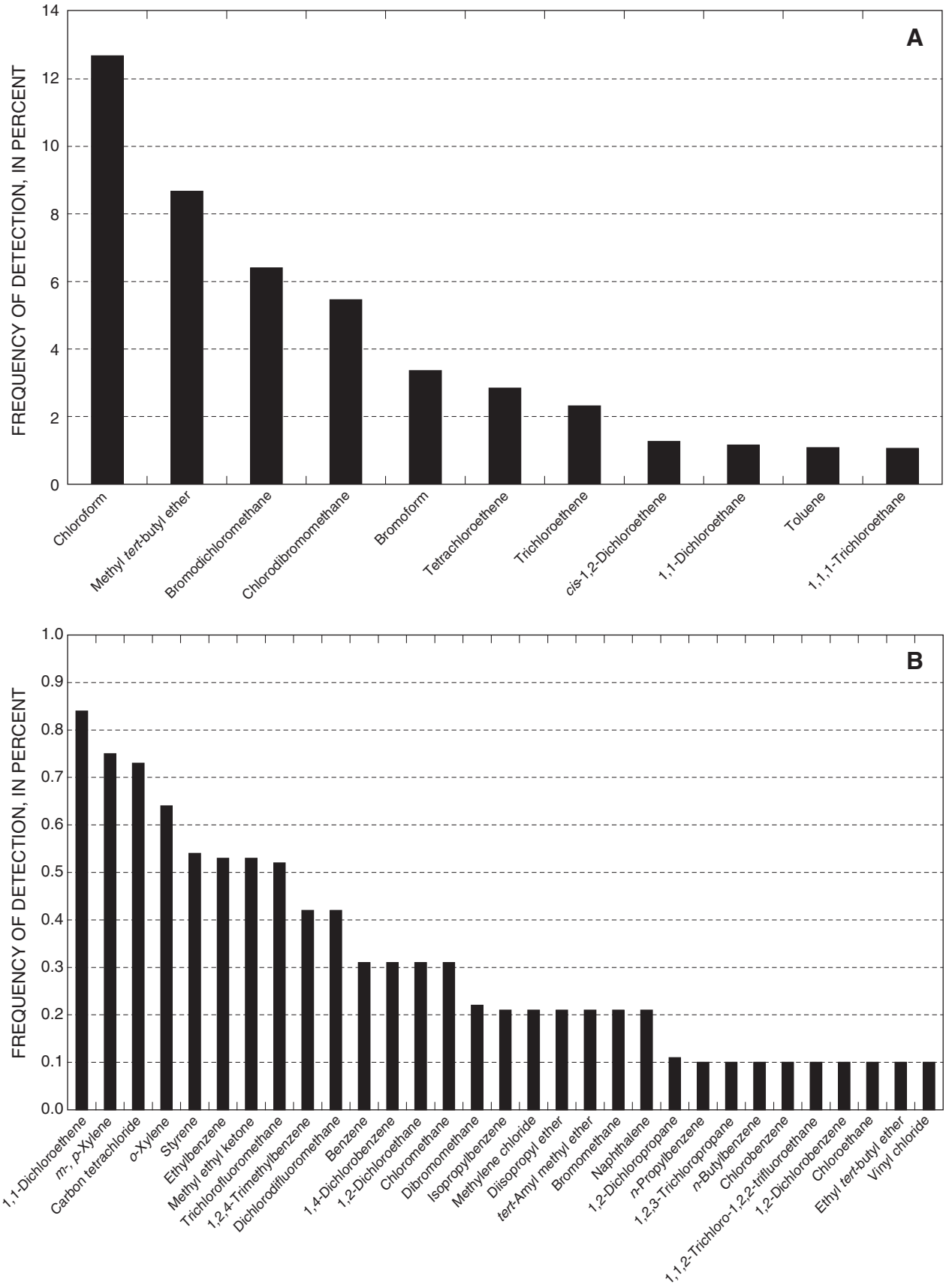

Figure 8. Frequency of detection of volatile organic compounds detected in (A) more than 1.0 percent of source-water samples and (B) less than 1.0 percent of source-water samples.

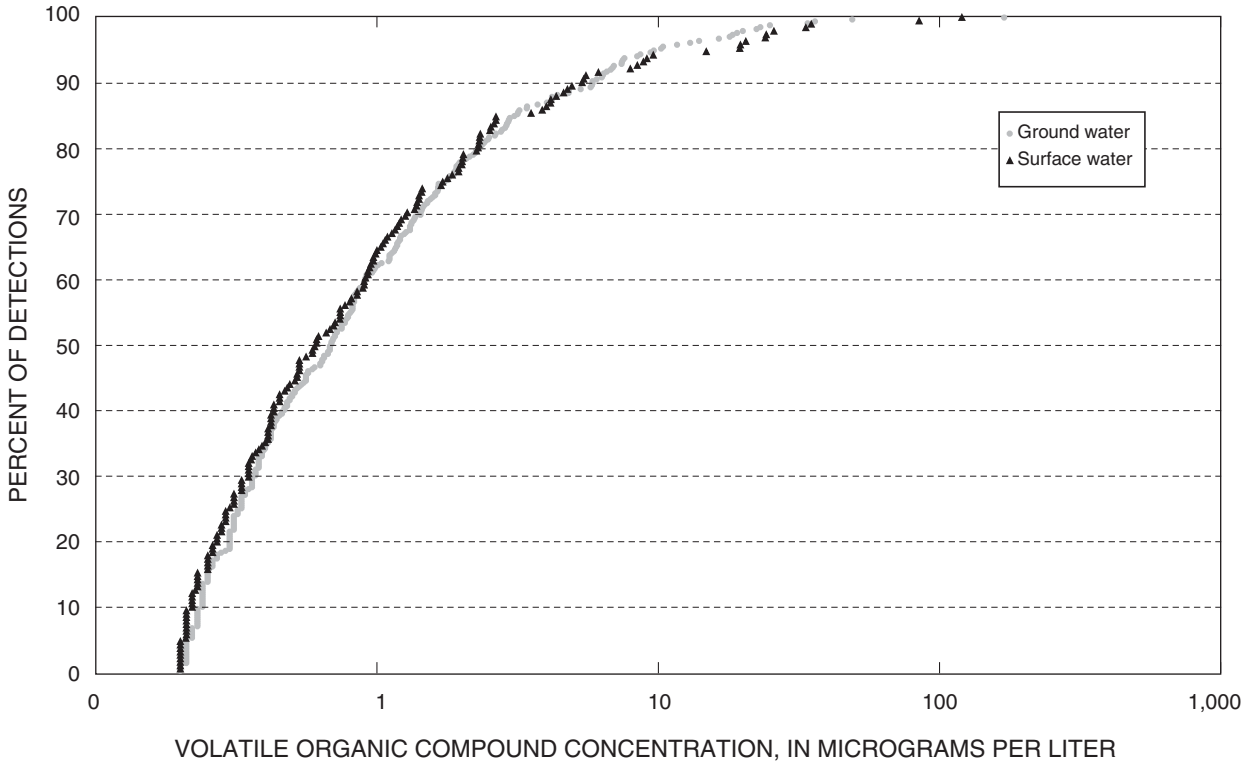

Figure 9. Cumulative distribution of concentrations of volatile organic compounds detected in source-water samples from ground-water and surface-water sources.

When VOCs were detected in source-water samples, co-occurrence of several VOCs was fairly common, with multiple detections in nearly half (47 percent) of the 257 samples with VOC detections. Ground-water sources were more likely to contain multiple VOCs than surface-water sources (fig. 10), particularly when five or more VOCs occurred together. One ground-water sample contained 17 individual compounds and another contained 10 compounds. The percent co-occurrence among the 42 VOCs detected in source-water samples is equal to the number of times compound X also was detected among the samples that contained compound Y, multiplied by 100 (appendix 3). The appendix shows that 46 pairs of VOCs co-occurred at least 20 percent of the time (when 10 or more samples contained 1 of the paired VOCs), and that 17 pairs exhibited co-occurrence 50 percent or more of the time. Co-occurrence of VOCs in source-water samples most frequently involved detections of solvents, THMs, and gasoline compounds.

Co-occurrence can take place when several VOCs have a common source; for example, the presence of several trihalomethanes in a sample may be related to disinfection with chlorine, or the co-occurrence of several BTEX compounds suggests a gasoline source. A high percentage of co-occurrence also can reflect the degradation of parent VOC compounds to their by-products, for example, the co-occurrence of tetrachloroethene and trichloroethene in 83 and 91 percent, respectively, of the source-water samples that contained *cis*-1,2-dichloroethene. By contrast, the co-occurrence of multiple VOCs from different subgroups, including MTBE, chloroform and other trihalomethanes, and several common solvents in source-water samples does not necessarily imply a common source for these contaminants. Rather, their frequent co-occurrence may be an artifact of their overlapping widespread occurrence.

The 42 VOCs detected in source water at concentrations equal to or greater than the MRL are classified in table 9 into 6 subgroups based on their most common use or probable source relative to their occurrence in water. These include (1) disinfection by-products, (2) gasoline compounds, (3) solvents, (4) refrigerants, (5) VOCs used in the synthesis of other organic chemicals, and (6) fumigants. Similarities in the uses and (or)

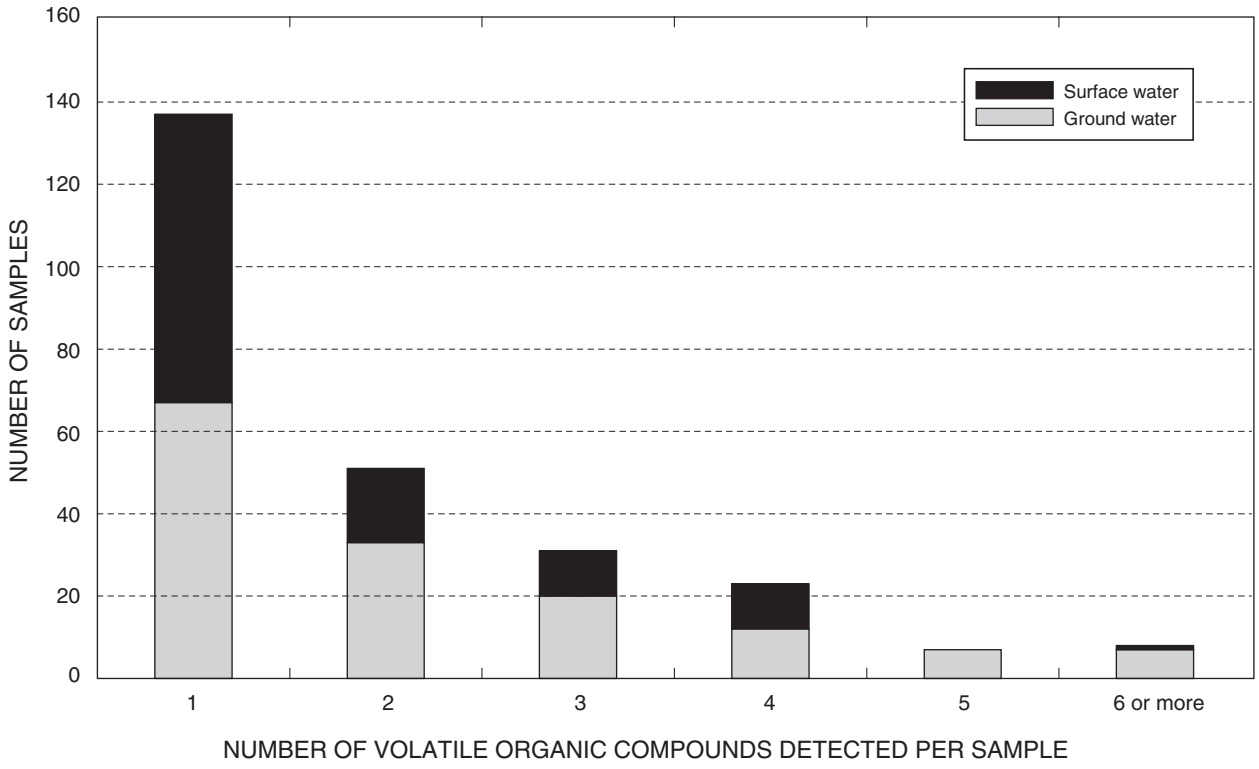

Figure 10. Number of volatile organic compounds detected in source-water samples from ground-water and surface-water sources.

sources of VOCs in each of the six subgroups may be reflected in their occurrence or co-occurrence and their distribution. Although most VOCs have numerous uses in industry, commerce, and household applications, the purpose of identifying a predominant use or source subgroup is to facilitate comparisons of their occurrence and distribution by type of source water, size of CWSs, as well as by anthropogenic factors later in this report. This classification does not imply that other uses or sources for specific compounds do not exist.

Comparison by Type of Source Water and Size of Community Water System

Proportionally, slightly more surface-water samples (30 percent) than ground-water samples (25 percent) contained VOCs, but the differences in detection frequency by type of source water were not statistically significant for most VOC subgroups (table 10). A contingency-table analysis showed that gasoline compounds in general, and MTBE in particular, were detected significantly more frequently in surface-water samples than ground-water samples. BTEX compounds also were detected more frequently in surface water than in ground water, but the number of BTEX detections were too few to demonstrate a statistically significant relation with source-water type. The elevated detection frequencies for gasoline-related VOCs in surface waters may relate to watercraft use on the affected water bodies. Because most concentrations of gasoline compounds were small, atmospheric and (or) storm-water runoff sources also may contribute to the more frequent detections (Delzer and others, 1996; Lopes and Bender, 1998; Bender and others, 2000). Incidents of contamination of ground water from solvents are well-documented, and these compounds were detected more frequently in samples from ground-water sources than from surface-water sources in the Random Survey, as were the rarely detected chlorofluorocarbon refrigerants. Generally, the number and variety of compounds detected were greater for ground-water samples than for surface-water samples. VOCs would likely be subjected to faster and more effective dilution and degradation processes in surface water than in ground water.

Table 9. Chemical subgroups of volatile organic compounds detected in source-water samples

Chemical use or source subgroup	Compounds detected (listed in order of decreasing detection frequency)	Number of detections	Number (percent) of samples with detections
Disinfection by-products	Chloroform, bromodichloromethane, chlorodibromoethane, bromoform	265	141 (15)
Gasoline compounds	Methyl *tert*-butyl ether, toluene, *m*-, *p*-xylene, *o*-xylene, ethylbenzene, benzene, diisopropyl ether, *tert*-amyl methyl ether, naphthalene, ethyl *tert*-butyl ether, *n*-butylbenzene	120	94 (9.8)
Solvents	Tetrachloroethene, trichloroethene, *cis*-1,2-dichloroethene, 1,1-dichloroethane, 1,1,1-trichloroethane, 1,1-dichloroethene, carbon tetrachloride, methyl ethyl ketone, 1,2-dichloroethane, dibromomethane, methylene chloride, 1,2-dichloropropane, chlorobenzene, chloroethane, 1,2-dichlorobenzene, *n*-propylbenzene, 1,2,3-trichloropropane	115	60 (6.3)
Refrigerants	Trichlorofluoromethane, dichlorodifluoromethane, chloromethane, 1,2,2-trichloro-1,1,2-trifluoroethane	13	10 (1.0)
Organic synthesis compounds	Styrene, 1,2,4-trimethylbenzene, isopropylbenzene, vinyl chloride	12	10 (1.0)
Fumigants	1,4-dichlorobenzene, bromomethane	5	5 (0.5)

Table 10. Statistical comparison of the occurrence of volatile organic compounds in source-water samples by type of source water

[<, less than]

Volatile organic compound, subgroup, or related compounds	p-value[1]	Type of source water and frequency of detection (population[2])	
		Percentage of surface-water samples	Percentage of ground-water samples
Any volatile organic compound	0.1567	30 (A)	25 (A)
Trihalomethanes	0.6086	14 (A)	16 (A)
Non-trihalomethane compounds	0.113	18 (A)	14 (A)
Any gasoline compound	**<0.0001**	15 (B)	6.6 (A)
Methyl *tert*-butyl ether	**<0.0001**	14 (B)	5.4 (A)
BTEX[3] compounds	0.4877	2.4 (A)	1.6 (A)
Solvents	**0.0001**	2.4 (A)	8.8 (B)
Refrigerants	**0.0256**	0 (A)	1.7 (B)
Fumigants	0.6236	.8 (A)	.3 (A)
Organic synthesis compounds	0.3071	1.6 (A)	.7 (A)

[1]p-value is the attained significance level; values shown in bold are significant at the 95-percent confidence level.
[2]Source-water type populations that share the same letter are not significantly different at the 95-percent confidence level.
[3]Benzene, toluene, ethylbenzene, and *m*-, *o*- and *p*-xylenes.

For most VOC subgroups, detections were more frequent in samples from the very large water systems (table 11), particularly for ground-water sources. A contingency-table analysis of detection frequencies in surface-water sources by size category, however, found few significant differences at the 95-percent confidence level. Overall, the frequency of detecting any VOC at or above the MRL was greatest (42 percent) in ground-water sources used by the very large systems (table 11) followed by (33 percent) surface-water sources for medium-sized systems. However, VOCs were detected in nearly 20 percent or more of source-water samples for all source-size categories. Although detections of any VOC collectively were significantly more frequent in ground-water sources of very large CWSs than in ground water supplying very small, small, and medium-sized CWSs, the p-value for this comparison is even more significant when the four trihalomethane compounds are removed and only non-trihalomethane compound detections are compared (see table 11). Detections of any gasoline compound, solvent, and refrigerant also were significantly more frequent in ground-water sources to very large CWSs (table 11) than in ground-water sources of smaller-sized CWSs.

Table 11. Statistical comparison of the occurrence of volatile organic compounds in source-water samples by type of source water and size of community water systems

[CWSs, community water systems]

Volatile organic compound or related compounds	Type of source water	p-value[1]	Size of CWSs and frequency of detection (population)[2]				
			Very small	Small	Medium	Large	Very large
Any volatile organic compound	Ground water	**0.0381**	26 (A)	20 (A)	20 (A)	24 (AB)	42 (B)
	Surface water	0.7714	25 (A)	19 (A)	33 (A)	29 (A)	31 (A)
Trihalomethanes	Ground water	0.4030	18 (A)	13 (A)	12 (A)	9.5 (A)	17 (A)
	Surface water	0.4635	8.3 (A)	16 (A)	24 (A)	16 (A)	12 (A)
Non-trihalomethane volatile organic compounds	Ground water	**0.0001**	11 (A)	12 (A)	10 (A)	19 (AB)	36 (B)
	Surface water	0.2190	17 (A)	3.8 (A)	17 (A)	15 (A)	22 (A)
Any gasoline compound	Ground water	**0.0466**	5.8 (A)	5.0 (AB)	2.0 (A)	9.5 (AB)	15 (B)
	Surface water	0.1414	8.3 (A)	0 (A)	13 (A)	14 (A)	18 (A)
Methyl *tert*-butyl ether	Ground water	0.0511	4.8 (A)	3.4 (A)	2.0 (A)	8.2 (A)	13 (A)
	Surface water	0.1054	8.3 (A)	0 (A)	6.7 (A)	13 (A)	17 (A)
BTEX[3] compounds	Ground water	0.5642	1.7 (A)	0.8 (A)	0 (A)	1.6 (A)	3.8 (A)
	Surface water	0.0678	0 (A)	0 (A)	10 (A)	2.5 (A)	1.8 (A)
Solvents	Ground water	**<0.0001**	4.1 (A)	8.3 (AB)	8.0 (AB)	14 (BC)	30 (C)
	Surface water	0.2687	8.3 (A)	0 (A)	6.7 (A)	2.5 (A)	1.8 (A)
Refrigerants	Ground water	**0.0002**	1.4 (A)	0 (A)	2.0 (AB)	0 (AB)	9.4 (B)
	Surface water	1.0000	0 (A)	0 (A)	0 (A)	0 (A)	0 (A)
Fumigants	Ground water	0.3572	0.3 (A)	0 (A)	0 (A)	0 (A)	1.9 (A)
	Surface water	0.7450	0 (A)	0 (A)	0 (A)	0 (A)	1.3 (A)
Organic synthesis compounds	Ground water	0.0619	0.7 (A)	0 (A)	0 (A)	0 (A)	3.8 (A)
	Surface water	**0.0245**	8.3 (AB)	3.8 (AB)	6.7 (B)	1.3 (AB)	0.4 (A)

[1]p-value is the attained significance level; values shown in bold are significant at the 95-percent confidence level.
[2]Source-size populations that share the same letter symbol are not significantly different at the 95-percent confidence level.
[3]Benzene, toluene, ethylbenzene, and *m*-, *o*- and *p*-xylenes.

The more frequent occurrence of VOCs in source waters used by larger CWSs likely reflects the greater proximity of drinking-water sources for larger systems to high-population density, urban areas compared to the locations of drinking-water sources for the smaller CWSs (fig. 11). Urban land use and high-population density have been shown to be related to increased VOC detection frequencies in a number of previous studies (Reiser and O'Brien, 1998; Grady, 1994; Grady and Mullaney, 1998; Squillace and others, 1999; Bush and others, 2000). The relations between the occurrence of VOCs and population density and urban land use are evaluated further in a later section of this report.

Trihalomethane Disinfection By-Products

Four trihalomethane compounds—chloroform, bromodichloromethane, chlorodibromomethane, and bromoform—are among the by-products commonly generated by the disinfection of drinking-water supplies with chlorine and (or) bromine. The four THM compounds were among the five most frequently detected VOCs in the source-water samples (fig. 8A) and, collectively, were detected in 14 percent of the surface-water sources and in 16 percent of the ground-water sources (table 10). Detections of chloroform and bromodichloromethane (fig. 12) were slightly more common in source-water samples from rivers than in samples from ground water or reservoirs, but detection frequencies of all four THMs were comparable (that is, not significantly different) among the three source-water types. Furthermore, the frequency of detection of THMs was not particularly related to CWS size—proportionally, just as many source-water samples from very small ground-water systems had THM detections as did samples from the very large ground-water systems (table 11), and medium-sized surface-water CWSs reported the most frequent THM detections among the surface-water sources.

Because the Random Survey specifically targeted untreated source waters, the widespread occurrence of THMs was not anticipated. The presence of THMs and other disinfectant by-products in finished drinking water has been well-documented (Westrick,

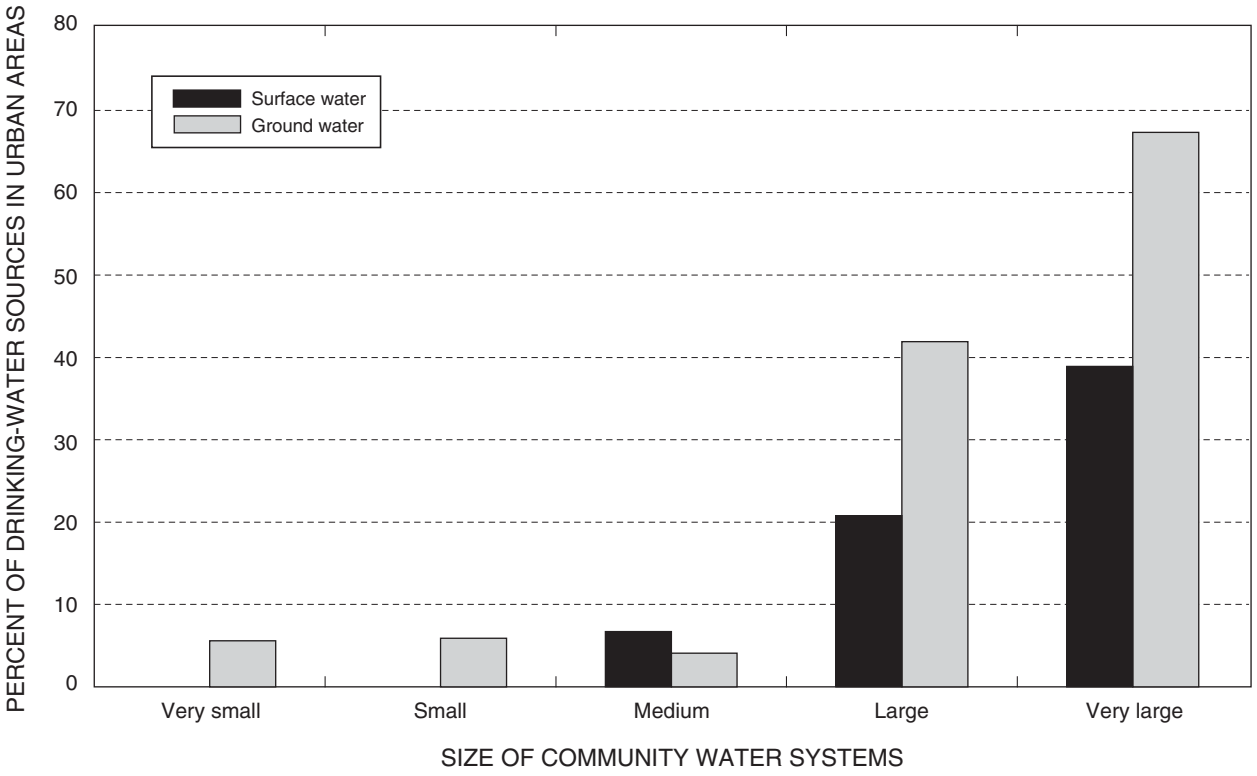

Figure 11. Relation between size of community water systems and percentage of drinking-water sources in urban areas.

1990; Minear and Amy, 1995; Pomes and others, 1999). Grady and Casey (2001) reported that drinking water supplied by nearly half of all CWSs surveyed in that study contained one or more of the four THMs. Indeed, drinking-water suppliers are required to maintain sufficient chlorine residual levels in their water-distribution systems to prevent the existence of waterborne pathogens. It is possible that samplers from some of the participating CWSs misinterpreted the sample-collection instructions and collected finished-water samples rather than source-water samples. Alternatively, some CWSs report that they back flush their filters with chlorinated water that is discharged back into the source waters. The cause of the anomalous occurrence of concentrations of the total of the four trihalomethane compounds (THMs) in excess of 20 µg/L in nine source-water samples and in excess of the 80-µg/L MCL in one sample (fig. 13) is undetermined.

Chloroform in source waters could originate from sources other than a by-product of disinfection, including manufacture of pharmaceuticals, dry cleaning, fire extinguishers, and fumigants. However, chloroform frequently co-occurred in source-water samples with other THMs in the following proportions: chloroform > bromodichloromethane > chlorodibromomethane > bromoform. THMs in chlorinated water typically are present in the same proportions. An explanation for widespread low-level THM detections in source waters is that they may represent residual concentrations of disinfectant by-products that formed initially at water or wastewater-treatment plants. Disinfectant by-product residuals persist in the environment from irrigation of lawns and parks, sewer exfiltration, and treatment-plant effluents. They circulate in surface water and ground water until intercepted by water-supply intakes and are detected in the source-water samples. Ambient ground water was reported to frequently contain THMs, particularly chloroform, that was attributed to infiltration of treated water used to water lawns or from leaky water and sewer lines, but median concentrations were less than 1.0 µg/L (Squillace and others, 1999). THM concentrations measured in the source-water samples were similar,

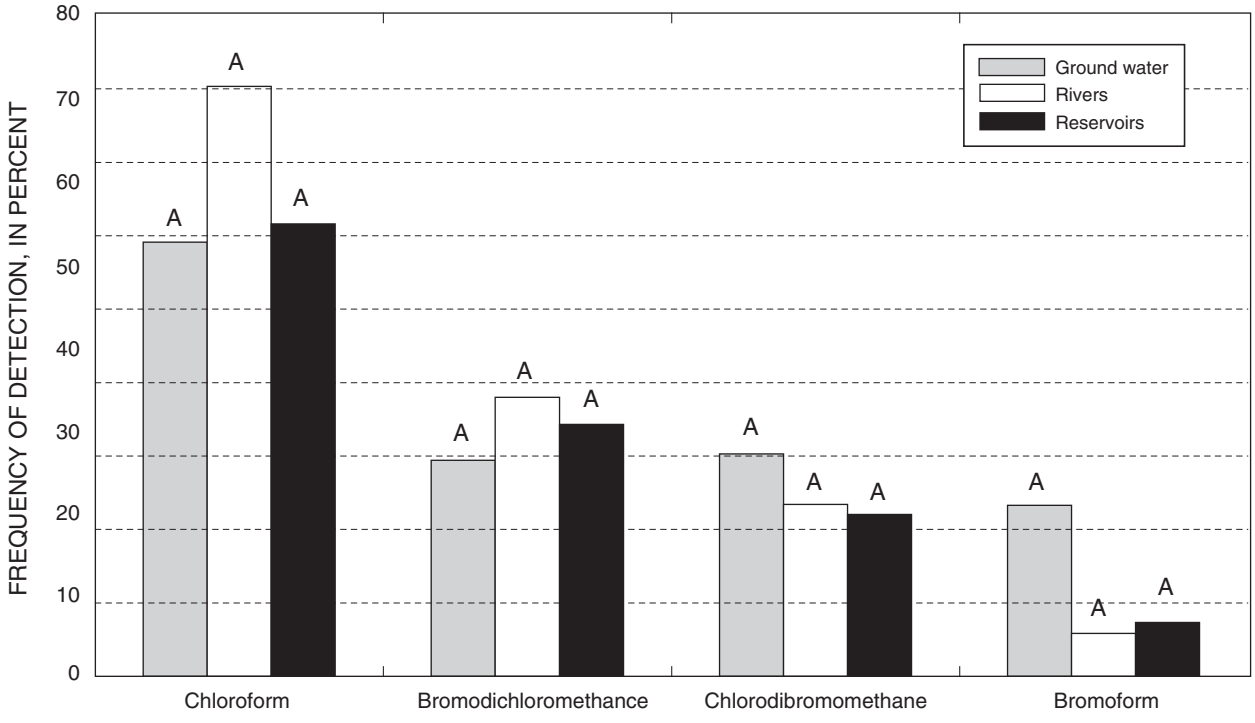

Figure 12. Frequency of detection of trihalomethanes in source-water samples from ground water, rivers, and reservoirs (populations that share the same letter symbol are not significantly different at the 95-percent confidence level).

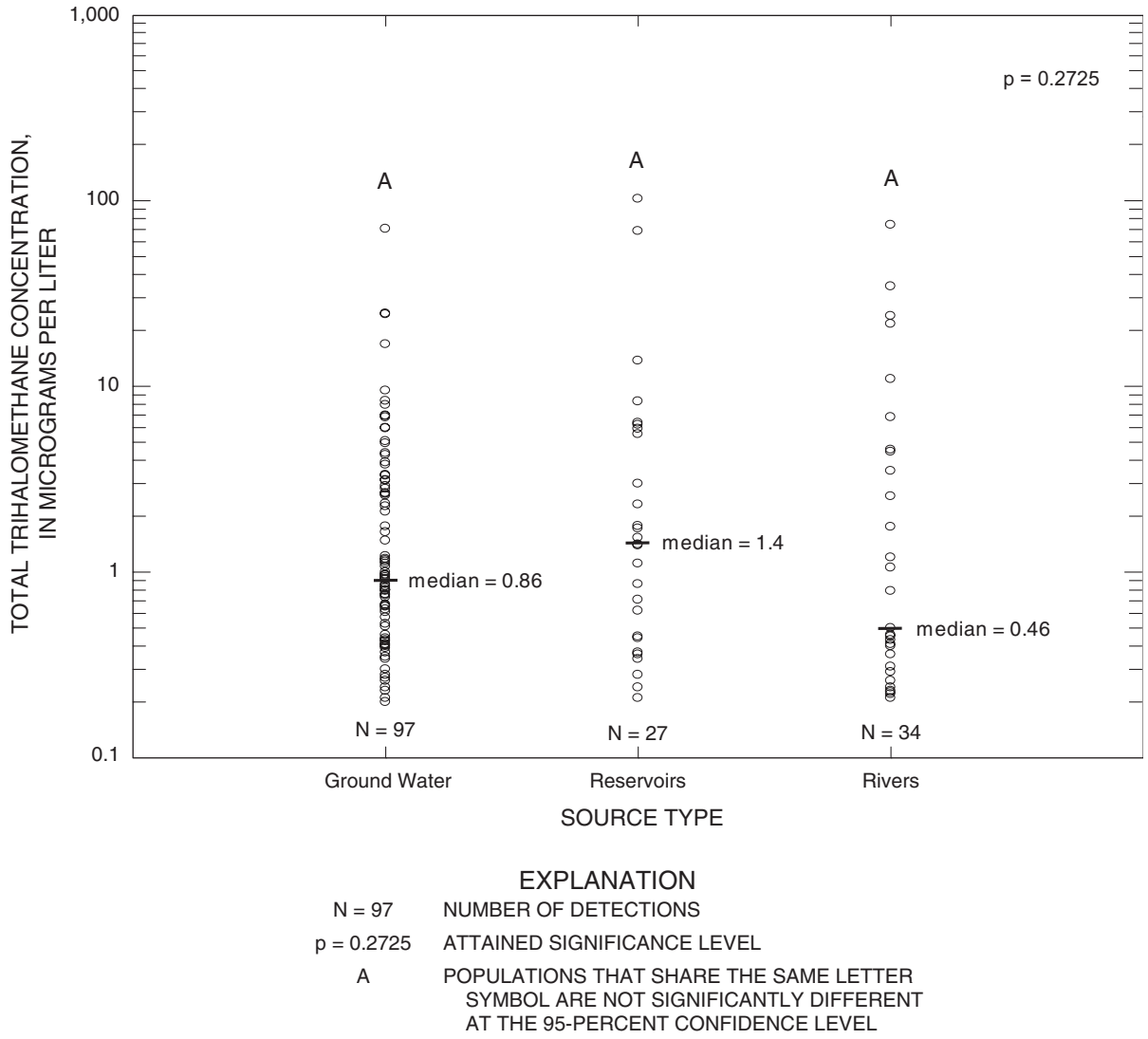

Figure 13. Concentrations of total trihalomethanes in source-water samples from ground water, rivers, and reservoirs.

and were not significantly different among the three source-water types (fig. 13). The median concentration of TTHMs in ground-water sources (0.86 µg/L) was comparable to the 2.5-µg/L median reported by Grady and Casey (2001, p. 36) for finished drinking water from ground-water supplied CWSs. Median concentrations of TTHMs in surface-water sources (fig. 13), however, were substantially lower than the elevated median TTHM concentrations of 20 to 30 µg/L reported by Grady and Casey (2001, p. 36) in finished drinking water from surface-water supplied CWSs.

The temporal distribution of THM detections also was examined to determine if any seasonal patterns were evident for any particular source-water type. Although substantial differences in the frequency of THM detections from month to month were found in both ground-water and surface-water samples, these variations appear to be random. THM detections were somewhat less frequent in most summer months (May through August) than in other months of the year in both ground- and surface-water sources, but with variations of nearly an order of magnitude (for example, surface-water detections in 2.9 percent of samples in May and in 26 percent of samples in June), no systematic seasonal pattern is evident in the data (fig. 14).

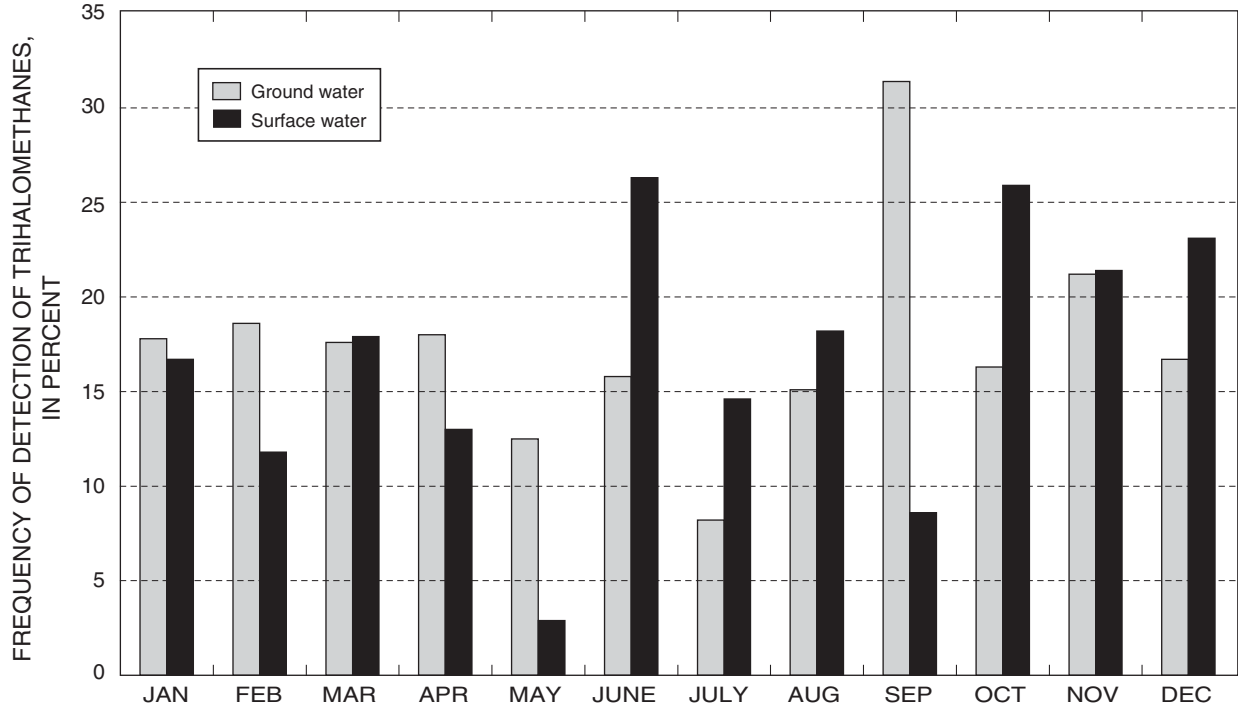

Figure 14. Frequency of detection of trihalomethanes in ground- and surface-water systems by month.

MTBE and Other Gasoline Compounds

Gasoline compounds were the second most frequently detected subgroup of VOCs and were measured in 9.8 percent of the source-water samples (table 9). MTBE alone accounted for two-thirds of all gasoline-compound detections (8.7 percent of the source-water samples), and was the second most frequently detected VOC in source waters after chloroform (fig. 8A). Ten additional VOCs that are intrinsic components of gasoline, such as benzene, toluene, ethylbenzene, and xylenes (BTEX), or are additives to gasoline (including the oxygenates ETBE, DIPE, and TAME), also were detected in source-water samples (table 9).

MTBE detections were significantly more frequent (table 10) in surface-water sources (14 percent) than in ground-water sources (5.4 percent), and river and reservoir samples contained MTBE more than twice as often as ground water (fig. 15). The occurrence of MTBE in 5.4 percent of ground-water sources in the Random Survey matched that observed in the national assessment of ambient ground water by Squillace and others (1999), also conducted at the same 0.2-µg/L MRL. However, Grady and Casey (2001) observed more frequent detections of MTBE in finished drinking water from CWSs in the Northeast. In that study, 7.8 percent of CWSs that used ground-water sources exclusively reported MTBE in drinking water (at a 1.0-µg/L MRL), whereas only 2.8 percent of these systems that use only surface-water sources had reported MTBE. CWSs in the Northeast that used both ground-water and surface-water sources, however, reported MTBE more frequently, in 16-percent of the multiple-source systems (Grady and Casey, 2001, p. 38). Toluene was the only other gasoline compound detected significantly more frequently in surface water than in ground water (p=0.0309), and it was detected six times more frequently in rivers than in ground water (fig. 15). Consistent with findings from Grady and Casey (2001), MTBE and other gasoline compounds generally were detected more frequently in the large CWSs regardless of type of source water (table 11).

Although widely detected, most MTBE concentrations measured in source-water samples were less than 5.0 µg/L, and median concentrations were less than 1.0 µg/L for each source-water type (fig.16). The largest MTBE concentration measured, 20 µg/L, was in a source-water sample from a reservoir in California, and equalled the lower value of the USEPA's

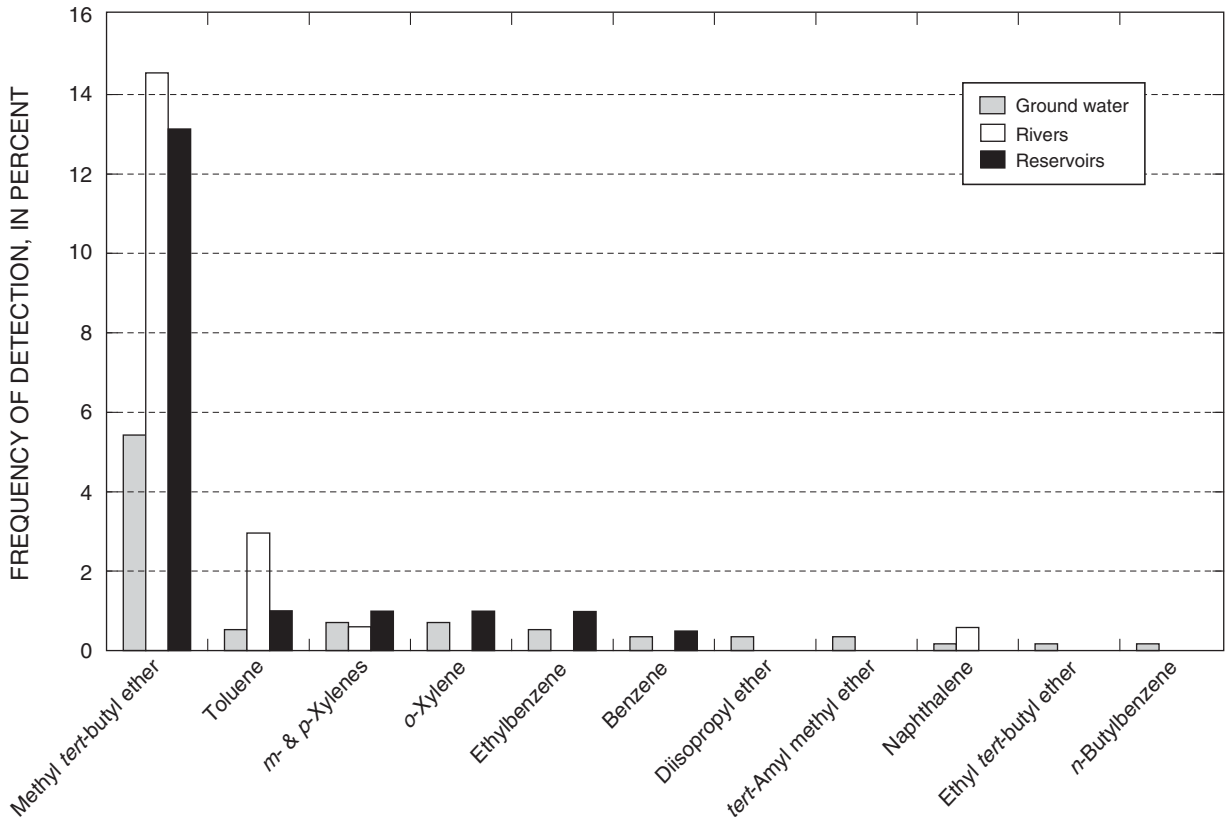

Figure 15. Frequency of detection of gasoline compounds in source-water samples from ground water, rivers, and reservoirs.

recommended drinking-water advisory range for drinking water of 20 to 40 µg/L (U.S. Environmental Protection Agency, 1997a). The operators of that CWS reported that numerous two-stroke, motorized personal watercraft use the reservoir for recreational purposes. MTBE concentrations did not differ significantly between ground-water and reservoir samples (fig. 16), but both were significantly greater than river samples. It is possible that the lower concentrations observed in river source-water samples is because mixing and dilution of gasoline contaminants is more effective in flowing water than stratified water bodies, or it may be that the rivers in this survey collectively receive less motorized watercraft use.

BTEX and other gasoline-related VOCs were detected only rarely in source waters (fig. 15) and even more rarely together with MTBE (fig. 17). Co-occurring detections of any BTEX compound with MTBE occurred in only 10 of 934 (1.1 percent) source-water samples. When MTBE was detected, BTEX compounds also were detected 12 percent of the time, but nearly 30 percent of the 34 source-water samples that contained BTEX compounds also contained MTBE. Most of the time when these two gasoline components co-occurred, and particularly when the concentrations of MTBE and BTEX were similar (fig. 17), the concentrations were low (less than 2.0 µg/L). The few MTBE detections that exceeded 2.0 µg/L were largely without BTEX in source-water samples. The lack of substantial co-occurrence of MTBE and BTEX likely reflects the different chemical properties that cause MTBE to be relatively persistent in the environment compared to BTEX, especially in ground water. Conversely, the ether oxygenates ETBE, DIPE, and TAME, while rare (they were detected only in two ground-water samples), were detected only where MTBE also was detected. The chemical properties of these compounds are similar to those of MTBE, and they are likely present in oxygenated gasoline as impurities or alteration products.

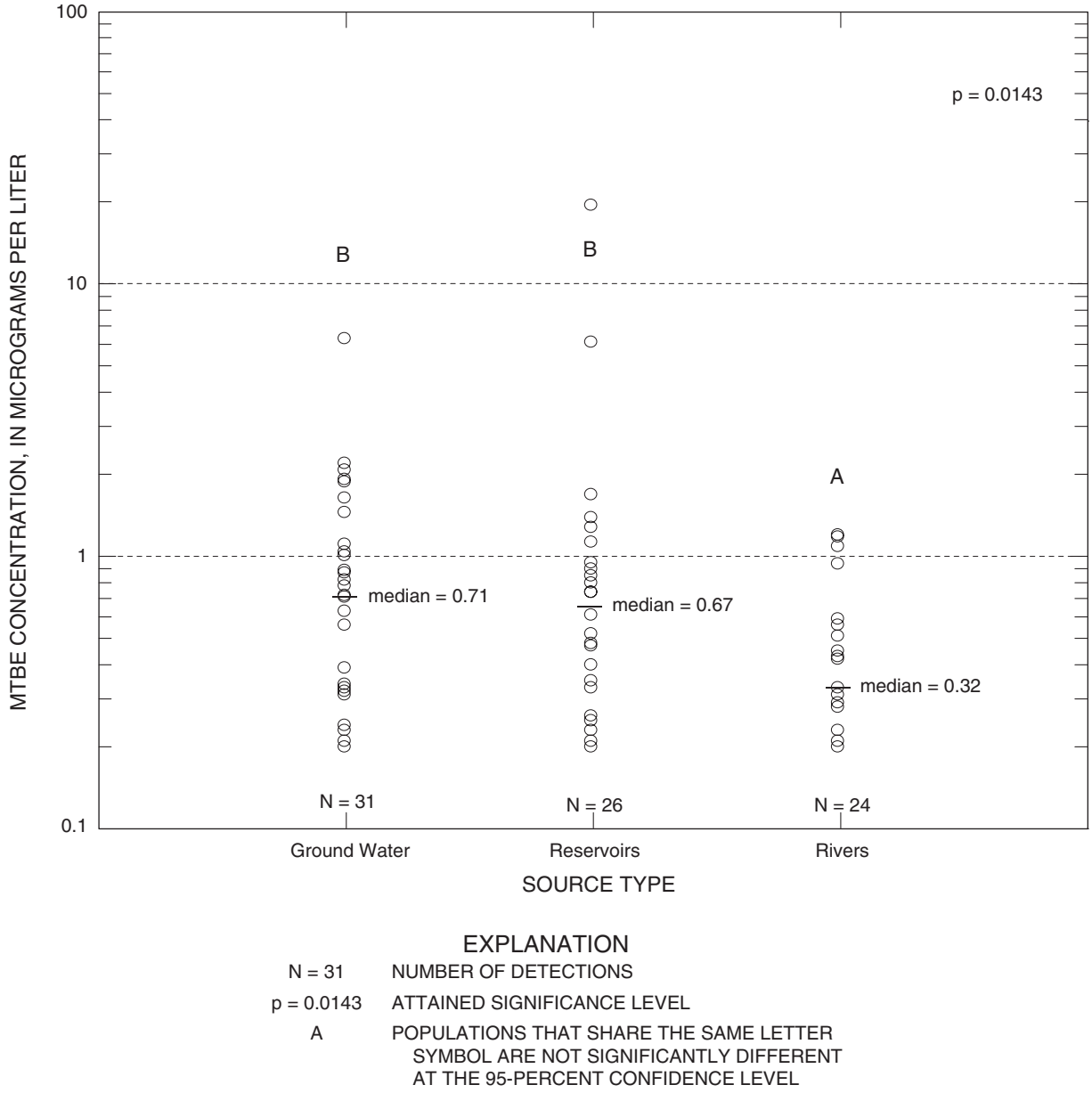

Figure 16. Concentrations of methyl *tert*-butyl ether (MTBE) in source-water samples from ground water, rivers, and reservoirs.

The temporal distribution of MTBE detections in ground-water sources and surface-water sources (fig. 18) demonstrates substantial differences. Although detection frequency varied randomly and no seasonal pattern is evident in the detection of MTBE in ground water, a seasonal influence seems apparent in the surface-water detections. MTBE detection frequency in surface-water samples increases almost monotonically from January to June and then similarly declines through October (fig. 18). This pattern may reflect the seasonal use of watercraft on surface-water bodies that are drinking-water sources. Emissions from gasoline-powered watercraft, and from personal recreation watercraft equipped with two-stroke engines in particular, have been associated with MTBE and BTEX contamination of surface waters (Juttner and others, 1995; Boughton and Lico, 1998; Reuter and others, 1998; Zapecza and Baehr, 1999; Dale and others, 2000; Gabele and Pyle, 2000).

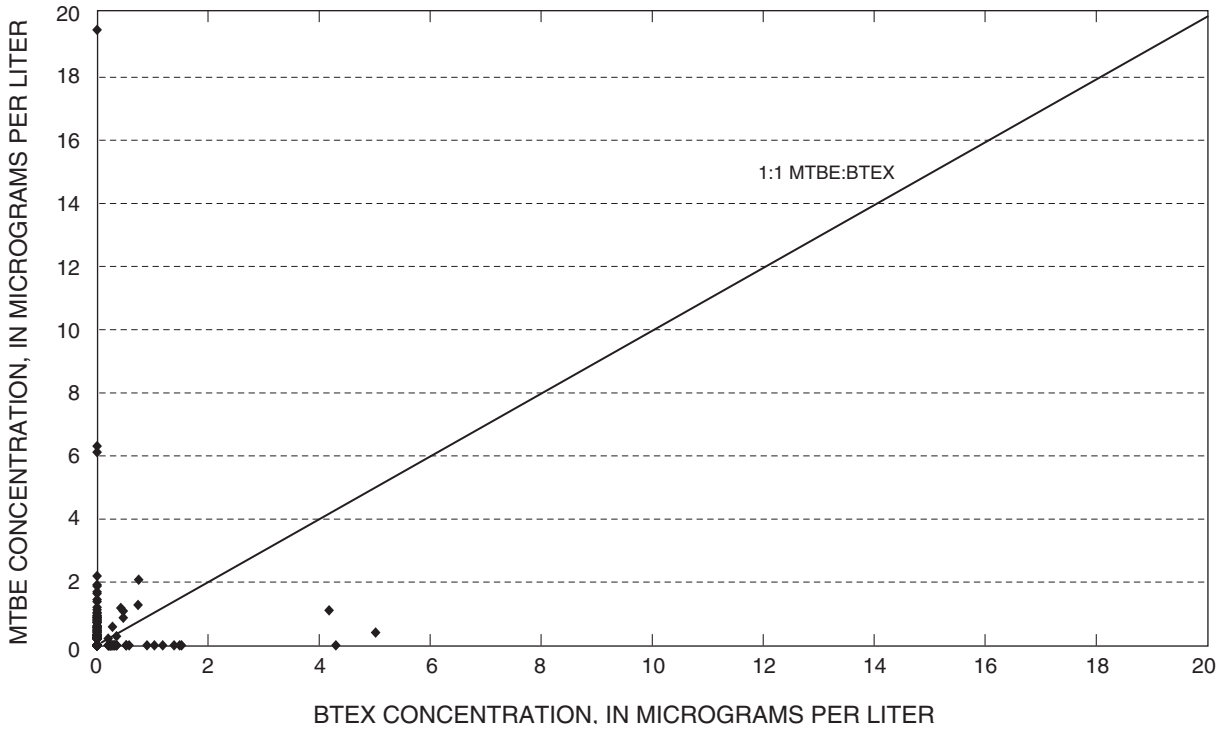

Figure 17. Comparison of concentrations of methyl *tert*-butyl ether (MTBE) to the sum of the concentrations of benzene, toluene, ethylbenzene, and xylene (BTEX) in 934 source-water samples.

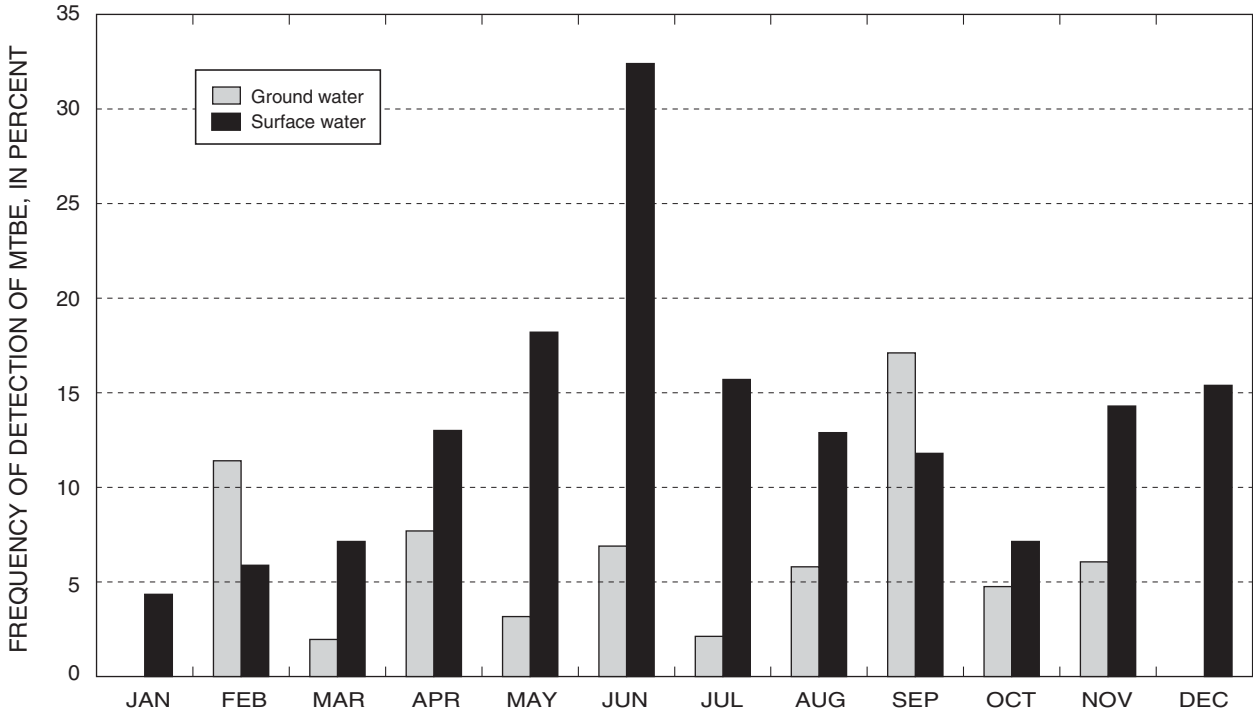

Figure 18. Frequency of detection of methyl *tert*-butyl ether (MTBE) in source-water samples from ground-water and surface-water sources by month.

Solvents and Other Volatile Organic Compounds

Solvents were the third most frequently detected subgroup of VOCs in drinking-water sources, present in 6.3 percent of the samples (table 9). Among the 17 chlorinated solvents detected in source-water samples (fig. 19) are several chemicals that have widespread industrial and commercial applications (for example, dry cleaning, textile production, and metal degreasing in automobile-repair and electronic-manufacturing facilities). These compounds also are commonly used in residential areas in household products such as paint strippers, degreasers, aerosols, and adhesives; consequently, solvents have been frequent contaminants in ambient ground water (Squillace and others, 1999) and in drinking water (Grady and Casey, 2001).

The occurrence of solvents in drinking-water sources is predominantly a ground-water phenomenon, as 88 percent of all solvent detections were in ground-water samples. Solvents were detected nearly four times more frequently in ground-water sources than in surface-water sources. Detection of one or more solvents in 8.8 percent of the ground-water samples was significantly greater than the 2.4-percent detection frequency for surface-water samples (table 10). Detections of 14 solvents were greater in ground water than rivers and reservoirs (fig. 19), and more than half of the 17 solvents detected in source water were present only in ground-water samples. Also, solvents were detected significantly more often in ground-water sources of the largest CWSs (table 11) than in ground-water sources of smaller systems.

Concentrations of solvents in source water were somewhat greater than VOCs in general, as 12 percent of solvent detections exceeded 10 µg/L compared to 5 percent for VOCs overall. Concentrations of tetrachloroethene, trichloroethene, and 1,1-dichloroethene exceeded drinking-water MCLs (5, 5, and 7 µg/L, respectively) 14 times collectively, with a maximum of 165 µg/L of tetrachloroethene measured in one ground-water sample. The samples were not finished drinking water, however, and presumably concentrations of that magnitude would be mitigated by some form of

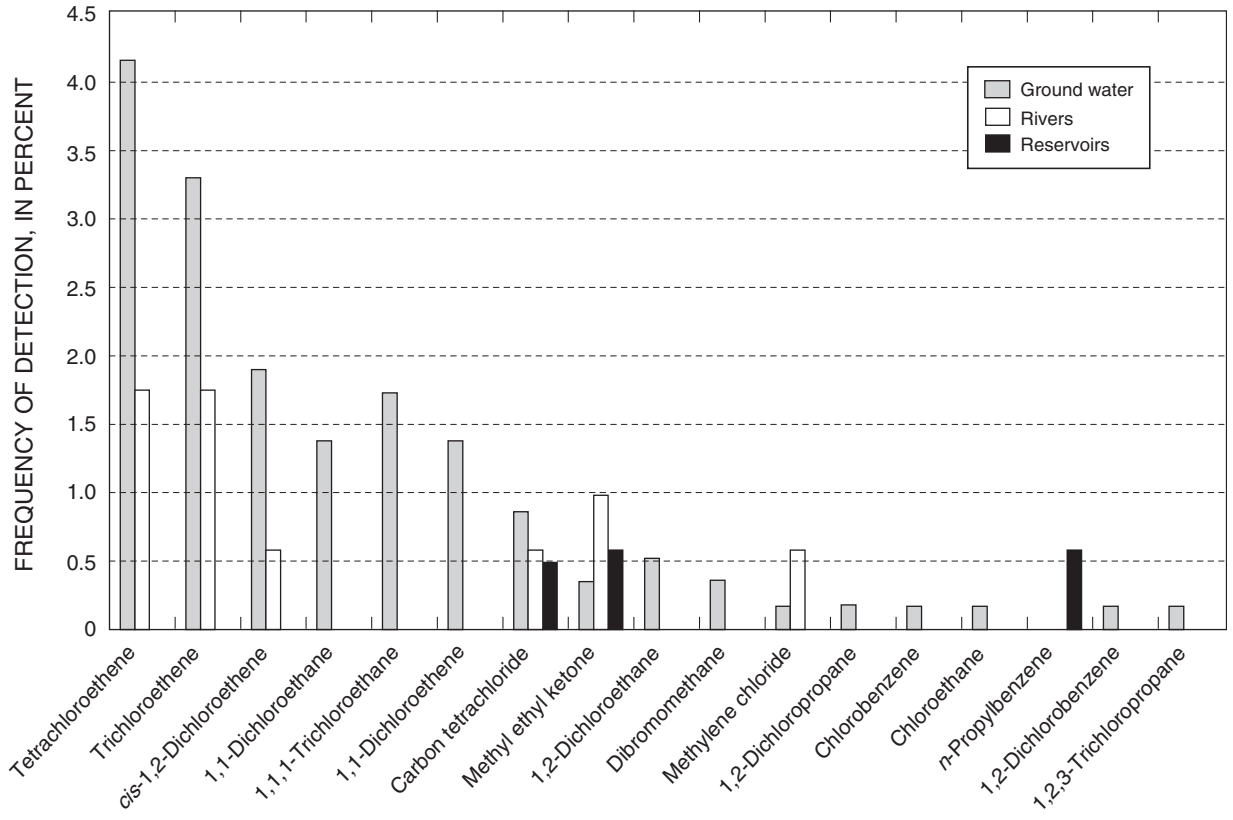

Figure 19. Frequency of detection of solvents in source-water samples from ground water, rivers, and reservoirs.

treatment or dilution by mixing with other source waters prior to distribution. At least 15 percent of the CWSs reported using some form of treatment to filter or remove VOCs from source waters sampled for this study (appendix 1). Overall, most solvent concentrations were not problematic, and the median solvent concentration was 1.2 µg/L. Also, perhaps because they were present predominantly in ground water or perhaps because their sources are widespread and random, detections of solvents demonstrated no seasonal patterns.

VOCs other than the trihalomethane disinfectant by-products, gasoline compounds, and solvents described above have been detected only rarely in drinking-water sources. Four refrigerants, four VOCs used mostly in the synthesis of other organic chemicals or products, and two fumigants were detected in less than 1 percent of the source-water samples (table 9). Of the three groups of VOCs, only refrigerants demonstrated a distinctive and statistically significant (see table 10) difference in their occurrence, as they were detected exclusively in ground water (fig. 20). The fumigant and organic synthesis VOCs detected in source-water samples were present in all source-water types but were slightly more prevalent in surface water.

Anthropogenic Factors Related to Occurrence and Distribution

Anthropogenic factors such as urban land use, population density, areas where MTBE use is high, and the density of gasoline storage tanks have been found to explain, at least in part, the occurrence and

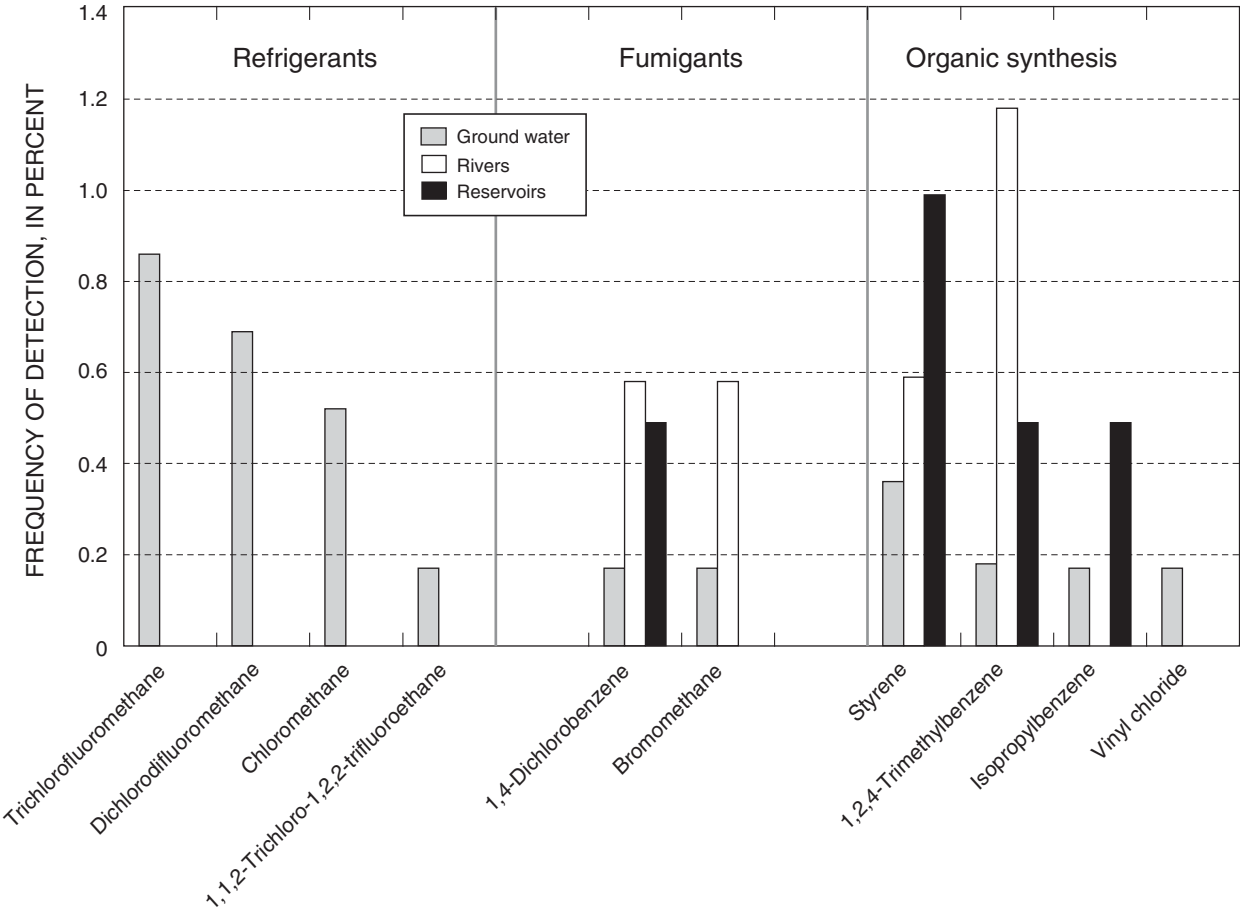

Figure 20. Frequency of detection of refrigerants, fumigants, and organic synthesis compounds in source-water samples from ground water, rivers, and reservoirs.

distribution of MTBE and other VOCs in drinking water and ambient ground water (Grady, 1994; Delzer and others, 1996; Grady and Mullaney, 1998; Hitzig and others, 1998; Lopes and Bender, 1998; State of Maine, 1998; Moran, Halde and others, 1999; Squillace and others, 1999; Squillace and Moran, 2000; Grady and Casey, 2001). Consequently, a similar analysis was performed for the Random Survey that used information on the location of the drinking-water sources sampled for this study with respect to these anthropogenic factors. The locations of the drinking-water sources were intersected with national GIS data on 1990 population density (Price and Clawges, 1999) and percentage of urban land use (Vogelmann and others, 2001) within the four 1-km^2 grid cells adjacent to the well or intake location. Population density was calculated as an average of the four neighboring grid cells weighted for distance of the well or intake from each cell. Urban land use was calculated as the percentage of total area in the four neighboring cells consisting of four land cover types: (1) low-intensity residential, (2) high-intensity residential, (3) commercial, industrial, and transportation, and (4) urban recreational grasses (for example, parks and golf courses).

High MTBE-use areas were defined as areas within the Federal Reformulated Gasoline (RFG) Program (U.S. Environmental Protection Agency, 1999b) whereby gasoline must contain 2-percent oxygen by weight and MTBE is the oxygenate of choice. Areas designated as "high use" had a median content of MTBE in gasoline greater than 9 percent by volume in at least one year or season from 1995 through 1999. Medians of MTBE by volume in gasoline were determined from yearly data from the Reformulated Gasoline Survey (Stuart Romanow, U.S. Environmental Protection Agency, written commun., 1999) and seasonal (winter and summer) data from motor gasoline surveys conducted by the National Institute for Petroleum and Energy Research. All areas participating in the Federal RFG Program during the April 1999 to October 2000 duration of the Random Survey were considered high MTBE-use areas, with the exception of the Chicago and Milwaukee metropolitan areas, which use ethanol in gasoline to meet Federal oxygenate requirements. Two areas that were previously in the Federal RFG Program also were considered high MTBE-use areas for this analysis. Areas of southern Maine voluntarily entered (opted into) the RFG Program in 1995 and opted out in 1999. Phoenix, Arizona voluntarily entered the RFG Program in 1997 and opted out in June 1998. Both of these areas have shown significant (>9 percent by volume) MTBE use during 1995-99.

Two other areas also were considered high MTBE-use areas for this analysis, although they did not actively participate in the Federal RFG Program. All of the State of California, including those areas outside RFG Program areas, are considered to be high MTBE-use areas because of documented statewide use of MTBE to meet the State wintertime oxygenate and (or) California Cleaner Gasoline requirements (California Environmental Protection Agency, 1997; California Senate, 1998; Gomez and others, 1998). Additionally, Yuma and Mohave counties in Arizona are considered high MTBE-use areas because they reportedly receive gasoline containing high MTBE content from California gasoline distributors (Arizona Department of Environmental Quality, 1999).

The three ancillary factors evaluated—population density, urban land use, and high MTBE-use areas—are autocorrelated to some degree. Clearly, areas with high population density (greater than 386 people/km^2 or 1,000 people/mi^2) are urban, and areas with more than 60 percent total urban land cover generally have high population density. Also, because the Federal RFG Program was directed at improving air quality in places within the country that exceeded air-quality standards, due in large part to emissions from congested automobile use, these areas typically include large urban centers and their surroundings. These ancillary factors are only indirect, surrogates for quantitative information on VOC sources, use, and releases to the environment within urban areas that generally is not available. The occurrence and distribution of VOCs in ground water and surface water, however, are related to, and to some degree can be anticipated by, these factors.

Urban land use within the 4-km^2 area surrounding 931 of the 954 drinking-water sources (data were not available for Alaska, Hawaii, and Puerto Rico) ranged from 0 to 99.9 percent. For this analysis, sites were segregated into five categories of urban land use corresponding to 0 to 20 percent, 21 to 40 percent, 41 to 60 percent, 61 to 80 percent, and 81 to 100 percent urban. The frequency of detection for various subgroups of VOCs were statistically compared using contingency-table analysis. The results of that analysis demonstrates that the frequency of detection of any VOC, non-THM VOCs, BTEX compounds, solvents, and refrigerants was significantly

related to urban land use at the 95-percent confidence level (table 12). For most of the VOC subgroups, the frequency of detection was significantly greater in the 81- to 100-percent urban land-use categories than in the 0- to 20-percent urban areas. The relation between VOC detections and urban land use can be seen in the comparison of the frequency of detection of non-THM VOCs for the five urban land-use percentage categories (fig. 21)—the frequency of detection of non-THM VOCs increased monotonically with increasing urban land use and was significantly greater for all areas with more than 20 percent urbanization.

A complementary analysis of the relation between urban areas and VOC detections in source waters was conducted by comparing the frequency of detection of each VOC subgroup for areas with population density less than and greater than the 1,000-people/mi^2 threshold adopted by Squillace and others (1999) to differentiate urban from rural settings. Squillace and others (1999) found population density to be a stronger explanatory variable than land use in statistical models that tested various explanatory factors for the frequency of VOC detections in ambient ground water. Similarly to urban land use, the relation between detection frequency of any VOC, non-THM VOC, solvent, and refrigerant and population density is statistically significant (table 13). Unlike urban land use, however, detections of any gasoline compound and MTBE were significantly greater in drinking-water sources from areas of high population density, although BTEX compounds were not. MTBE detections were almost three times more frequent in high population-density areas than in lower population-density areas.

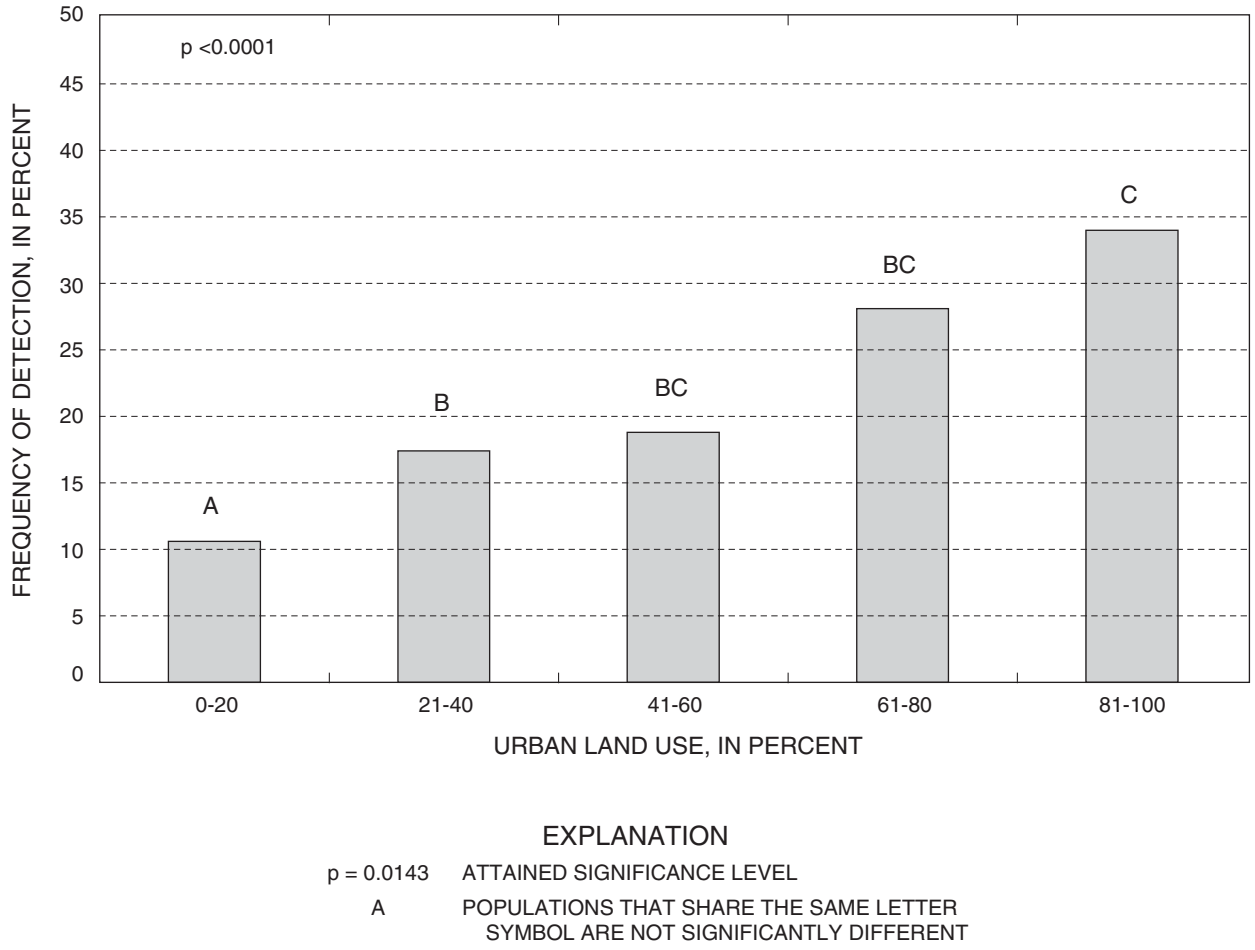

Figure 21. Relation between the frequency of detection of non-trihalomethane volatile organic compounds and urban land use.

Table 12. Statistical comparison of the occurrence of volatile organic compounds in source-water samples by percentage of urban land use

[Percentage of urban land use analyzed for four 1-km^2 grid cells adjacent to the drinking-water source]

Volatile organic compound or related compounds	p-value[1]	Percentage urban land use and frequency of detection (population[2])				
		0 - 20 percent urban	21 - 40 percent urban	41 - 60 percent urban	61 - 80 percent urban	81 - 100 percent urban
Any volatile organic compound	**0.0323**	24 (A)	29 (AB)	27 (AB)	33 (AB)	42 (B)
Trihalomethanes	0.8277	15 (A)	16 (A)	10 (A)	14 (A)	14 (A)
Non-trihalomethane compounds	**<0.0001**	11 (A)	17 (B)	19 (BC)	28 (BC)	34 (C)
Any gasoline compound	0.0749	8.3 (A)	11 (A)	12 (A)	19 (A)	14 (A)
Methyl *tert*-butyl ether	0.5055	7.9 (A)	9.0 (A)	9.9 (A)	12 (A)	14 (A)
BTEX[3] compounds	**0.0013**	1.1(A)	2.5 (AB)	1.0 (AB)	8.8 (B)	2.0 (AB)
Solvents	**<0.0001**	3.4 (A)	7.4 (B)	5.2 (AB)	16 (BC)	26 (C)
Refrigerants	**<0.0001**	0.5 (A)	0.6 (A)	1.0 (AB)	0 (AB)	8.0 (B)
Fumigants	0.0912	0.2 (A)	0.6 (A)	2.1 (A)	0 (A)	2.0 (A)
Organic synthesis compounds	0.2317	0.7 (A)	0.6 (A)	0 (A)	3.5 (A)	2.0 (A)

[1]p-value is the attained significance level; values shown in bold are significant at the 95-percent confidence level.

[2]Urban land-use populations that share the same letter are not significantly different at the 95-percent confidence level.

[3]Benzene, toluene, ethylbenzene, and *o*-, *m*-, and *p*-xylenes.

Table 13. Statistical comparison of the occurrence of volatile organic compounds in source-water samples by population density

[Population density analyzed for four 1-km^2 grid cells adjacent to the drinking-water source]

Volatile organic compound or related compounds	p-value[1]	Population density and frequency of detection (population[2])	
		Less than 1,000 people per square mile	Greater than 1,000 people per square mile
Any volatile organic compound	**0.0003**	24 (A)	38 (B)
Trihalomethanes	0.4921	14 (A)	16 (A)
Non-trihalomethane compounds	**<0.0001**	13 (A)	28 (B)
Any gasoline compound	**0.0001**	8.2 (A)	19 (B)
Methyl *tert*-butyl ether	**<0.0001**	7.0 (A)	17 (B)
BTEX[3] compounds	0.2192	1.6 (A)	3.3 (A)
Solvents	**0.0009**	4.9 (A)	12 (B)
Refrigerants	**0.0020**	0.4 (A)	3.3 (B)
Fumigants	0.3837	0.3 (A)	1.1 (A)
Organic synthesis compounds	0.9268	0.8 (A)	1.1 (A)

[1]p-value is the attained significance level; values shown in bold are significant at the 95-percent confidence level.

[2]Population-density populations that share the same letter are not significantly different at the 95-percent confidence level.

[3]Benzene, toluene, ethylbenzene, and *o*-, *m*-, and *p*-xylenes.

The occurrence of MTBE in finished drinking water (Squillace and Moran, 2000; Grady and Casey, 2001) and in ambient ground- and surface waters (Moran, Halde, and others, 1999; Moran, Zogorski, and others, 1999; Squillace and others, 1999; Moran and others, 2002) also has been previously shown to be associated with patterns of MTBE use. Areas of the country that participate in the Federal RFG Program (U.S. Environmental Protection Agency, 1999b) and (or) the winter OXY Program (U.S. Environmental Protection Agency, 1999c), and where MTBE is known to be currently or formerly the oxygenate used to meet program requirements, have been found by the above investigators to correlate with higher MTBE occurrence. Similarly, the distribution of source waters that have concentrations of MTBE equal to or greater than the MRL also is related to the distribution of high MTBE-use areas (fig. 22). A statistical comparison of the frequency of detection of MTBE and other gasoline-related VOCs for areas that have and have not used fuels containing elevated concentrations of MTBE is summarized in table 14. MTBE was detected in drinking-water sources five times more frequently in the high MTBE-use areas than in areas that have not had comparable MTBE use. Although a similar pattern was observed for the subgroup "any gasoline compound," this is probably due to the fact that MTBE alone contributes two-thirds of all gasoline compound detections in source waters. BTEX compounds, which were comparatively rarely detected (1.9 percent) in source-water samples, were not statistically related to MTBE-use patterns. BTEX compounds, however, are intrinsic components of all types of gasoline and would not be expected to be statistically related to either high or low MTBE-use areas.

Lastly, the occurrence of gasoline-related VOCs in source water was compared to the density of chemical storage tanks, the great majority of which store gasoline, near the drinking-water source. Information on the locations of above- and below-ground storage tanks, as well as information on the number of leaking underground storage tanks, was obtained from StarView Real Estate Version 2.6.1 (Vista Information Solutions, 1999), and the density of these sites within the 4-km^2 grid surrounding source-water locations was calculated. Drinking-water sources were then characterized as having storage-tank densities of 0, greater than 0 to 1.0 (numerical average density), greater than 1.0 to 5.0, greater than 5.0 to 10.0, or greater than 10.0 tanks/mi^2 in their vicinity, and the frequency of detection of gasoline compounds was tested for independence with respect to tank-density category. The results of this analysis (table 15) show that any gasoline compound, collectively, and BTEX compounds were detected significantly more often where there were more than 10 storage tanks per square mile. MTBE detections, conversely, were not related to storage-tank density at all. Although leaking underground storage tanks clearly have been sources of MTBE contamination of ground water (Happel and others, 1998; Hitzig and others, 1998), other studies have similarly reported the lack of a statistically significant association between MTBE detections in drinking-water wells and the proximity (State of Maine, 1998) or density (Shelton and others, 2001) of gasoline storage tanks. The lack of a statistically significant relation between MTBE detections and storage-tank density may reflect the enhanced mobility and recalcitrance of MTBE relative to most other gasoline compounds in ground water and (or) a greater variety of nonpoint sources such as small leaks and spills, urban runoff, recreational water-craft use, and atmospheric transport.

Table 14. Statistical comparison of the occurrence of methyl *tert*-butyl ether (MTBE) and other gasoline-related volatile organic compounds in source-water samples by MTBE-use area

Volatile organic compound or related compounds	p-value[1]	MTBE use and frequency of detection (population[2])	
		Source waters not in high MTBE-use area	Source waters in high MTBE-use area
Any gasoline compound	**<0.0001**	6.2 (A)	23 (B)
Methyl *tert*-butyl ether	**<0.0001**	4.4 (A)	23 (B)
BTEX[3] compounds	0.9485	2.0 (A)	1.8 (A)

[1]p-value is the attained significance level; values shown in bold are significant at the 95-percent confidence level.

[2]MTBE-use populations that share the same letter are not significantly different at the 95-percent confidence level.

[3]Benzene, toluene, ethylbenzene, and *o*-xylene and, *m*-, *p*-xylene.

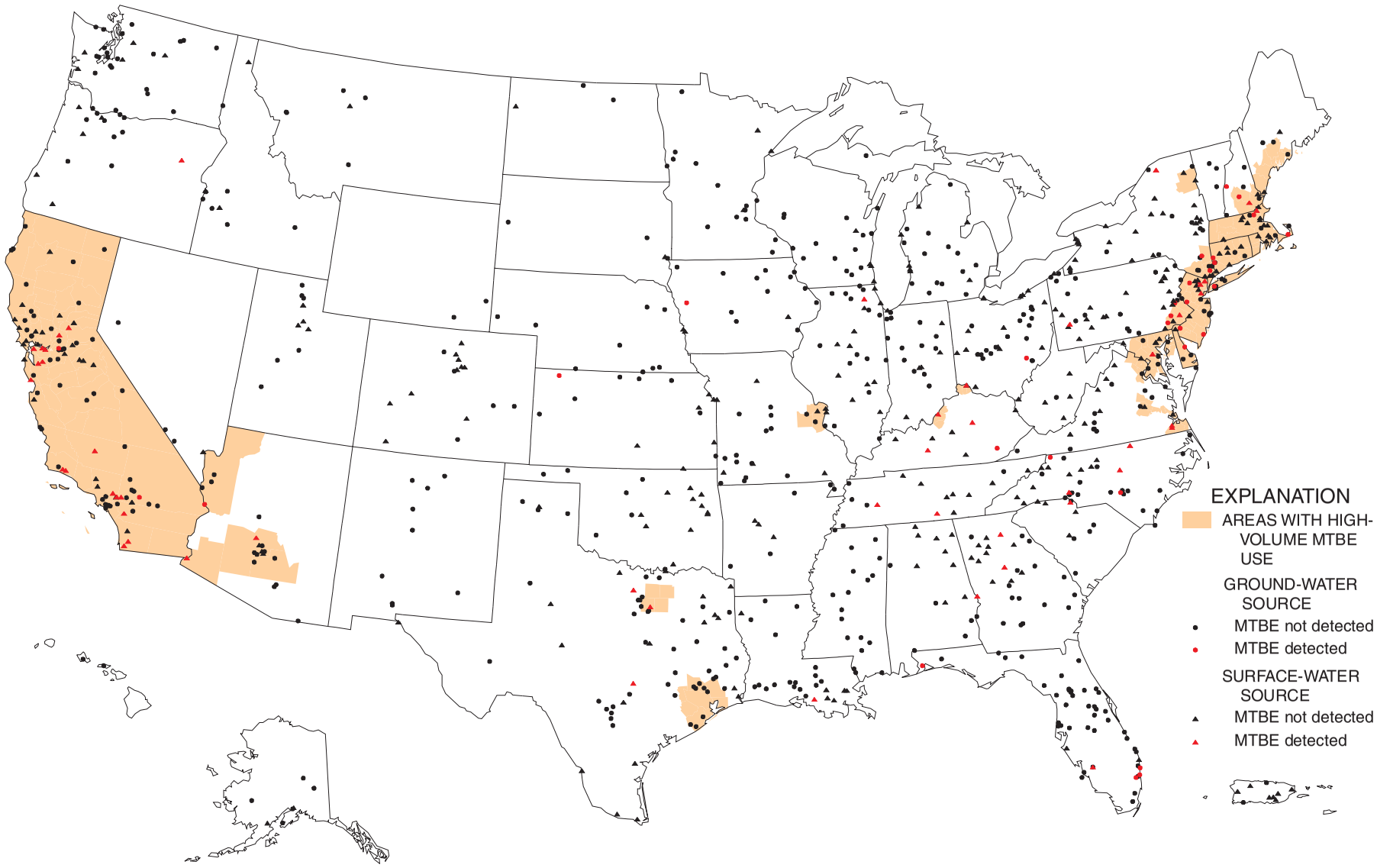

Figure 22. Distribution of methyl *tert*-butyl ether (MTBE) detections in ground- and surface-water sources in the United States and Puerto Rico in relation to high MTBE-use areas.

Table 15. Statistical comparison of the occurrence of methyl *tert*-butyl ether (MTBE) and other gasoline-related volatile organic compounds in source-water samples by storage-tank density

[Storage tank density analyzed for four 1-km^2 grid cells adjacent to the drinking-water source; mi^2, square mile; >, greater than]

Volatile organic compound or related compound	p-value[1]	Storage-tank density and frequency of detection (population[2])				
		0 tanks/mi^2	>0 to 1.0 tanks/mi^2	>1.0 to 5.0 tanks/mi^2	>5.0 to 10.0 tanks/mi^2	>10.0 tanks/mi^2
Any gasoline compound	**0.0356**	8.7 (A)	7.3 (A)	12 (AB)	15 (AB)	20 (B)
MTBE	0.4271	8.4 (A)	7.0 (A)	9.8 (A)	13 (A)	14 (A)
BTEX[3]	**0.0192**	1.3 (AB)	0.4 (A)	2.9 (AB)	3.6 (AB)	6.8 (B)

[1]p-value is the attained significance level; values shown in bold are significant at the 95-percent confidence level.
[2]Storage-tank density populations that share the same letter are not significantly different at the 95-percent confidence level.
[3]Benzene, toluene, ethylbenzene, and *o*-xylene, and *m*-, *p*-xylene.

In summary, the occurrence of several subgroups of VOCs were shown to be statistically related to certain anthropogenic factors. The frequency of detection of any VOC, non-THM VOC, solvent, and refrigerant was significantly greater in some areas where the percentage of urban land use exceeded 20 percent and where population density exceeded 1,000 people/mi^2. Although the frequency of detection of any gasoline-related compound in general, and MTBE in particular, was not related to percentage of urban land use, the frequency of detection was greater in the high population-density areas and in areas with high-MTBE use as an oxygenate in gasoline. In particular, MTBE detections were five times more frequent in source waters in high MTBE-use areas than outside of these areas. Conversely, BTEX detections were greater in some more urbanized areas, but not directly related to population density or to high MTBE-use areas. Finally, the density of storage tanks around source waters affects the frequency of detection of gasoline-related VOCs in general, and BTEX in particular, but not MTBE.

SUMMARY AND CONCLUSIONS

The Random Survey was designed to provide representative information on the frequency of detection, concentration, distribution, and temporal variability of MTBE, other ether gasoline oxygenates, and other VOCs in source waters used by CWSs in the United States. The survey, sponsored by the American Water Works Association Research Foundation, was conducted by the U.S. Geological Survey in cooperation with Metropolitan Water District of Southern California and the Oregon Health & Science University.

Source-water samples for the Random Survey were collected from 954 CWSs in the 50 States, Native American Lands, and Puerto Rico from May 3, 1999 to October 23, 2000. Samples were allocated proportionally to the total number of systems in each of the five population-served size categories, the total number of people served by each of the source-size category, and the type of source waters used. Untreated source-water samples from 579 ground-water sources (wells and springs) and 375 surface-water sources (rivers, lakes, and reservoirs) were collected by CWS personnel and sent to the MWDSC laboratory for analysis of MTBE, 3 other ether gasoline oxygenates, and 62 additional VOCs. One source-water sample was collected and analyzed from each participating CWS.

Forty-two of the 66 VOC analytes were detected in at least one sample at concentrations equal to or greater than the MRL of 0.2 µg/L (for all VOCs except methyl ethyl ketone, which has an MRL of 2.0 µg/L). One or more VOCs were detected in 257 (27 percent) of the 954 source-water samples. Chloroform was the most frequently detected VOC in 13 percent of the samples; MTBE was second, detected in 8.7 percent of the samples. Although VOC detections were frequent, concentrations were generally less than 10 µg/L—95 percent of all 530 VOC detections—and 63 percent were less than 1.0 µg/L. However, eight source-water samples contained one or more VOCs at concentrations that would have exceeded Federal maximum contaminant levels (MCLs) established for drinking water. When VOCs were detected in source-water samples, co-occurrence of several VOCs was fairly common,

with multiple detections in nearly half (47 percent) the 257 samples with VOC detections.

Proportionally, more surface-water samples (30 percent) than ground-water samples (25 percent) contained VOCs. Gasoline compounds collectively and MTBE were detected significantly more often in surface-water sources than ground-water sources at the 95-percent confidence level, whereas, the opposite was true of solvents and refrigerants. For most VOC subgroups, detections were more frequent in samples from the largest water systems as their source waters are more likely to be in urban settings. Detection frequencies for any VOC, non-THM VOCs, BTEX compounds, solvents, and refrigerants were significantly greater in source-water samples from areas with 60 percent or more urban land use than in less urbanized areas. Also, drinking-water sources in areas with population density greater than 1,000 people per square mile contained any VOC, non-THM VOCs, gasoline compounds collectively, MTBE, solvents, and refrigerants significantly more often than source waters in less densely populated settings.

The widespread occurrence of THM disinfectant by-products in source waters probably represents the persistence of residual concentrations of disinfectant by-products from chlorinated drinking water and wastewater circulating through the hydrologic cycle. The more frequent detections of MTBE in surface-water sources (14 percent) than ground-water sources (5.4 percent) probably is related to emissions and leaks or spills of gasoline from personal and commercial motorized watercraft operated on surface-water bodies that are used for drinking-water supply. Detections of MTBE in surface-water samples were most frequent in samples collected during summer months, reflecting the seasonal use of watercraft, whereas detections in ground water did not demonstrate any seasonal effects. Concentrations of MTBE in source-water samples were generally less than 5.0 µg/L, however, and only one sample approached the 20-µg/L lower level of the Federal recommended drinking-water advisory. Co-occurrence of MTBE and BTEX was limited to a few samples with low concentrations of both gasoline contaminants. Detections of other ether gasoline oxygenates—ethyl *tert*-butyl ether, *tert*-amyl methyl ether, and diisopropyl ether—were rare and only occurred with MTBE.

The frequency of detecting MTBE in source-water samples was significantly greater in source waters located in areas of the Nation where MTBE is used in high volume in gasoline (23 percent) compared to drinking-water sources outside of these areas (4.4 percent). This five-fold increase in MTBE detections in high MTBE-use areas is consistent with observations made in two previous studies—a national study of MTBE occurrence in ambient ground water and a regional study for the Northeast and Mid-Atlantic regions in drinking water. Although detections of gasoline compounds collectively and BTEX compounds were greater in source-water samples from areas with 10 or more gasoline storage tanks, MTBE detections were not significantly related to the density of gasoline storage tanks near the source waters. Similar observations regarding the lack of an association between MTBE detections in drinking water and storage-tank density and (or) proximity were made by previous investigations in California and Maine. This observation reflects the enhanced mobility and recalcitrance of MTBE relative to other gasoline contaminants and points to a greater variety of potential nonpoint MTBE sources such as small leaks and spills, urban runoff, recreational watercraft use, and atmospheric transport.

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APPENDIXES

Appendix 1. Summary of ancillary information from respondents to mail-in questionnaire provided to community water systems participating in the Random Survey

[Data from 941 of 954 participating community water systems that returned a response; VSM = very small (less than 500 people served); SM = small (501 to 3,300 people served); MED = medium (3,301 to 10,000 people served); LRG = large (10,001 to 50,000 people served); VLRG = very large (more than 50,000 people served); --, not applicable; >, greater than; <, less than]

Question	Source-water type and size of community water system																		TOTAL
	Ground water						Rivers						Reservoirs						
	VSM	SM	MED	LRG	VLRG	TOTAL	VSM	SM	MED	LRG	VLRG	TOTAL	VSM	SM	MED	LRG	VLRG	TOTAL	
1. What type of source water was sampled for this study?																			
ground water	291	120	49	62	53	575	--	--	--	--	--	--	--	--	--	--	--	--	575
surface water	--	--	--	--	--	--	7	14	15	39	88	163	4	10	15	39	135	203	366
total	291	120	49	62	53	575	7	14	15	39	88	163	4	10	15	39	135	203	941
2. How often do you monitor volatile organic compounds in the drinking-water source being sampled for this study?																			
>once per month	0	1	0	1	3	5	0	0	0	0	7	7	0	0	0	1	2	3	15
monthly	29	5	4	3	8	49	1	0	1	4	2	8	0	0	0	0	6	6	63
quarterly	32	17	8	12	11	80	0	1	4	7	25	37	1	4	6	15	32	58	175
annual	44	23	5	10	10	92	4	8	6	13	26	57	0	2	5	13	58	78	227
every 2 years	6	1	0	0	1	8	0	0	0	0	1	1	0	0	0	0	0	0	9
every 3 years	52	21	7	11	5	96	1	0	0	2	4	7	2	1	0	2	4	9	112
<every 3 years	3	0	4	3	1	11	1	1	0	1	1	4	0	0	0	0	2	2	17
as required	2	1	1	0	0	4	0	0	0	0	1	1	0	0	0	0	2	2	7
other	113	48	20	20	14	215	0	3	4	9	15	31	1	3	4	7	21	36	282
did not answer	10	3	0	2	0	15	0	1	0	3	6	10	0	0	0	1	8	9	34
total	291	120	49	62	53	575	7	14	15	39	88	163	4	10	15	39	135	203	941
3. Do you monitor source water, finished water, or both?																			
source water	115	50	16	17	15	213	2	0	3	2	5	12	3	0	1	5	11	20	245
finished water	85	31	14	18	13	161	4	6	6	25	42	83	1	6	9	25	55	96	340
both	79	34	19	26	24	182	1	8	5	12	40	66	0	4	5	9	63	81	329
did not answer	12	5	0	1	1	19	0	0	1	0	1	2	0	0	0	0	6	6	27
total	291	120	49	62	53	575	7	14	15	39	88	163	4	10	15	39	135	203	941
4. Has methyl *tert*-butyl ether been detected in source-water samples from this drinking-water source within the last three years?																			
yes	2	1	4	2	3	12	1	0	0	1	7	9	0	0	0	0	9	9	30
no	193	82	33	47	43	398	3	6	8	15	46	78	3	4	8	14	73	102	578
uncertain	76	31	8	11	3	129	2	8	4	17	26	57	1	5	4	19	37	66	252
did not answer	20	6	4	2	4	36	1	0	3	6	9	19	0	1	3	6	16	26	81
total	291	120	49	62	53	575	7	14	15	39	88	163	4	10	15	39	135	203	941

Appendix 1. Summary of ancillary information from respondents to mail-in questionnaire provided to community water systems participating in the Random Survey–Continued

[Data from 941 of 954 participating community water systems that returned a response; VSM = very small (less than 500 people served); SM = small (501 to 3,300 people served); MED = medium (3,301 to 10,000 people served); LRG = large (10,001 to 50,000 people served); VLRG = very large (more than 50,000 people served); --, not applicable; >, greater than; <, less than]

Question	Source-water type and size of community water system																		TOTAL
	Ground water						Rivers						Reservoirs						
	VSM	SM	MED	LRG	VLRG	TOTAL	VSM	SM	MED	LRG	VLRG	TOTAL	VSM	SM	MED	LRG	VLRG	TOTAL	
5. Has methyl *tert*-butyl ether been detected in finished-water samples from this drinking-water source within the last three years?																			
yes	3	0	2	2	4	11	0	0	0	0	5	5	0	1	0	1	10	12	28
no	172	64	31	45	38	350	6	7	10	28	54	105	3	4	11	23	85	126	581
uncertain	63	32	12	6	4	117	1	6	3	10	19	39	1	4	4	14	29	52	208
did not answer	53	24	4	9	7	97	0	1	2	1	10	14	0	1	0	1	11	13	124
total	291	120	49	62	53	575	7	14	15	39	88	163	4	10	15	39	135	203	941
6. Have other volatile organic compounds (excluding trihalomethanes and other disinfectant by-products) been detected in source-water samples from this drinking-water source within the last three years?																			
yes	11	10	5	10	12	48	0	1	1	8	14	24	0	0	1	1	4	6	78
no	200	72	35	45	35	387	3	7	6	14	41	71	3	4	7	23	84	121	579
uncertain	60	28	6	4	2	100	1	6	4	12	22	45	1	3	3	7	26	40	185
did not answer	20	10	3	3	4	40	3	0	4	5	11	23	0	3	4	8	21	36	99
total	291	120	49	62	53	575	7	14	15	39	88	163	4	10	15	39	135	203	941
7. Have other volatile organic compounds (excluding trihalomethanes and other disinfectant by-products) been detected in finished-water samples from this source within the last three years?																			
yes	17	5	4	5	13	44	1	2	2	8	18	31	0	3	4	8	18	33	108
no	170	62	32	45	32	341	4	10	9	26	61	110	2	5	9	26	98	140	591
uncertain	55	26	9	6	1	97	1	1	2	4	5	13	1	1	1	4	8	15	125
did not answer	49	27	4	6	7	93	1	1	2	1	4	9	1	1	1	1	11	15	117
total	291	120	49	62	53	575	7	14	15	39	88	163	4	10	15	39	135	203	941
8. (Pertaining to fuel use) Is the source water in an ozone non-attainment area?																			
yes	15	5	1	2	2	25	0	0	0	2	16	18	1	0	1	0	18	20	63
no	98	29	12	26	23	188	5	5	6	13	23	52	0	4	4	12	43	63	303
uncertain	174	83	35	33	28	353	2	9	9	23	47	90	3	6	10	26	70	115	558
did not answer	4	3	1	1	0	9	0	0	0	1	2	3	0	0	0	1	4	5	17
total	291	120	49	62	53	575	7	14	15	39	88	163	4	10	15	39	135	203	941
9. Is the source water in an area where use of reformulated gasoline is required?																			
yes	15	5	6	6	12	44	0	1	0	5	25	31	0	0	0	7	42	49	124
no	164	65	27	40	28	324	6	8	8	19	29	70	2	5	11	16	46	80	474
uncertain	102	47	15	16	13	193	1	5	7	15	33	61	2	5	4	15	43	69	323
did not answer	10	3	1	0	0	14	0	0	0	1	1	2	0	0	0	0	4	4	20
total	291	120	49	62	53	575	7	14	15	40	88	164	4	10	15	38	135	202	941

Appendix 1. Summary of ancillary information from respondents to mail-in questionnaire provided to community water systems participating in the Random Survey–Continued

[Data from 941 of 954 participating community water systems that returned a response; VSM = very small (less than 500 people served); SM = small (501 to 3,300 people served); MED = medium (3,301 to 10,000 people served); LRG = large (10,001 to 50,000 people served); VLRG = very large (more than 50,000 people served); --, not applicable; >, greater than; <, less than]

Question	Source-water type and size of community water system																		TOTAL
	Ground water						Rivers						Reservoirs						
	VSM	SM	MED	LRG	VLRG	TOTAL	VSM	SM	MED	LRG	VLRG	TOTAL	VSM	SM	MED	LRG	VLRG	TOTAL	
10. What type of ground-water source was sampled for this study?																			
well	284	115	46	60	53	558	--	--	--	--	--	--	--	--	--	--	--	--	558
spring	6	3	3	1	0	13	--	--	--	--	--	--	--	--	--	--	--	--	13
gallery	1	1	0	1	0	3	--	--	--	--	--	--	--	--	--	--	--	--	3
did not answer	0	1	0	0	0	1	--	--	--	--	--	--	--	--	--	--	--	--	1
total	291	120	49	62	53	575	--	--	--	--	--	--	--	--	--	--	--	--	575
11. If source is a well (or wells), what is the depth of the well(s) below land surface (feet)?																			
0 - 250	141	51	20	28	19	259	--	--	--	--	--	--	--	--	--	--	--	--	259
251 - 500	82	33	15	12	9	151	--	--	--	--	--	--	--	--	--	--	--	--	151
501 - 750	23	11	3	11	8	56	--	--	--	--	--	--	--	--	--	--	--	--	56
751 - 1,000	12	4	3	4	5	28	--	--	--	--	--	--	--	--	--	--	--	--	28
>1,000	8	13	3	5	7	36	--	--	--	--	--	--	--	--	--	--	--	--	36
did not answer	25	8	5	2	5	45	--	--	--	--	--	--	--	--	--	--	--	--	45
total	291	120	49	62	53	575	--	--	--	--	--	--	--	--	--	--	--	--	575
12. What is the depth of the intake for the well pump (feet)?																			
0 - 250	151	61	22	42	41	317	--	--	--	--	--	--	--	--	--	--	--	--	317
251 - 500	32	17	6	5	3	63	--	--	--	--	--	--	--	--	--	--	--	--	63
501 - 750	12	3	1	5	1	22	--	--	--	--	--	--	--	--	--	--	--	--	22
751 - 1,000	1	1	1	1	0	4	--	--	--	--	--	--	--	--	--	--	--	--	4
>1,000	1	0	0	0	1	2	--	--	--	--	--	--	--	--	--	--	--	--	2
did not answer	94	38	19	9	7	167	--	--	--	--	--	--	--	--	--	--	--	--	167
total	291	120	49	62	53	575	--	--	--	--	--	--	--	--	--	--	--	--	575
13. What is the depth to the water level under static conditions (feet)?																			
0 - 200	164	76	33	49	41	363	--	--	--	--	--	--	--	--	--	--	--	--	363
200 - 400	11	11	5	6	3	36	--	--	--	--	--	--	--	--	--	--	--	--	36
>400	6	4	2	0	0	12	--	--	--	--	--	--	--	--	--	--	--	--	12
did not answer	110	29	9	7	9	164	--	--	--	--	--	--	--	--	--	--	--	--	164
total	291	120	49	62	53	575	--	--	--	--	--	--	--	--	--	--	--	--	575

Appendix 1. Summary of ancillary information from respondents to mail-in questionnaire provided to community water systems participating in the Random Survey–Continued

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Question	Source-water type and size of community water system																		TOTAL
	Ground water						Rivers						Reservoirs						
	VSM	SM	MED	LRG	VLRG	TOTAL	VSM	SM	MED	LRG	VLRG	TOTAL	VSM	SM	MED	LRG	VLRG	TOTAL	
14. What is the depth to the water level under pumping conditions (feet)?																			
0 - 250	112	63	29	48	37	289	--	--	--	--	--	--	--	--	--	--	--	--	289
251 - 500	8	7	3	6	2	26	--	--	--	--	--	--	--	--	--	--	--	--	26
501 - 750	3	2	2	0	0	7	--	--	--	--	--	--	--	--	--	--	--	--	7
751 - 1,000	1	0	0	0	0	1	--	--	--	--	--	--	--	--	--	--	--	--	1
did not answer	167	48	15	8	14	252	--	--	--	--	--	--	--	--	--	--	--	--	252
total	291	120	49	62	53	575	--	--	--	--	--	--	--	--	--	--	--	--	575
15. What is the average volume pumped per day (gallons)?																			
0 - 50,000	208	23	7	5	5	248	--	--	--	--	--	--	--	--	--	--	--	--	248
50,001 - 100,000	19	26	3	1	0	49	--	--	--	--	--	--	--	--	--	--	--	--	49
>100,000	21	66	34	56	46	223	--	--	--	--	--	--	--	--	--	--	--	--	223
did not answer	43	5	5	0	2	55	--	--	--	--	--	--	--	--	--	--	--	--	55
total	291	120	49	62	53	575	--	--	--	--	--	--	--	--	--	--	--	--	575
16. (Pertaining to well construction) How is the well finished?																			
screened	160	80	35	49	37	361	--	--	--	--	--	--	--	--	--	--	--	--	361
open hole	40	16	5	7	14	82	--	--	--	--	--	--	--	--	--	--	--	--	82
uncertain	72	19	5	2	1	99	--	--	--	--	--	--	--	--	--	--	--	--	99
did not answer	19	5	4	4	1	33	--	--	--	--	--	--	--	--	--	--	--	--	33
total	291	120	49	62	53	575	--	--	--	--	--	--	--	--	--	--	--	--	575
17. What is the length of screened or open interval (feet)?																			
0 - 50	60	31	12	18	13	134	--	--	--	--	--	--	--	--	--	--	--	--	134
51 - 100	3	5	6	5	9	28	--	--	--	--	--	--	--	--	--	--	--	--	28
101 - 150	1	3	0	2	1	7	--	--	--	--	--	--	--	--	--	--	--	--	7
151 - 200	4	2	1	4	1	12	--	--	--	--	--	--	--	--	--	--	--	--	12
201 - 250	2	1	0	0	1	4	--	--	--	--	--	--	--	--	--	--	--	--	4
>250	4	1	0	2	5	12	--	--	--	--	--	--	--	--	--	--	--	--	12
unknown	8	2	0	0	0	10	--	--	--	--	--	--	--	--	--	--	--	--	10
did not answer	209	75	30	31	23	368	--	--	--	--	--	--	--	--	--	--	--	--	368
total	291	120	49	62	53	575	--	--	--	--	--	--	--	--	--	--	--	--	575

Appendix 1. Summary of ancillary information from respondents to mail-in questionnaire provided to community water systems participating in the Random Survey–Continued

[Data from 941 of 954 participating community water systems that returned a response; VSM = very small (less than 500 people served); SM = small (501 to 3,300 people served); MED = medium (3,301 to 10,000 people served); LRG = large (10,001 to 50,000 people served); VLRG = very large (more than 50,000 people served); --, not applicable; >, greater than; <, less than]

Question	Source-water type and size of community water system																		TOTAL
	Ground water						Rivers						Reservoirs						
	VSM	SM	MED	LRG	VLRG	TOTAL	VSM	SM	MED	LRG	VLRG	TOTAL	VSM	SM	MED	LRG	VLRG	TOTAL	
18. Is the aquifer lithology (composition) consolidated (for example, bedrock)?																			
yes	92	29	10	13	12	156	--	--	--	--	--	--	--	--	--	--	--	--	156
no	35	14	9	12	17	87	--	--	--	--	--	--	--	--	--	--	--	--	87
uncertain	77	28	10	7	7	129	--	--	--	--	--	--	--	--	--	--	--	--	129
did not answer	87	49	20	30	17	203	--	--	--	--	--	--	--	--	--	--	--	--	203
total	291	120	49	62	53	575	--	--	--	--	--	--	--	--	--	--	--	--	575
19. Is the aquifer lithology (composition) unconsolidated (for example, sand and gravel)?																			
yes	113	61	27	42	33	276	--	--	--	--	--	--	--	--	--	--	--	--	276
no	17	6	3	3	3	32	--	--	--	--	--	--	--	--	--	--	--	--	32
uncertain	79	27	9	7	6	128	--	--	--	--	--	--	--	--	--	--	--	--	128
did not answer	82	26	10	10	11	139	--	--	--	--	--	--	--	--	--	--	--	--	139
total	291	120	49	62	53	575	--	--	--	--	--	--	--	--	--	--	--	--	575
20. Is the aquifer confined (artesian conditions)?																			
yes	42	15	14	20	15	106	--	--	--	--	--	--	--	--	--	--	--	--	106
no	54	16	8	12	14	104	--	--	--	--	--	--	--	--	--	--	--	--	104
uncertain	72	27	3	6	5	113	--	--	--	--	--	--	--	--	--	--	--	--	113
did not answer	123	62	24	24	19	252	--	--	--	--	--	--	--	--	--	--	--	--	252
total	291	120	49	62	53	575	--	--	--	--	--	--	--	--	--	--	--	--	575
21. Is the aquifer unconfined (water-table conditions)?																			
yes	151	74	28	37	34	324	--	--	--	--	--	--	--	--	--	--	--	--	324
no	6	3	2	5	5	21	--	--	--	--	--	--	--	--	--	--	--	--	21
uncertain	76	23	4	4	4	111	--	--	--	--	--	--	--	--	--	--	--	--	111
did not answer	58	20	15	16	10	119	--	--	--	--	--	--	--	--	--	--	--	--	119
total	291	120	49	62	53	575	--	--	--	--	--	--	--	--	--	--	--	--	575
22. Is this source perceived or known to be under the influence of surface water?																			
yes	14	14	3	6	2	39	--	--	--	--	--	--	--	--	--	--	--	--	39
no	215	79	40	51	45	430	--	--	--	--	--	--	--	--	--	--	--	--	430
uncertain	59	21	6	5	5	96	--	--	--	--	--	--	--	--	--	--	--	--	96
did not answer	3	6	0	0	1	10	--	--	--	--	--	--	--	--	--	--	--	--	10
total	291	120	49	62	53	575	--	--	--	--	--	--	--	--	--	--	--	--	575

Appendix 1. Summary of ancillary information from respondents to mail-in questionnaire provided to community water systems participating in the Random Survey–Continued

[Data from 941 of 954 participating community water systems that returned a response; VSM = very small (less than 500 people served); SM = small (501 to 3,300 people served); MED = medium (3,301 to 10,000 people served); LRG = large (10,001 to 50,000 people served); VLRG = very large (more than 50,000 people served); --, not applicable; >, greater than; <, less than]

Question	Source-water type and size of community water system																		TOTAL
	Ground water						Rivers						Reservoirs						
	VSM	SM	MED	LRG	VLRG	TOTAL	VSM	SM	MED	LRG	VLRG	TOTAL	VSM	SM	MED	LRG	VLRG	TOTAL	
23. What is the distance to the nearest surface-water body (miles)?																			
<1	135	44	22	31	17	249	--	--	--	--	--	--	--	--	--	--	--	--	249
1 - 25	91	49	21	20	28	209	--	--	--	--	--	--	--	--	--	--	--	--	209
26 - 50	7	4	2	1	0	14	--	--	--	--	--	--	--	--	--	--	--	--	14
51 - 75	0	1	0	1	0	2	--	--	--	--	--	--	--	--	--	--	--	--	2
76 - 100	1	0	0	0	0	1	--	--	--	--	--	--	--	--	--	--	--	--	1
did not answer	57	22	4	9	8	100	--	--	--	--	--	--	--	--	--	--	--	--	100
total	291	120	49	62	53	575	--	--	--	--	--	--	--	--	--	--	--	--	575
24. Are there any petroleum refineries, pipelines, gas stations, or chemical underground storage tanks within 1/4-mile of the sampled source?																			
yes	44	29	16	16	18	123	0	2	2	6	17	27	0	2	0	3	22	27	177
no	225	84	29	43	28	409	6	11	13	30	54	114	4	7	14	35	102	162	685
uncertain	19	6	4	3	6	38	1	1	0	3	15	20	0	1	1	1	5	8	66
did not answer	3	1	0	0	1	5	0	0	0	0	2	2	0	0	0	0	6	6	13
total	291	120	49	62	53	575	7	14	15	39	88	163	4	10	15	39	135	203	941
25. Are there any known contaminant sources in proximity to the sampled source that may impact chemical quality of the sampled source?																			
yes	36	24	15	17	19	111	0	3	1	4	15	23	0	1	1	2	19	23	157
no	224	81	25	42	28	400	6	4	13	30	57	110	4	8	14	36	105	167	677
uncertain	26	12	7	3	5	53	1	7	1	5	14	28	0	1	0	1	5	7	88
did not answer	5	3	2	0	1	11	0	0	0	0	2	2	0	0	0	0	6	6	19
total	291	120	49	62	53	575	7	14	15	39	88	163	4	10	15	39	135	203	941
26. Are there any oil fields within 1/4-mile of the sampled source?																			
yes	6	2	1	0	2	11	0	0	0	1	0	1	0	1	1	0	6	8	20
no	265	107	45	57	47	521	6	12	12	33	80	143	4	9	14	37	114	178	842
uncertain	16	10	3	5	3	37	1	2	3	5	6	17	0	0	0	2	14	16	70
did not answer	4	1	0	0	1	6	0	0	0	0	2	2	0	0	0	0	1	1	9
total	291	120	49	62	53	575	7	14	15	39	88	163	4	10	15	39	135	203	941
27. Has this well or any well within 1/4-mile of the well been closed within the past three years due to contamination by volatile organic compounds?																			
yes	3	1	0	2	4	10	--	--	--	--	--	--	--	--	--	--	--	--	10
no	256	106	46	60	47	515	--	--	--	--	--	--	--	--	--	--	--	--	515
uncertain	29	10	1	0	1	41	--	--	--	--	--	--	--	--	--	--	--	--	41
did not answer	3	3	2	0	1	9	--	--	--	--	--	--	--	--	--	--	--	--	9
total	291	120	49	62	53	575	--	--	--	--	--	--	--	--	--	--	--	--	575

Appendix 1. Summary of ancillary information from respondents to mail-in questionnaire provided to community water systems participating in the Random Survey–Continued

[Data from 941 of 954 participating community water systems that returned a response; VSM = very small (less than 500 people served); SM = small (501 to 3,300 people served); MED = medium (3,301 to 10,000 people served); LRG = large (10,001 to 50,000 people served); VLRG = very large (more than 50,000 people served); --, not applicable; >, greater than; <, less than]

Question	Source-water type and size of community water system																		TOTAL
	Ground water						Rivers						Reservoirs						
	VSM	SM	MED	LRG	VLRG	TOTAL	VSM	SM	MED	LRG	VLRG	TOTAL	VSM	SM	MED	LRG	VLRG	TOTAL	
28. Have there been any unusual storm events in the past two months?																			
yes	17	9	4	7	6	43	2	3	2	2	13	22	2	2	1	4	24	33	98
no	250	105	43	45	41	484	2	11	13	30	58	114	2	8	9	30	90	139	737
did not answer	24	6	2	10	6	48	3	0	0	7	17	27	0	0	5	5	21	31	106
total	291	120	49	62	53	575	7	14	15	39	88	163	4	10	15	39	135	203	941
29. Is there a watershed pollution prevention program at this source?																			
yes	--	--	--	--	--	--	2	2	5	14	38	61	0	3	4	17	74	98	159
no	--	--	--	--	--	--	5	10	10	21	38	84	3	6	10	19	48	86	170
did not answer	--	--	--	--	--	--	0	2	0	4	12	18	1	1	1	3	13	19	37
total	--	--	--	--	--	--	7	14	15	39	88	163	4	10	15	39	135	203	366
30. Is any fuel or chemical that might be a source of volatile organic compounds commercially transported on this water body within 1/4-mile of the intake of the sampled source?																			
yes	--	--	--	--	--	--	0	1	0	7	18	26	1	0	1	2	20	24	50
no	--	--	--	--	--	--	7	11	14	30	55	117	3	10	12	34	97	156	273
uncertain	--	--	--	--	--	--	0	2	1	2	13	18	0	0	2	3	17	22	40
did not answer	--	--	--	--	--	--	0	0	0	0	2	2	0	0	0	0	1	1	3
total	--	--	--	--	--	--	7	14	15	39	88	163	4	10	15	39	135	203	366
31. Are private motorized watercraft operated on this water body?																			
yes	--	--	--	--	--	--	1	5	12	24	66	108	4	6	8	19	82	119	227
no	--	--	--	--	--	--	6	9	3	15	19	52	0	4	7	20	51	82	134
uncertain	--	--	--	--	--	--	0	0	0	0	0	0	0	0	0	0	0	0	0
did not answer	--	--	--	--	--	--	0	0	0	0	3	3	0	0	0	0	2	2	5
total	--	--	--	--	--	--	7	14	15	39	88	163	4	10	15	39	135	203	366
32. Are official use, motorized watercraft operated on this water body?																			
yes	--	--	--	--	--	--	1	5	3	17	54	80	4	4	7	21	115	151	231
no	--	--	--	--	--	--	6	9	12	21	29	77	0	6	8	18	17	49	126
uncertain	--	--	--	--	--	--	0	0	0	1	1	2	0	0	0	0	0	0	2
did not answer	--	--	--	--	--	--	0	0	0	0	4	4	0	0	0	0	3	3	7
total	--	--	--	--	--	--	7	14	15	39	88	163	4	10	15	39	135	203	366

Appendix 1. Summary of ancillary information from respondents to mail-in questionnaire provided to community water systems participating in the Random Survey–Continued

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Question	Source-water type and size of community water system																		TOTAL
	Ground water						Rivers						Reservoirs						
	VSM	SM	MED	LRG	VLRG	TOTAL	VSM	SM	MED	LRG	VLRG	TOTAL	VSM	SM	MED	LRG	VLRG	TOTAL	
33. What is the estimated number of two-stroke motorized watercraft operated monthly on this water body?																			
0 - 10	--	--	--	--	--	--	3	5	7	3	8	26	0	2	1	7	15	25	51
10 - 50	--	--	--	--	--	--	0	0	0	2	8	10	0	0	2	3	12	17	27
>100	--	--	--	--	--	--	0	2	3	8	28	41	2	2	3	9	52	68	109
did not answer	--	--	--	--	--	--	4	7	5	26	44	86	2	5	9	20	56	92	178
total	--	--	--	--	--	--	7	14	15	39	88	163	4	9	15	39	135	202	365
34. What is the estimated number of four-stroke motorized watercraft operated monthly on this water body?																			
0 - 10	--	--	--	--	--	--	3	3	3	3	11	23	0	1	1	7	9	18	41
10 - 50	--	--	--	--	--	--	0	0	0	3	9	12	0	0	2	3	10	15	27
>100	--	--	--	--	--	--	0	2	1	6	24	33	2	1	2	10	43	58	91
did not answer	--	--	--	--	--	--	4	9	11	27	44	95	2	8	10	19	73	112	207
total	--	--	--	--	--	--	7	14	15	39	88	163	4	10	15	39	135	203	366
35. What is the estimated number of personal motorized watercraft (jet skis) operated monthly on this water body?																			
0 - 10	--	--	--	--	--	--	3	3	2	3	9	20	0	1	2	5	17	25	45
10 - 50	--	--	--	--	--	--	0	0	0	1	10	11	0	0	2	3	6	11	22
>100	--	--	--	--	--	--	0	2	0	6	24	32	2	1	2	8	39	52	84
did not answer	--	--	--	--	--	--	4	9	13	29	45	100	2	8	9	23	73	115	215
total	--	--	--	--	--	--	7	14	15	39	88	163	4	10	15	39	135	203	366
36. Are there any horsepower restrictions on motorized watercraft used on this water body?																			
yes	--	--	--	--	--	--	0	1	2	2	7	12	0	2	3	10	30	45	57
no	--	--	--	--	--	--	3	8	12	30	64	117	4	4	6	17	79	110	227
did not answer	--	--	--	--	--	--	4	5	1	7	17	34	0	4	6	12	26	48	82
total	--	--	--	--	--	--	7	14	15	39	88	163	4	10	15	39	135	203	366
37. Are there any restrictions on the number of watercraft that can be operated on this water body?																			
yes	--	--	--	--	--	--	0	1	1	1	7	10	0	0	1	11	36	48	58
no	--	--	--	--	--	--	3	8	12	30	64	117	4	6	8	17	77	112	229
did not answer	--	--	--	--	--	--	4	5	2	8	17	36	0	4	6	11	22	43	79
total	--	--	--	--	--	--	7	14	15	39	88	163	4	10	15	39	135	203	366

Appendix 1. Summary of ancillary information from respondents to mail-in questionnaire provided to community water systems participating in the Random Survey–Continued

[Data from 941 of 954 participating community water systems that returned a response; VSM = very small (less than 500 people served); SM = small (501 to 3,300 people served); MED = medium (3,301 to 10,000 people served); LRG = large (10,001 to 50,000 people served); VLRG = very large (more than 50,000 people served); --, not applicable; >, greater than; <, less than]

Question	Source-water type and size of community water system																		TOTAL
	Ground water						Rivers						Reservoirs						
	VSM	SM	MED	LRG	VLRG	TOTAL	VSM	SM	MED	LRG	VLRG	TOTAL	VSM	SM	MED	LRG	VLRG	TOTAL	
38. What is the distance from shoreline to the intake opening (feet)?																			
<10	--	--	--	--	--	--	4	3	4	16	45	72	0	2	0	6	19	27	99
10 - 100	--	--	--	--	--	--	1	8	9	11	11	40	2	5	11	16	50	84	124
101 - 1,000	--	--	--	--	--	--	0	2	0	3	9	14	2	3	1	6	31	43	57
>1,000	--	--	--	--	--	--	0	0	1	1	3	5	0	0	1	4	21	26	31
did not answer	--	--	--	--	--	--	2	1	1	8	20	32	0	0	2	7	14	23	55
total	--	--	--	--	--	--	7	14	15	39	88	163	4	10	15	39	135	203	366
39. What is the depth of intake below the water surface (feet)?																			
<10	--	--	--	--	--	--	4	7	7	19	44	81	1	8	7	4	15	35	0
10 - 100	--	--	--	--	--	--	1	4	7	13	26	51	3	2	8	27	96	136	0
>100	--	--	--	--	--	--	0	0	0	0	0	0	0	0	0	2	9	11	0
did not answer	--	--	--	--	--	--	2	3	1	7	18	31	0	0	0	6	15	21	0
total	--	--	--	--	--	--	7	14	15	39	88	163	4	10	15	39	135	203	0
40. What is the intake construction material?																			
concrete	--	--	--	--	--	--	1	3	6	17	52	79	0	2	6	13	63	84	163
iron or steel	--	--	--	--	--	--	4	9	8	19	22	62	2	8	9	23	50	92	154
other material	--	--	--	--	--	--	1	0	0	1	4	6	2	0	0	0	16	18	24
did not answer	--	--	--	--	--	--	1	2	1	2	10	16	0	0	0	3	6	9	25
total	--	--	--	--	--	--	7	14	15	39	88	163	4	10	15	39	135	203	366
41. How does water flow enter the intake?																			
pumped	--	--	--	--	--	--	3	5	8	20	44	80	3	7	8	11	56	85	165
gravity flow	--	--	--	--	--	--	4	9	5	14	37	69	0	2	7	24	69	102	171
both	--	--	--	--	--	--	0	0	1	4	4	9	0	0	0	4	5	9	18
did not answer	--	--	--	--	--	--	0	0	1	1	3	5	1	1	0	0	5	7	12
total	--	--	--	--	--	--	7	14	15	39	88	163	4	10	15	39	135	203	366
42. What is the distance from the intake to the sample-collection port (feet)?																			
<1,000	--	--	--	--	--	--	2	5	5	19	44	75	0	7	8	12	49	76	151
1,000 - 10,000	--	--	--	--	--	--	2	6	5	9	16	38	1	0	2	13	30	46	84
>10,000	--	--	--	--	--	--	0	1	3	4	4	12	0	1	3	7	23	34	46
did not answer	--	--	--	--	--	--	3	2	2	7	24	38	3	2	2	7	33	47	85
total	--	--	--	--	--	--	7	14	15	39	88	163	4	10	15	39	135	203	366

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Question	Source-water type and size of community water system																		TOTAL
	Ground water						Rivers						Reservoirs						
	VSM	SM	MED	LRG	VLRG	TOTAL	VSM	SM	MED	LRG	VLRG	TOTAL	VSM	SM	MED	LRG	VLRG	TOTAL	
43. Is there a tiered tower at the intake to allow for withdrawals from selective depths?																			
yes	--	--	--	--	--	--	0	2	1	3	8	14	0	2	7	18	67	94	108
no	--	--	--	--	--	--	5	11	9	29	66	120	4	6	8	21	58	97	217
did not answer	--	--	--	--	--	--	2	1	5	7	14	29	0	2	0	0	10	12	41
total	--	--	--	--	--	--	7	14	15	39	88	163	4	10	15	39	135	203	366
44. What is the surface area of the lake or reservoir (acres)?																			
<1,000	--	--	--	--	--	--	--	--	--	--	--	--	0	8	8	23	50	89	89
1,000 - 10,000	--	--	--	--	--	--	--	--	--	--	--	--	0	0	0	0	39	39	39
10,000 - 100,000	--	--	--	--	--	--	--	--	--	--	--	--	1	0	2	4	8	15	15
>100,000	--	--	--	--	--	--	--	--	--	--	--	--	1	1	0	3	15	20	20
did not answer	--	--	--	--	--	--	--	--	--	--	--	--	2	1	5	9	23	40	40
total	--	--	--	--	--	--	--	--	--	--	--	--	4	10	15	39	135	203	203
45. What is the average depth of the lake or reservoir (feet)?																			
<20	--	--	--	--	--	--	--	--	--	--	--	--	0	6	6	11	26	49	0
20 - 100	--	--	--	--	--	--	--	--	--	--	--	--	1	4	7	13	63	88	88
>100	--	--	--	--	--	--	--	--	--	--	--	--	1	0	0	4	17	22	22
did not answer	--	--	--	--	--	--	--	--	--	--	--	--	2	0	2	11	29	44	44
total	--	--	--	--	--	--	--	--	--	--	--	--	4	10	15	39	135	203	203
46. What is the storage volume of the lake or reservoir (million gallons)?																			
<1,000	--	--	--	--	--	--	--	--	--	--	--	--	0	6	9	19	14	48	48
1,000 - 10,000	--	--	--	--	--	--	--	--	--	--	--	--	1	0	1	5	42	49	49
10,000 - 100,000	--	--	--	--	--	--	--	--	--	--	--	--	0	0	1	1	38	40	40
>100,000	--	--	--	--	--	--	--	--	--	--	--	--	0	1	0	5	16	22	22
did not answer	--	--	--	--	--	--	--	--	--	--	--	--	3	3	4	9	25	44	44
total	--	--	--	--	--	--	--	--	--	--	--	--	4	10	15	39	135	203	203
47. What is the average flow in the river (cubic feet per second)?																			
<100	--	--	--	--	--	--	0	4	6	12	8	30	--	--	--	--	--	--	30
100 - 1,000	--	--	--	--	--	--	1	1	3	7	15	27	--	--	--	--	--	--	27
>1,000	--	--	--	--	--	--	0	2	0	8	33	43	--	--	--	--	--	--	43
did not answer	--	--	--	--	--	--	6	7	6	12	32	63	--	--	--	--	--	--	63
total	--	--	--	--	--	--	7	14	15	39	88	163	--	--	--	--	--	--	163

Appendix 1. Summary of ancillary information from respondents to mail-in questionnaire provided to community water systems participating in the Random Survey–Continued

[Data from 941 of 954 participating community water systems that returned a response; VSM = very small (less than 500 people served); SM = small (501 to 3,300 people served); MED = medium (3,301 to 10,000 people served); LRG = large (10,001 to 50,000 people served); VLRG = very large (more than 50,000 people served); --, not applicable; >, greater than; <, less than]

Question	Source-water type and size of community water system																		TOTAL
	Ground water						Rivers						Reservoirs						
	VSM	SM	MED	LRG	VLRG	TOTAL	VSM	SM	MED	LRG	VLRG	TOTAL	VSM	SM	MED	LRG	VLRG	TOTAL	
48. Does the lake or reservoir stratify during the year?																			
yes	--	--	--	--	--	--	--	--	--	--	--	--	2	6	11	26	99	144	144
no	--	--	--	--	--	--	--	--	--	--	--	--	0	1	0	6	16	23	23
uncertain	--	--	--	--	--	--	--	--	--	--	--	--	2	2	4	4	11	23	23
did not answer	--	--	--	--	--	--	--	--	--	--	--	--	0	1	0	3	9	13	23
total	--	--	--	--	--	--	--	--	--	--	--	--	4	10	15	39	135	203	203
49. Does the source water body freeze over during the winter?																			
yes	--	--	--	--	--	--	--	--	--	--	--	--	2	8	6	23	60	99	99
no	--	--	--	--	--	--	--	--	--	--	--	--	2	2	8	15	66	93	93
uncertain	--	--	--	--	--	--	--	--	--	--	--	--	0	0	0	0	0	0	0
did not answer	--	--	--	--	--	--	--	--	--	--	--	--	0	0	1	1	9	11	11
total	--	--	--	--	--	--	--	--	--	--	--	--	4	10	15	39	135	203	203
50. Is the source water disinfected prior to final distribution?																			
yes	194	91	43	54	46	428	6	13	15	39	84	157	4	10	14	38	129	195	780
no	34	12	2	3	4	55	0	0	0	0	1	1	0	0	0	0	0	0	56
did not answer	63	17	4	5	3	92	1	1	0	0	3	5	0	0	1	1	6	8	105
total	291	120	49	62	53	575	7	14	15	39	88	163	4	10	15	39	135	203	941
51. Is the source water aerated prior to final distribution?																			
yes	15	18	15	24	19	91	--	--	--	--	--	--	--	--	--	--	--	--	91
no	144	60	18	19	18	259	--	--	--	--	--	--	--	--	--	--	--	--	259
did not answer	132	42	16	19	16	225	--	--	--	--	--	--	--	--	--	--	--	--	225
total	291	120	49	62	53	575	--	--	--	--	--	--	--	--	--	--	--	--	575
52. Is the source water treated for iron and (or) manganese removal prior to final distribution?																			
yes	37	25	13	25	10	110	--	--	--	--	--	--	--	--	--	--	--	--	110
no	126	53	17	16	22	234	--	--	--	--	--	--	--	--	--	--	--	--	234
did not answer	128	42	19	21	21	231	--	--	--	--	--	--	--	--	--	--	--	--	231
total	291	120	49	62	53	575	--	--	--	--	--	--	--	--	--	--	--	--	575

Appendix 1. Summary of ancillary information from respondents to mail-in questionnaire provided to community water systems participating in the Random Survey–Continued

[Data from 941 of 954 participating community water systems that returned a response; VSM = very small (less than 500 people served); SM = small (501 to 3,300 people served); MED = medium (3,301 to 10,000 people served); LRG = large (10,001 to 50,000 people served); VLRG = very large (more than 50,000 people served); --, not applicable; >, greater than; <, less than]

Question	Source-water type and size of community water system																		TOTAL
	Ground water						Rivers						Reservoirs						
	VSM	SM	MED	LRG	VLRG	TOTAL	VSM	SM	MED	LRG	VLRG	TOTAL	VSM	SM	MED	LRG	VLRG	TOTAL	
53. Is the source water treated by oxidation prior to final distribution?																			
yes	8	7	3	13	9	40	--	--	--	--	--	--	--	--	--	--	--	--	40
no	145	63	23	21	21	273	--	--	--	--	--	--	--	--	--	--	--	--	273
did not answer	138	50	23	28	23	262	--	--	--	--	--	--	--	--	--	--	--	--	262
total	291	120	49	62	53	575	--	--	--	--	--	--	--	--	--	--	--	--	575
54. Is the source water treated by conventional filtration prior to final distribution?																			
yes	--	--	--	--	--	--	3	11	13	37	77	141	2	7	11	30	111	161	302
no	--	--	--	--	--	--	2	2	1	1	7	13	1	1	1	2	15	20	33
did not answer	--	--	--	--	--	--	2	1	1	1	4	9	1	2	3	7	9	22	31
total	--	--	--	--	--	--	7	14	15	39	88	163	4	10	15	39	135	203	366
55. Is the source water treated by direct filtration prior to final distribution?																			
yes	--	--	--	--	--	--	1	3	1	1	4	10	0	0	0	5	16	21	31
no	--	--	--	--	--	--	3	4	3	13	38	61	2	1	4	15	56	78	139
did not answer	--	--	--	--	--	--	3	7	11	25	46	92	2	9	11	19	63	104	196
total	--	--	--	--	--	--	7	14	15	39	88	163	4	10	15	39	135	203	366
56. Is the source water treated by in-line filtration prior to final distribution?																			
yes	--	--	--	--	--	--	2	0	1	1	1	5	2	1	0	1	4	8	13
no	--	--	--	--	--	--	2	6	3	13	38	62	1	0	5	18	63	87	149
did not answer	--	--	--	--	--	--	3	8	11	25	49	96	1	9	10	20	68	108	204
total	--	--	--	--	--	--	7	14	15	39	88	163	4	10	15	39	135	203	366
57. Is the source water treated by slow sand filtration prior to final distribution?																			
yes	--	--	--	--	--	--	4	2	2	4	6	18	1	3	5	1	7	17	35
no	--	--	--	--	--	--	2	5	4	12	36	59	1	1	2	16	62	82	141
did not answer	--	--	--	--	--	--	1	7	9	23	46	86	2	6	8	22	66	104	190
total	--	--	--	--	--	--	7	14	15	39	88	163	4	10	15	39	135	203	366
58. Is the source water treated by softening prior to final distribution?																			
yes	--	--	--	--	--	--	0	0	0	4	9	13	1	2	2	3	10	18	31
no	--	--	--	--	--	--	4	7	4	13	35	63	2	1	5	17	62	87	150
did not answer	--	--	--	--	--	--	3	7	11	22	44	87	1	7	8	19	63	98	185
total	--	--	--	--	--	--	7	14	15	39	88	163	4	10	15	39	135	203	366

Appendix 1. Summary of ancillary information from respondents to mail-in questionnaire provided to community water systems participating in the Random Survey–Continued

[Data from 941 of 954 participating community water systems that returned a response; VSM = very small (less than 500 people served); SM = small (501 to 3,300 people served); MED = medium (3,301 to 10,000 people served); LRG = large (10,001 to 50,000 people served); VLRG = very large (more than 50,000 people served); --, not applicable; >, greater than; <, less than]

Question	Source-water type and size of community water system																		TOTAL
	Ground water						Rivers						Reservoirs						
	VSM	SM	MED	LRG	VLRG	TOTAL	VSM	SM	MED	LRG	VLRG	TOTAL	VSM	SM	MED	LRG	VLRG	TOTAL	
59. Is the source water treated by two-stage softening prior to final distribution?																			
yes	--	--	--	--	--	--	0	0	0	0	3	3	0	0	0	0	0	0	3
no	--	--	--	--	--	--	4	7	4	14	40	69	2	1	5	19	68	95	164
did not answer	--	--	--	--	--	--	3	7	11	25	45	91	2	8	10	20	67	108	199
total	--	--	--	--	--	--	7	14	15	39	88	163	4	9	15	39	135	203	366
60. Is the source water treated by coagulation and (or) sedimentation softening prior to final distribution?																			
yes	--	--	--	--	--	--	1	6	11	28	49	95	2	9	13	23	69	116	211
no	--	--	--	--	--	--	3	5	1	5	14	28	1	0	0	5	35	41	69
did not answer	--	--	--	--	--	--	3	3	3	6	25	40	1	1	2	11	31	46	86
total	--	--	--	--	--	--	7	14	15	39	88	163	4	10	15	39	135	203	366
61. Is the source water treated by split-treatment-softening prior to final distribution?																			
yes	--	--	--	--	--	--	0	0	0	1	3	4	0	0	0	0	1	1	5
no	--	--	--	--	--	--	4	7	4	13	40	68	2	1	5	18	68	94	162
did not answer	--	--	--	--	--	--	3	7	11	25	45	91	2	9	10	21	66	108	199
total	--	--	--	--	--	--	7	14	15	39	88	163	4	10	15	39	135	203	366
62. Is the source water treated by complex-parallel-train softening prior to final distribution?																			
yes	--	--	--	--	--	--	0	0	0	1	1	2	0	0	0	0	0	0	2
no	--	--	--	--	--	--	4	7	4	13	41	69	2	1	5	18	68	94	163
did not answer	--	--	--	--	--	--	3	7	11	25	46	92	2	9	10	21	67	109	201
total	--	--	--	--	--	--	7	14	15	39	88	163	4	10	15	39	135	203	366
63. Does the source water receive no treatment prior to final distribution?																			
yes	--	--	--	--	--	--	0	0	0	0	1	1	0	0	0	0	4	4	5
no	--	--	--	--	--	--	4	5	3	14	38	64	2	1	3	23	56	85	149
did not answer	--	--	--	--	--	--	3	9	12	25	49	98	2	9	12	16	75	114	212
total	--	--	--	--	--	--	7	14	15	39	88	163	4	10	15	39	135	203	366
64. Are there any other treatment process used on the source water prior to final distribution?																			
yes	57	29	21	24	30	161	0	1	2	7	13	23	0	0	0	7	34	41	225
no	97	37	11	14	12	171	3	5	0	5	16	29	1	0	3	8	27	39	239
did not answer	137	54	17	24	11	243	4	8	13	27	59	111	3	10	12	24	74	123	477
total	291	120	49	62	53	575	7	14	15	39	88	163	4	10	15	39	135	203	941

Appendix 1. Summary of ancillary information from respondents to mail-in questionnaire provided to community water systems participating in the Random Survey–Continued

[Data from 941 of 954 participating community water systems that returned a response; VSM = very small (less than 500 people served); SM = small (501 to 3,300 people served); MED = medium (3,301 to 10,000 people served); LRG = large (10,001 to 50,000 people served); VLRG = very large (more than 50,000 people served); --, not applicable; >, greater than; <, less than]

Question	Source-water type and size of community water system																		TOTAL
	Ground water						Rivers						Reservoirs						
	VSM	SM	MED	LRG	VLRG	TOTAL	VSM	SM	MED	LRG	VLRG	TOTAL	VSM	SM	MED	LRG	VLRG	TOTAL	
65. Is the source water treated by granular activated carbon to remove volatile or other organic compounds?																			
yes	1	2	2	0	6	11	1	0	0	2	22	25	0	2	1	2	15	20	56
no	11	3	5	1	2	22	2	2	0	2	8	14	0	0	0	6	20	26	62
did not answer	279	115	42	61	45	542	4	12	15	35	58	124	4	8	14	31	100	157	823
total	291	120	49	62	53	575	7	14	15	39	88	163	4	10	15	39	135	203	941
66. Is the source water treated by powdered activated carbon to remove volatile or other organic compounds?																			
yes	1	0	0	0	0	1	0	5	7	13	43	68	0	3	7	14	53	77	146
no	11	3	5	1	2	22	4	5	2	9	19	39	2	1	2	9	37	51	112
did not answer	279	117	44	61	51	552	3	4	6	17	26	56	2	6	6	16	45	75	683
total	291	120	49	62	53	575	7	14	15	39	88	163	4	10	15	39	135	203	941
67. Is the source water treated with a membrane to remove volatile or other organic compounds?																			
yes	1	0	0	0	1	2	1	0	0	1	0	2	0	0	0	0	5	5	9
no	10	3	5	1	2	21	3	6	4	13	42	68	2	1	4	18	65	90	179
did not answer	280	117	44	61	50	552	3	8	11	25	46	93	2	9	11	21	65	108	753
total	291	120	49	62	53	575	7	14	15	39	88	163	4	10	15	39	135	203	941
68. Is the source water treated with ozone to remove volatile or other organic compounds?																			
yes	0	0	0	0	1	1	0	0	0	0	3	3	0	0	0	0	11	11	15
no	11	3	5	1	2	22	2	2	0	2	11	17	0	0	0	7	19	26	65
did not answer	280	117	44	61	50	552	5	12	15	37	74	143	4	10	15	32	105	166	861
total	291	120	49	62	53	575	7	14	15	39	88	163	4	10	15	39	135	203	941
69. Is the source water treated with aeration to remove volatile or other organic compounds?																			
yes	4	7	5	5	9	30	0	0	0	3	2	5	0	2	2	2	9	15	50
no	11	3	5	1	1	21	2	2	0	2	10	16	0	0	0	6	20	26	63
did not answer	276	110	39	56	43	524	5	12	15	34	76	142	4	8	13	31	106	162	828
total	291	120	49	62	53	575	7	14	15	39	88	163	4	10	15	39	135	203	941
70. Is the source water treated with air stripping towers to remove volatile or other organic compounds?																			
yes	1	1	2	5	6	15	0	0	0	2	0	2	1	0	0	0	0	1	18
no	11	3	5	1	2	22	2	2	0	2	12	18	0	0	0	7	23	30	70
did not answer	279	116	42	56	45	538	5	12	15	35	76	143	3	10	15	32	112	172	853
total	291	120	49	62	53	575	7	14	15	39	88	163	4	10	15	39	135	203	941

Appendix 2. Frequency of detection and concentrations of volatile organic compounds in 954 source-water samples collected from May 3, 1999, through October 23, 2000, for the Random Survey, by type of source water and size of community water system

[Detection frequency is percent of source-water samples with volatile organic compound concentrations equal to or greater than the minimum reporting level (MRL); MRL, 0.2 µg/L (micrograms per liter) for all compounds except methyl ethyl ketone which was 2.0 µg/L; Min, minimum; Max, maximum; <, less than]

Volatile organic compound	Statistic	Type of source water					Size of community water system				
		All sources	Ground water	Surface water	River	Reservoir	Very small	Small	Medium	Large	Very Large
Acrylonitrile	Number of samples	954	579	375	171	204	304	147	80	142	281
	Number of detects	0	0	0	0	0	0	0	0	0	0
	Detection frequency	0	0	0	0	0	0	0	0	0	0
	Min. concentration	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
	Max. concentration	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
tert-Amyl methyl ether	Number of samples	954	579	375	171	204	304	147	80	142	281
	Number of detects	2	2	0	0	0	1	0	0	1	0
	Detection frequency	0.21	0.34	0	0	0	0.33	0	0	0.70	0
	Min. concentration	0.21	0.21	<0.2	<0.2	<0.2	0.31	<0.2	<0.2	0.21	<0.2
	Max. concentration	0.31	0.31	<0.2	<0.2	<0.2	0.31	<0.2	<0.2	0.21	<0.2
Benzene	Number of samples	953	578	375	171	204	303	147	80	142	281
	Number of detects	3	2	1	0	1	0	0	0	1	2
	Detection frequency	0.31	0.34	0.27	0	0.49	0	0	0	0.7	0.7
	Min. concentration	0.22	0.75	0.22	<0.2	0.22	<0.2	<0.2	<0.2	3.0	0.22
	Max. concentration	3.0	3.0	0.22	<0.2	0.22	<0.2	<0.2	<0.2	3.0	0.75
Bromobenzene	Number of samples	954	579	375	171	204	304	147	80	142	281
	Number of detects	0	0	0	0	0	0	0	0	0	0
	Detection frequency	0	0	0	0	0	0	0	0	0	0
	Min. concentration	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
	Max. concentration	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Bromochloromethane	Number of samples	953	579	374	170	204	304	147	80	142	280
	Number of detects	0	0	0	0	0	0	0	0	0	0
	Detection frequency	0	0	0	0	0	0	0	0	0	0
	Min. concentration	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
	Max. concentration	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2

Appendix 2. Frequency of detection and concentrations of volatile organic compounds in 954 source-water samples collected from May 3, 1999, through October 23, 2000, for the Random Survey, by type of source water and size of community water system–Continued

[Detection frequency is percent of source-water samples with volatile organic compound concentrations equal to or greater than the minimum reporting level (MRL); MRL, 0.2 µg/L (micrograms per liter) for all compounds except methyl ethyl ketone which was 2.0 µg/L; Min, minimum; Max, maximum; <, less than]

Volatile organic compound	Statistic	Type of source water					Size of community water system				
		All sources	Ground water	Surface water	River	Reservoir	Very small	Small	Medium	Large	Very Large
Bromodichloromethane	Number of samples	953	578	375	171	204	303	147	80	142	281
	Number of detects	61	34	27	13	14	22	8	4	9	18
	Detection frequency	6.4	5.9	7.2	7.6	6.9	7.3	5.4	5.0	6.3	6.4
	Min. concentration	0.20	0.20	0.25	0.39	0.25	0.22	0.21	0.20	0.23	0.25
	Max. concentration	26	7.4	26	26	24	7.4	26	24	3.9	15
Bromoform	Number of samples	954	579	375	171	204	304	147	80	142	281
	Number of detects	32	27	5	2	3	17	6	5	1	3
	Detection frequency	3.4	4.7	1.3	1.2	1.5	5.6	4.1	6.2	0.7	1.1
	Min. concentration	0.21	0.21	0.23	0.53	0.23	0.21	0.30	0.23	5.8	0.33
	Max. concentration	49	49	3.5	3.5	0.62	49	3.5	6.0	5.8	2.4
Bromomethane	Number of samples	954	579	375	171	204	304	147	80	142	281
	Number of detects	2	1	1	1	0	1	0	0	0	1
	Detection frequency	0.21	0.17	0.27	0.58	0	0.33	0	0	0	0.36
	Min. concentration	0.22	6.4	0.22	0.22	<0.2	6.4	<0.2	<0.2	<0.2	0.22
	Max. concentration	6.4	6.4	0.22	0.22	<0.2	6.4	<0.2	<0.2	<0.2	0.22
n-Butylbenzene	Number of samples	954	579	375	171	204	304	147	80	142	281
	Number of detects	1	1	0	0	0	1	0	0	0	0
	Detection frequency	0.10	0.17	0	0	0	0.33	0	0	0	0
	Min. concentration	0.21	0.21	<0.2	<0.2	<0.2	0.21	<0.2	<0.2	<0.2	<0.2
	Max. concentration	0.21	0.21	<0.2	<0.2	<0.2	0.21	<0.2	<0.2	<0.2	<0.2
sec-Butylbenzene	Number of samples	954	579	375	171	204	304	147	80	142	281
	Number of detects	0	0	0	0	0	0	0	0	0	0
	Detection frequency	0	0	0	0	0	0	0	0	0	0
	Min. concentration	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
	Max. concentration	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2

Appendix 2. Frequency of detection and concentrations of volatile organic compounds in 954 source-water samples collected from May 3, 1999, through October 23, 2000, for the Random Survey, by type of source water and size of community water system–Continued

[Detection frequency is percent of source-water samples with volatile organic compound concentrations equal to or greater than the minimum reporting level (MRL); MRL, 0.2 µg/L (micrograms per liter) for all compounds except methyl ethyl ketone which was 2.0 µg/L; Min, minimum; Max, maximum; <, less than]

Volatile organic compound	Statistic	Type of source water					Size of community water system				
		All sources	Ground water	Surface water	River	Reservoir	Very small	Small	Medium	Large	Very Large
tert-Butylbenzene	Number of samples	954	579	375	171	204	304	147	80	142	281
	Number of detects	0	0	0	0	0	0	0	0	0	0
	Detection frequency	0	0	0	0	0	0	0	0	0	0
	Min. concentration	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
	Max. concentration	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Carbon tetrachloride	Number of samples	954	579	375	171	204	304	147	80	142	281
	Number of detects	7	5	2	1	1	2	2	0	1	2
	Detection frequency	0.73	0.86	0.53	0.58	0.49	0.66	1.4	0	0.7	0.71
	Min. concentration	0.25	0.38	0.25	0.43	0.25	0.47	0.38	<0.2	0.43	0.25
	Max. concentration	1.8	1.8	0.43	0.43	0.25	1.2	0.39	<0.2	0.43	1.8
Chlorobenzene	Number of samples	954	579	375	171	204	304	147	80	142	281
	Number of detects	1	1	0	0	0	0	0	0	0	1
	Detection frequency	0.10	0.17	0	0	0	0	0	0	0	0.36
	Min. concentration	1.6	1.6	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	1.6
	Max. concentration	1.6	1.6	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	1.6
Chlorodibromomethane	Number of samples	953	578	375	171	204	303	147	80	142	281
	Number of detects	52	35	17	8	9	25	5	4	6	12
	Detection frequency	5.5	6.1	4.5	4.7	4.4	8.2	3.4	5.0	4.2	4.3
	Min. concentration	0.21	0.21	0.22	0.25	0.22	0.21	0.30	0.48	0.22	0.25
	Max. concentration	20	9.4	20	20	8.9	9.4	20	8.9	2.3	4.2
Chloroethane	Number of samples	954	579	375	171	204	304	147	80	142	281
	Number of detects	1	1	0	0	0	1	0	0	0	0
	Detection frequency	0.10	0.17	0	0	0	0.33	0	0	0	0
	Min. concentration	2.6	2.6	<0.2	<0.2	<0.2	2.6	<0.2	<0.2	<0.2	<0.2
	Max. concentration	2.6	2.6	<0.2	<0.2	<0.2	2.6	<0.2	<0.2	<0.2	<0.2

Appendix 2. Frequency of detection and concentrations of volatile organic compounds in 954 source-water samples collected from May 3, 1999, through October 23, 2000, for the Random Survey, by type of source water and size of community water system–Continued

[Detection frequency is percent of source-water samples with volatile organic compound concentrations equal to or greater than the minimum reporting level (MRL); MRL, 0.2 µg/L (micrograms per liter) for all compounds except methyl ethyl ketone which was 2.0 µg/L; Min, minimum; Max, maximum; <, less than]

Volatile organic compound	Statistic	Type of source water					Size of community water system				
		All sources	Ground water	Surface water	River	Reservoir	Very small	Small	Medium	Large	Very Large
Chloroform	Number of samples	946	575	371	168	203	302	144	79	140	281
	Number of detects	120	68	52	27	25	40	16	11	16	37
	Detection frequency	13	12	14	16	12	13	11	14	11	13
	Min. concentration	0.20	0.21	0.20	0.20	0.21	0.21	0.23	0.21	0.23	0.20
	Max. concentration	85	22	85	34	85	22	24	35	34	85
Chloromethane	Number of samples	954	579	375	171	204	304	147	80	142	281
	Number of detects	3	3	0	0	0	2	0	0	0	1
	Detection frequency	0.31	0.52	0	0	0	0.66	0	0	0	0.36
	Min. concentration	0.20	0.20	<0.2	<0.2	<0.2	0.20	<0.2	<0.2	<0.2	0.69
	Max. concentration	0.69	0.69	<0.2	<0.2	<0.2	0.40	<0.2	<0.2	<0.2	0.69
2-Chlorotoluene	Number of samples	954	579	375	171	204	304	147	80	142	281
	Number of detects	0	0	0	0	0	0	0	0	0	0
	Detection frequency	0	0	0	0	0	0	0	0	0	0
	Min. concentration	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
	Max. concentration	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
4-Chlorotoluene	Number of samples	954	579	375	171	204	304	147	80	142	281
	Number of detects	0	0	0	0	0	0	0	0	0	0
	Detection frequency	0	0	0	0	0	0	0	0	0	0
	Min. concentration	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
	Max. concentration	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Dibromomethane	Number of samples	920	562	358	163	195	295	145	77	140	263
	Number of detects	2	2	0	0	0	1	1	0	0	0
	Detection frequency	0.22	0.36	0	0	0	0.34	0.69	0	0	0
	Min. concentration	0.33	0.33	<0.2	<0.2	<0.2	0.33	0.75	<0.2	<0.2	<0.2
	Max. concentration	0.75	0.75	<0.2	<0.2	<0.2	0.33	0.75	<0.2	<0.2	<0.2

Appendix 2. Frequency of detection and concentrations of volatile organic compounds in 954 source-water samples collected from May 3, 1999, through October 23, 2000, for the Random Survey, by type of source water and size of community water system–Continued

[Detection frequency is percent of source-water samples with volatile organic compound concentrations equal to or greater than the minimum reporting level (MRL); MRL, 0.2 µg/L (micrograms per liter) for all compounds except methyl ethyl ketone which was 2.0 µg/L; Min, minimum; Max, maximum; <, less than]

Volatile organic compound	Statistic	Type of source water					Size of community water system				
		All sources	Ground water	Surface water	River	Reservoir	Very small	Small	Medium	Large	Very Large
1,2-Dichlorobenzene	Number of samples	954	579	375	171	204	304	147	80	142	281
	Number of detects	1	1	0	0	0	0	0	0	0	1
	Detection frequency	0.10	0.17	0	0	0	0	0	0	0	0.36
	Min. concentration	0.37	0.37	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	0.37
	Max. concentration	0.37	0.37	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	0.37
1,3-Dichlorobenzene	Number of samples	954	579	375	171	204	304	147	80	142	281
	Number of detects	0	0	0	0	0	0	0	0	0	0
	Detection frequency	0	0	0	0	0	0	0	0	0	0
	Min. concentration	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
	Max. concentration	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
1,4-Dichlorobenzene	Number of samples	953	579	374	171	203	304	147	80	141	281
	Number of detects	3	1	2	1	1	0	0	0	0	3
	Detection frequency	0.31	0.17	0.53	0.58	0.49	0	0	0	0	1.1
	Min. concentration	0.22	0.25	0.22	0.22	0.36	<0.2	<0.2	<0.2	<0.2	0.22
	Max. concentration	0.36	0.25	0.36	0.22	0.36	<0.2	<0.2	<0.2	<0.2	0.36
Dichlorodifluoromethane	Number of samples	954	579	375	171	204	304	147	80	142	281
	Number of detects	4	4	0	0	0	1	0	0	0	3
	Detection frequency	0.42	0.69	0	0	0	0.33	0	0	0	1.1
	Min. concentration	1.1	1.1	<0.2	<0.2	<0.2	18	<0.2	<0.2	<0.2	1.1
	Max. concentration	18	18	<0.2	<0.2	<0.2	18	<0.2	<0.2	<0.2	7.5
1,1-Dichloroethane	Number of samples	954	579	375	171	204	304	147	80	142	281
	Number of detects	11	11	0	0	0	2	0	2	2	5
	Detection frequency	1.2	1.9	0	0	0	0.66	0	2.5	1.4	1.8
	Min. concentration	0.21	0.21	<0.2	<0.2	<0.2	0.21	<0.2	1.95	0.31	0.29
	Max. concentration	10	10	<0.2	<0.2	<0.2	0.22	<0.2	10	0.38	5.3

Appendix 2. Frequency of detection and concentrations of volatile organic compounds in 954 source-water samples collected from May 3, 1999, through October 23, 2000, for the Random Survey, by type of source water and size of community water system–Continued

[Detection frequency is percent of source-water samples with volatile organic compound concentrations equal to or greater than the minimum reporting level (MRL); MRL, 0.2 µg/L (micrograms per liter) for all compounds except methyl ethyl ketone which was 2.0 µg/L; Min, minimum; Max, maximum; <, less than]

Volatile organic compound	Statistic	Type of source water					Size of community water system				
		All sources	Ground water	Surface water	River	Reservoir	Very small	Small	Medium	Large	Very Large
1,2-Dichloroethane	Number of samples	954	579	375	171	204	304	147	80	142	281
	Number of detects	3	3	0	0	0	1	0	1	0	1
	Detection frequency	0.31	0.52	0	0	0	0.33	0	1.2	0	0.36
	Min. concentration	0.27	0.27	<0.2	<0.2	<0.2	0.27	<0.2	0.48	<0.2	0.65
	Max. concentration	0.65	0.65	<0.2	<0.2	<0.2	0.27	<0.2	0.48	<0.2	0.65
1,1-Dichloroethene	Number of samples	954	579	375	171	204	304	147	80	142	281
	Number of detects	8	8	0	0	0	1	0	2	1	4
	Detection frequency	0.84	1.4	0	0	0	0.33	0	2.5	0.7	1.4
	Min. concentration	0.22	0.22	<0.2	<0.2	<0.2	23	<0.2	2.9	0.22	0.27
	Max. concentration	23	23	<0.2	<0.2	<0.2	23	<0.2	2.9	0.22	20
cis-1,2-Dichloroethene	Number of samples	954	579	375	171	204	304	147	80	142	281
	Number of detects	12	11	1	1	0	0	1	3	2	6
	Detection frequency	1.3	1.9	0.27	0.58	0	0	0.68	3.8	1.4	2.1
	Min. concentration	0.33	0.33	0.93	0.93	<0.2	<0.2	0.51	0.33	0.93	0.38
	Max. concentration	14	14	0.93	0.93	<0.2	<0.2	0.51	2.1	1.3	14
trans-1,2-Dichloroethene	Number of samples	954	579	375	171	204	304	147	80	142	281
	Number of detects	0	0	0	0	0	0	0	0	0	0
	Detection frequency	0	0	0	0	0	0	0	0	0	0
	Min. concentration	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
	Max. concentration	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
1,2-Dichloropropane	Number of samples	919	561	358	163	195	295	144	77	140	263
	Number of detects	1	1	0	0	0	0	0	1	0	0
	Detection frequency	0.11	0.18	0	0	0	0	0	1.3	0	0
	Min. concentration	0.47	0.47	<0.2	<0.2	<0.2	<0.2	<0.2	0.47	<0.2	<0.2
	Max. concentration	0.47	0.47	<0.2	<0.2	<0.2	<0.2	<0.2	0.47	<0.2	<0.2

Appendix 2. Frequency of detection and concentrations of volatile organic compounds in 954 source-water samples collected from May 3, 1999, through October 23, 2000, for the Random Survey, by type of source water and size of community water system–Continued

[Detection frequency is percent of source-water samples with volatile organic compound concentrations equal to or greater than the minimum reporting level (MRL); MRL, 0.2 µg/L (micrograms per liter) for all compounds except methyl ethyl ketone which was 2.0 µg/L; Min, minimum; Max, maximum; <, less than]

Volatile organic compound	Statistic	Type of source water					Size of community water system				
		All sources	Ground water	Surface water	River	Reservoir	Very small	Small	Medium	Large	Very Large
1,3-Dichloropropane	Number of samples	942	569	373	170	203	302	143	80	138	279
	Number of detects	0	0	0	0	0	0	0	0	0	0
	Detection frequency	0	0	0	0	0	0	0	0	0	0
	Min. concentration	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
	Max. concentration	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
2,2-Dichloropropane	Number of samples	954	579	375	171	204	304	147	80	142	281
	Number of detects	0	0	0	0	0	0	0	0	0	0
	Detection frequency	0	0	0	0	0	0	0	0	0	0
	Min. concentration	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
	Max. concentration	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
1,1-Dichloropropene	Number of samples	954	579	375	171	204	304	147	80	142	281
	Number of detects	0	0	0	0	0	0	0	0	0	0
	Detection frequency	0	0	0	0	0	0	0	0	0	0
	Min. concentration	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
	Max. concentration	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
cis-1,3-Dichloropropene	Number of samples	954	579	375	171	204	304	147	80	142	281
	Number of detects	0	0	0	0	0	0	0	0	0	0
	Detection frequency	0	0	0	0	0	0	0	0	0	0
	Min. concentration	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
	Max. concentration	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
trans-1,3-Dichloropropene	Number of samples	954	579	375	171	204	304	147	80	142	281
	Number of detects	0	0	0	0	0	0	0	0	0	0
	Detection frequency	0	0	0	0	0	0	0	0	0	0
	Min. concentration	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
	Max. concentration	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2

Appendix 2. Frequency of detection and concentrations of volatile organic compounds in 954 source-water samples collected from May 3, 1999, through October 23, 2000, for the Random Survey, by type of source water and size of community water system–Continued

[Detection frequency is percent of source-water samples with volatile organic compound concentrations equal to or greater than the minimum reporting level (MRL); MRL, 0.2 µg/L (micrograms per liter) for all compounds except methyl ethyl ketone which was 2.0 µg/L; Min, minimum; Max, maximum; <, less than]

Volatile organic compound	Statistic	Type of source water					Size of community water system				
		All sources	Ground water	Surface water	River	Reservoir	Very small	Small	Medium	Large	Very Large
Diisopropyl ether	Number of samples	954	579	375	171	204	304	147	80	142	281
	Number of detects	2	2	0	0	0	1	0	0	0	1
	Detection frequency	0.21	0.34	0	0	0	0.33	0	0	0	0.36
	Min. concentration	0.23	0.23	<0.2	<0.2	<0.2	1.7	<0.2	<0.2	<0.2	0.23
	Max. concentration	1.7	1.7	<0.2	<0.2	<0.2	1.7	<0.2	<0.2	<0.2	0.23
Ethylbenzene	Number of samples	939	566	373	170	203	297	143	78	141	280
	Number of detects	5	3	2	0	2	1	1	2	0	1
	Detection frequency	0.53	0.53	0.54	0	0.98	0.34	0.70	2.6	0	0.36
	Min. concentration	0.23	0.23	0.26	<0.2	0.26	0.42	0.23	0.26	<0.2	0.63
	Max. concentration	1.0	0.63	1.0	<0.2	1.0	0.42	0.23	1.0	<0.2	0.63
Ethyl *tert*-butyl ether	Number of samples	954	579	375	171	204	304	147	80	142	281
	Number of detects	1	1	0	0	0	1	0	0	0	0
	Detection frequency	0.10	0.17	0	0	0	0.33	0	0	0	0
	Min. concentration	0.25	0.25	<0.2	<0.2	<0.2	0.25	<0.2	<0.2	<0.2	<0.2
	Max. concentration	0.25	0.25	<0.2	<0.2	<0.2	0.25	<0.2	<0.2	<0.2	<0.2
Hexachlorobutadiene	Number of samples	954	579	375	171	204	304	147	80	142	281
	Number of detects	0	0	0	0	0	0	0	0	0	0
	Detection frequency	0	0	0	0	0	0	0	0	0	0
	Min. concentration	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
	Max. concentration	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Hexachloroethane	Number of samples	954	579	375	171	204	304	147	80	142	281
	Number of detects	0	0	0	0	0	0	0	0	0	0
	Detection frequency	0	0	0	0	0	0	0	0	0	0
	Min. concentration	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
	Max. concentration	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2

Appendix 2. Frequency of detection and concentrations of volatile organic compounds in 954 source-water samples collected from May 3, 1999, through October 23, 2000, for the Random Survey, by type of source water and size of community water system–Continued

[Detection frequency is percent of source-water samples with volatile organic compound concentrations equal to or greater than the minimum reporting level (MRL); MRL, 0.2 µg/L (micrograms per liter) for all compounds except methyl ethyl ketone which was 2.0 µg/L; Min, minimum; Max, maximum; <, less than]

Volatile organic compound	Statistic	Type of source water					Size of community water system				
		All sources	Ground water	Surface water	River	Reservoir	Very small	Small	Medium	Large	Very Large
Isopropylbenzene	Number of samples	947	573	374	170	204	302	145	78	142	280
	Number of detects	2	1	1	0	1	1	0	1	0	0
	Detection frequency	0.21	0.17	0.27	0	0.49	0.33	0	1.3	0	0
	Min. concentration	0.37	0.38	0.37	<0.2	0.37	0.38	<0.2	0.37	<0.2	<0.2
	Max. concentration	0.38	0.38	0.37	<0.2	0.37	0.38	<0.2	0.37	<0.2	<0.2
p-Isopropyltoluene	Number of samples	954	579	375	171	204	304	147	80	142	281
	Number of detects	0	0	0	0	0	0	0	0	0	0
	Detection frequency	0	0	0	0	0	0	0	0	0	0
	Min. concentration	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
	Max. concentration	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Methylene chloride	Number of samples	952	577	375	171	204	303	147	79	142	281
	Number of detects	2	1	1	1	0	0	1	1	0	0
	Detection frequency	0.21	0.17	0.27	0.58	0	0	0.68	1.27	0	0
	Min. concentration	1.6	1.6	2.6	2.6	<0.2	<0.2	1.6	2.6	<0.2	<0.2
	Max. concentration	2.6	1.6	2.6	2.6	<0.2	<0.2	1.6	2.6	<0.2	<0.2
Methyl ethyl ketone	Number of samples	952	577	375	171	204	304	147	79	142	281
	Number of detects	5	2	3	1	2	2	0	1	0	2
	Detection frequency	0.53	0.35	0.80	0.98	0.58	0.66	0	1.3	0	0.71
	Min. concentration	2.3	3.4	0.66	120	2.3	3.4	<2.0	2.3	<2.0	5.7
	Max. concentration	120	5.8	120	120	9.1	9.1	<2.0	2.3	<2.0	120
Methyl *tert*-butyl ether	Number of samples	934	571	363	165	198	301	145	79	138	271
	Number of detects	81	31	50	24	26	15	4	3	15	44
	Detection frequency	8.7	5.4	14	14	13	5.0	2.8	3.8	11	16
	Min. concentration	0.20	0.20	0.20	0.20	0.2	0.21	0.32	0.20	0.20	0.20
	Max. concentration	20	6.3	20	1.2	20	1.6	1.4	0.94	2.2	20

Appendix 2. Frequency of detection and concentrations of volatile organic compounds in 954 source-water samples collected from May 3, 1999, through October 23, 2000, for the Random Survey, by type of source water and size of community water system–Continued

[Detection frequency is percent of source-water samples with volatile organic compound concentrations equal to or greater than the minimum reporting level (MRL); MRL, 0.2 µg/L (micrograms per liter) for all compounds except methyl ethyl ketone which was 2.0 µg/L; Min, minimum; Max, maximum; <, less than]

Volatile organic compound	Statistic	Type of source water					Size of community water system				
		All sources	Ground water	Surface water	River	Reservoir	Very small	Small	Medium	Large	Very Large
Naphthalene	Number of samples	954	579	375	171	204	304	147	80	142	281
	Number of detects	2	1	1	1	0	0	1	0	0	1
	Detection frequency	0.21	0.17	0.27	0.58	0	0	0.68	0	0	0.36
	Min. concentration	0.22	0.22	1.2	1.2	<0.2	<0.2	0.22	<0.2	<0.2	1.2
	Max. concentration	1.2	0.22	1.2	1.2	<0.2	<0.2	0.22	<0.2	<0.2	1.2
n-Propylbenzene	Number of samples	953	579	374	170	204	304	147	80	142	280
	Number of detects	1	0	1	0	1	0	0	1	0	0
	Detection frequency	0.10	0	0.27	0	0.58	0	0	1.2	0	0
	Min. concentration	0.21	<0.2	0.21	<0.2	0.21	<0.2	<0.2	0.21	<0.2	<0.2
	Max. concentration	0.21	<0.2	0.21	<0.2	0.21	<0.2	<0.2	0.21	<0.2	<0.2
Styrene	Number of samples	933	562	371	169	202	293	142	78	141	279
	Number of detects	5	2	3	1	2	2	0	2	0	1
	Detection frequency	0.54	0.36	0.81	0.59	0.99	0.68	0	2.6	0	0.36
	Min. concentration	0.21	0.21	0.41	2.3	0.41	0.21	<0.2	0.41	<0.2	0.83
	Max. concentration	2.3	0.83	2.3	2.3	0.97	2.3	<0.2	0.97	<0.2	0.83
1,1,1,2-Tetrachloroethane	Number of samples	954	579	375	171	204	304	147	80	142	281
	Number of detects	0	0	0	0	0	0	0	0	0	0
	Detection frequency	0	0	0	0	0	0	0	0	0	0
	Min. concentration	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
	Max. concentration	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
1,1,2,2-Tetrachloroethane	Number of samples	954	579	375	171	204	304	147	80	142	281
	Number of detects	0	0	0	0	0	0	0	0	0	0
	Detection frequency	0	0	0	0	0	0	0	0	0	0
	Min. concentration	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
	Max. concentration	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2

Appendix 2. Frequency of detection and concentrations of volatile organic compounds in 954 source-water samples collected from May 3, 1999, through October 23, 2000, for the Random Survey, by type of source water and size of community water system–Continued

[Detection frequency is percent of source-water samples with volatile organic compound concentrations equal to or greater than the minimum reporting level (MRL); MRL, 0.2 µg/L (micrograms per liter) for all compounds except methyl ethyl ketone which was 2.0 µg/L; Min, minimum; Max, maximum; <, less than]

Volatile organic compound	Statistic	Type of source water					Size of community water system				
		All sources	Ground water	Surface water	River	Reservoir	Very small	Small	Medium	Large	Very Large
Tetrachloroethene	Number of samples	952	577	375	171	204	303	147	80	142	280
	Number of detects	27	24	3	3	0	3	4	3	4	13
	Detection frequency	2.8	4.2	0.80	1.8	0	0.99	2.7	3.8	2.8	4.6
	Min. concentration	0.2	0.2	0.29	0.29	<0.2	0.21	0.2	0.77	0.38	0.22
	Max. concentration	36	36	5.5	5.5	<0.2	2.8	19	36	5.5	34
Toluene	Number of samples	931	562	369	169	200	296	140	77	139	279
	Number of detects	10	3	7	5	2	2	0	1	2	5
	Detection frequency	1.1	0.53	1.9	3.0	1.0	0.68	0	1.3	1.4	1.8
	Min. concentration	0.20	1.1	0.20	0.20	0.52	1.2	<0.2	1.0	0.20	0.20
	Max. concentration	4.2	4.2	1.0	0.45	1.0	4.2	<0.2	1.0	0.27	1.1
1,2,3-Trichlorobenzene	Number of samples	954	579	375	171	204	304	147	80	142	281
	Number of detects	0	0	0	0	0	0	0	0	0	0
	Detection frequency	0	0	0	0	0	0	0	0	0	0
	Min. concentration	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
	Max. concentration	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
1,2,4-Trichlorobenzene	Number of samples	954	579	375	171	204	304	147	80	142	281
	Number of detects	0	0	0	0	0	0	0	0	0	0
	Detection frequency	0	0	0	0	0	0	0	0	0	0
	Min. concentration	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
	Max. concentration	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
1,1,1-Trichloroethane	Number of samples	953	578	375	171	204	303	147	80	142	281
	Number of detects	10	10	0	0	0	1	1	3	3	2
	Detection frequency	1.0	1.7	0	0	0	0.33	0.68	3.8	2.1	0.71
	Min. concentration	0.21	0.21	<0.2	<0.2	<0.2	6.9	13	0.26	0.21	1.4
	Max. concentration	13	13	<0.2	<0.2	<0.2	6.9	13	10	6.8	7.6

Appendix 2. Frequency of detection and concentrations of volatile organic compounds in 954 source-water samples collected from May 3, 1999, through October 23, 2000, for the Random Survey, by type of source water and size of community water system–Continued

[Detection frequency is percent of source-water samples with volatile organic compound concentrations equal to or greater than the minimum reporting level (MRL); MRL, 0.2 µg/L (micrograms per liter) for all compounds except methyl ethyl ketone which was 2.0 µg/L; Min, minimum; Max, maximum; <, less than]

Volatile organic compound	Statistic	Type of source water					Size of community water system				
		All sources	Ground water	Surface water	River	Reservoir	Very small	Small	Medium	Large	Very Large
1,1,2-Trichloroethane	Number of samples	954	579	375	171	204	304	147	80	142	281
	Number of detects	0	0	0	0	0	0	0	0	0	0
	Detection frequency	0	0	0	0	0	0	0	0	0	0
	Min. concentration	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
	Max. concentration	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Trichloroethene	Number of samples	951	576	375	171	204	303	147	79	142	280
	Number of detects	22	19	3	3	0	1	4	2	5	10
	Detection frequency	2.3	3.3	0.80	1.8	0	0.33	2.7	2.5	3.5	3.6
	Min. concentration	0.23	0.23	0.31	0.31	<0.2	1.6	0.53	4.2	0.59	0.23
	Max. concentration	170	170	2.0	2.0	<0.2	1.6	1.9	18	8.6	170
Trichlorofluoromethane	Number of samples	954	579	375	171	204	304	147	80	142	281
	Number of detects	5	5	0	0	0	1	0	1	0	3
	Detection frequency	0.52	0.86	0	0	0	0.33	0	1.2	0	1.1
	Min. concentration	0.24	0.24	<0.2	<0.2	<0.2	0.24	<0.2	0.42	<0.2	0.92
	Max. concentration	1.3	1.3	<0.2	<0.2	<0.2	0.24	<0.2	0.42	<0.2	1.3
1,2,3-Trichloropropane	Number of samples	954	579	375	171	204	304	147	80	142	281
	Number of detects	1	1	0	0	0	0	0	1	0	0
	Detection frequency	0.10	0.17	0	0	0	0	0	1.2	0	0
	Min. concentration	0.31	0.31	<0.2	<0.2	<0.2	<0.2	<0.2	0.31	<0.2	<0.2
	Max. concentration	0.31	0.31	<0.2	<0.2	<0.2	<0.2	<0.2	0.31	<0.2	<0.2
1,1,2-Trichloro-1,2,2-trifluoroethane	Number of samples	954	579	375	171	204	304	147	80	142	281
	Number of detects	1	1	0	0	0	0	0	0	0	1
	Detection frequency	0.10	0.17	0	0	0	0	0	0	0	0.36
	Min. concentration	0.91	0.91	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	0.91
	Max. concentration	0.91	0.91	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	0.91

Appendix 2. Frequency of detection and concentrations of volatile organic compounds in 954 source-water samples collected from May 3, 1999, through October 23, 2000, for the Random Survey, by type of source water and size of community water system–Continued

[Detection frequency is percent of source-water samples with volatile organic compound concentrations equal to or greater than the minimum reporting level (MRL); MRL, 0.2 µg/L (micrograms per liter) for all compounds except methyl ethyl ketone which was 2.0 µg/L; Min, minimum; Max, maximum; <, less than]

Volatile organic compound	Statistic	Type of source water					Size of community water system				
		All sources	Ground water	Surface water	River	Reservoir	Very small	Small	Medium	Large	Very Large
1,2,4-Trimethylbenzene	Number of samples	945	571	374	170	204	300	145	79	141	280
	Number of detects	4	1	3	2	1	0	1	0	1	2
	Detection frequency	0.42	0.18	0.80	1.2	0.49	0	0.69	0	0.71	0.71
	Min. concentration	0.36	0.46	0.36	0.43	0.36	<0.2	0.36	<0.2	0.43	0.46
	Max. concentration	0.77	0.46	0.77	0.77	0.36	<0.2	0.36	<0.2	0.43	0.77
1,3,5-Trimethylbenzene	Number of samples	954	579	375	171	204	304	147	80	142	281
	Number of detects	0	0	0	0	0	0	0	0	0	0
	Detection frequency	0	0	0	0	0	0	0	0	0	0
	Min. concentration	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
	Max. concentration	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Vinyl bromide	Number of samples	954	579	375	171	204	304	147	80	142	281
	Number of detects	0	0	0	0	0	0	0	0	0	0
	Detection frequency	0	0	0	0	0	0	0	0	0	0
	Min. concentration	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
	Max. concentration	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Vinyl chloride	Number of samples	954	579	375	171	204	304	147	80	142	281
	Number of detects	1	1	0	0	0	0	0	0	0	1
	Detection frequency	0.10	0.17	0	0	0	0	0	0	0	0.36
	Min. concentration	3.2	3.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	3.2
	Max. concentration	3.2	3.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	3.2
o-Xylene	Number of samples	938	566	372	170	202	298	143	78	140	279
	Number of detects	6	4	2	0	2	2	1	2	0	1
	Detection frequency	0.64	0.71	0.54	0	0.99	0.67	0.70	2.6	0	0.36
	Min. concentration	0.26	0.26	0.45	<0.2	0.45	0.36	0.26	0.45	<0.2	0.91
	Max. concentration	1.4	0.91	1.4	<0.2	1.4	0.44	0.26	1.4	<0.2	0.91

Appendix 2. Frequency of detection and concentrations of volatile organic compounds in 954 source-water samples collected from May 3, 1999, through October 23, 2000, for the Random Survey, by type of source water and size of community water system–Continued

[Detection frequency is percent of source-water samples with volatile organic compound concentrations equal to or greater than the minimum reporting level (MRL); MRL, 0.2 µg/L (micrograms per liter) for all compounds except methyl ethyl ketone which was 2.0 µg/L; Min, minimum; Max, maximum; <, less than]

Volatile organic compound	Statistic	Type of source water					Size of community water system				
		All sources	Ground water	Surface water	River	Reservoir	Very small	Small	Medium	Large	Very Large
m-, *p*-Xylene	Number of samples	934	564	370	168	202	296	143	78	138	279
	Number of detects	7	4	3	1	2	2	1	2	1	1
	Detection frequency	0.75	0.71	0.81	0.60	0.99	0.68	0.70	2.6	0.72	0.36
	Min. concentration	0.33	0.33	0.35	0.35	0.71	0.33	0.90	0.71	0.35	1.6
	Max. concentration	2.5	1.6	2.5	0.35	2.5	0.51	0.90	2.5	0.35	1.6

Appendix 3. Co-occurrence of volatile organic compounds (VOCs) in source-water samples for the Random Survey with VOC detections

[Co-occurrence is calculated as the percentage of samples with detections of the compound specified by row beneath the heading "Volatile organic compounds" that also had detections of the compound specified beneath the column heading "Co-occurrence, in percent", for example, 33 percent (20 samples) of the 61 source-water samples that contained bromodichloromethane also contained bromoform; values are shown in bold when co-occurrence equaled or exceeded 20 percent and there were 10 or more detections of the compound specified by row; --, not applicable; ND, no detections of compound specified in the column heading]

Volatile organic compound (number of detections)	Co-occurrence, in percent						
	Benzene	Bromo-dichloro-methane	Bromoform	Bromo-methane	*n*-Butyl-benzene	Carbon tetra-chloride	Chloro-benzene
Benzene (3)	--	0	0	0	0	0	0
Bromodichloromethane (61)	0	--	**33**	1.6	1.6	4.9	0
Bromoform (32)	0	**62**	--	3.1	3.1	0	0
Bromomethane (2)	0	50	50	--	0	0	0
n-Butylbenzene (1)	0	100	100	0	--	0	0
Carbon tetrachloride (7)	0	43	0	0	0	--	0
Chlorobenzene (1)	0	0	0	0	0	0	--
Chlorodibromomethane (52)	0	**86**	**50**	1.9	1.9	5.8	0
Chloroethane (1)	0	100	100	100	0	0	0
Chloroform (120)	0.8	**43**	14	0.8	0	3.3	0.8
Chloromethane (3)	0	33	0	0	0	0	33
Dibromomethane (2)	0	100	100	50	0	0	0
1,2-Dichlorobenzene (1)	0	0	0	0	0	0	100
1,4-Dichlorobenzene (3)	0	0	0	0	0	0	33
Dichlorodifluoromethane (4)	0	0	0	0	0	0	25
1,1-Dichloroethane (11)	9.1	9.1	18	0	0	0	9.1
1,2-Dichloroethane (3)	0	0	0	0	0	0	33
1,1-Dichloroethene (8)	0	0	0	0	0	0	12
cis-1,2-Dichloroethene (12)	0	8.3	0	0	0	8.3	8.3
1,2-Dichloropropane (1)	0	0	0	0	0	0	0
Diisopropyl ether (2)	0	0	0	0	0	0	50
Ethylbenzene (5)	0	0	0	0	0	0	0
Ethyl *tert*-butyl ether (1)	0	0	0	0	0	0	0
Isopropylbenzene (2)	0	0	0	0	0	0	0
Methylene chloride (2)	0	0	0	0	0	0	0
Methyl ethyl ketone (5)	0	0	0	0	0	0	0
Methyl *tert*-butyl ether (81)	2.5	7.4	3.7	0	1.2	1.2	1.2
Naphthalene (2)	0	0	0	0	0	0	0
n-Propylbenzene (1)	0	0	0	0	0	0	0
Styrene (5)	0	0	0	0	0	0	0
tert-Amyl methyl ether (2)	0	0	0	0	0	0	0
Tetrachloroethene (27)	3.7	3.7	3.7	0	0	0	3.7
Toluene (10)	10	0	0	0	0	0	0
1,1,1-Trichloroethane (10)	0	10	0	0	0	0	10
Trichloroethene (22)	0	4.6	4.6	0	0	0	4.6
Trichlorofluoromethane (5)	0	0	0	0	0	0	20
1,2,3-Trichloropropane (1)	0	0	0	0	0	0	0
1,1,2-Trichloro-1,2,2-trifluoroethane (1)	0	100	0	0	0	100	0
1,2,4-Trimethylbenzene (4)	0	0	0	0	0	0	0
Vinyl chloride (1)	0	0	0	0	0	0	100
o-Xylene (6)	0	0	0	0	0	0	0
m-, *p*-Xylene (7)	0	0	0	0	0	0	0

Appendix 3. Co-occurrence of volatile organic compounds (VOCs) in source-water samples for the Random Survey with VOC detections—Continued

Volatile organic compound (number of detections)	Co-occurrence, in percent						
	Chloro-dibromo-methane	Chloro-ethane	Chloroform	Chloro-methane	Dibromo-methane	1,2-Dichloro-benzene	1,4-Dichloro-benzene
Benzene (3)	0	0	33	0	0	0	0
Bromodichloromethane (61)	**74**	1.6	**85**	1.6	3.4	0	0
Bromoform (32)	**81**	3.1	**53**	0	6.2	0	0
Bromomethane (2)	50	50	50	0	50	0	0
n-Butylbenzene (1)	100	0	100	0	0	0	0
Carbon tetrachloride (7)	43	0	57	0	0	0	0
Chlorobenzene (1)	0	0	100	100	ND	100	100
Chlorodibromomethane (52)	--	1.9	**71**	1.9	4.0	0	0
Chloroethane (1)	100	--	100	0	100	0	0
Chloroform (120)	**31**	0.8	--	2.5	1.7	0.8	1.7
Chloromethane (3)	33	0	100	--	0	33.3	33
Dibromomethane (2)	100	50	100	0	--	0	0
1,2-Dichlorobenzene (1)	0	0	100	100	ND	--	100
1,4-Dichlorobenzene (3)	0	0	67	33	0	33	--
Dichlorodifluoromethane (4)	0	0	50	25	0	0	25
1,1-Dichloroethane (11)	9.1	0	**54**	9.1	0	9.1	9.1
1,2-Dichloroethane (3)	0	0	67	33	0	33	33
1,1-Dichloroethene (8)	0	0	38	12	0	12	12
cis-1,2-Dichloroethene (12)	8.3	0	**25**	8.3	0	8.3	8.3
1,2-Dichloropropane (1)	0	0	100	0	0	0	0
Diisopropyl ether (2)	0	0	50	50	0	50	50
Ethylbenzene (5)	0	0	20	0	0	0	0
Ethyl *tert*-butyl ether (1)	0	0	0	0	0	0	0
Isopropylbenzene (2)	0	0	50	0	0	0	0
Methylene chloride (2)	0	0	0	0	0	0	0
Methyl ethyl ketone (5)	0	0	20	0	0	0	0
Methyl *tert*-butyl ether (81)	6.2	0	19	1.2	0	1.2	1.2
Naphthalene (2)	0	0	0	0	0	0	0
n-Propylbenzene (1)	0	0	100	0	0	0	0
Styrene (5)	0	0	20	0	0	0	0
tert-Amyl methyl ether (2)	0	0	0	0	0	0	0
Tetrachloroethene (27)	3.7	0	18	3.7	0	3.7	3.7
Toluene (10)	0	0	10	0	0	0	0
1,1,1-Trichloroethane (10)	0	0	**50**	10	0	10	10
Trichloroethene (22)	0	0	18	4.6	0	4.6	4.6
Trichlorofluoromethane (5)	0	0	20	20	0	20	20
1,2,3-Trichloropropane (1)	0	0	100	0	0	0	0
1,1,2-Trichloro-1,2,2-trifluoroethane (1)	100	0	100	0	0	0	0
1,2,4-Trimethylbenzene (4)	0	0	0	0	0	0	0
Vinyl chloride (1)	0	0	100	100	ND	100	100
o-Xylene (6)	0	0	17	0	0	0	0
m-, *p*-Xylene (7)	0	0	14	0	0	0	0

Appendix 3. Co-occurrence of volatile organic compounds (VOCs) in source-water samples for the Random Survey with VOC detections—Continued

Volatile organic compound (number of detections)	Co-occurrence, in percent						
	Dichloro-difluoro-methane	1,1-Dichloro-ethane	1,2-Dichloro-ethane	1,1-Dichloro-ethene	*cis*-1,2-Dichloro-ethene	1,2-Dichloro-propane	Diisopropyl ether
Benzene (3)	0	33	0	0	0	0	0
Bromodichloromethane (61)	0	1.6	0	0	1.6	0	0
Bromoform (32)	0	6.2	0	0	0	0	0
Bromomethane (2)	0	0	0	0	0	0	0
n-Butylbenzene (1)	0	0	0	0	0	0	0
Carbon tetrachloride (7)	0	0	0	0	14	0	0
Chlorobenzene (1)	100	100	100	100	100	ND	100
Chlorodibromomethane (52)	0	1.9	0	0	1.9	0	0
Chloroethane (1)	0	0	0	0	0	0	0
Chloroform (120)	1.7	5	1.7	2.5	2.5	0.9	0.8
Chloromethane (3)	33	33	33	33	33	0	33
Dibromomethane (2)	0	0	0	0	0	0	0
1,2-Dichlorobenzene (1)	100	100	0	100	100	ND	100
1,4-Dichlorobenzene (3)	33	33	33	33	33	0	33
Dichlorodifluoromethane (4)	--	25	25	25	75	0	25
1,1-Dichloroethane (11)	18	--	18	**46**	**46**	10	9.1
1,2-Dichloroethane (3)	33	67	--	67	67	50	33
1,1-Dichloroethene (8)	12	62	25	--	50	17	12
cis-1,2-Dichloroethene (12)	**25**	**42**	17	**33**	--	8.3	8.3
1,2-Dichloropropane (1)	0	100	100	100	100	--	0
Diisopropyl ether (2)	50	50	50	50	50	0	--
Ethylbenzene (5)	0	0	0	0	0	0	0
Ethyl *tert*-butyl ether (1)	0	0	0	0	0	0	0
Isopropylbenzene (2)	0	0	0	0	0	0	0
Methylene chloride (2)	0	0	0	0	0	0	0
Methyl ethyl ketone (5)	0	0	0	0	0	0	0
Methyl *tert*-butyl ether (81)	1.2	4.9	1.2	2.5	4.9	0	2.5
Naphthalene (2)	0	0	0	0	0	0	0
n-Propylbenzene (1)	0	0	0	0	0	0	0
Styrene (5)	0	0	0	0	0	0	0
tert-Amyl methyl ether (2)	0	0	0	0	0	0	50
Tetrachloroethene (27)	11	18	7.4	11	**37**	3.8	3.7
Toluene (10)	0	0	0	0	0	0	0
1,1,1-Trichloroethane (10)	10	**50**	**20**	**50**	**40**	11	10
Trichloroethene (22)	14	**23**	9.1	14	**46**	4.8	4.6
Trichlorofluoromethane (5)	40	60	20	40	60	0	20
1,2,3-Trichloropropane (1)	0	100	100	100	100	100	0
1,1,2-Trichloro-1,2,2-trifluoroethane (1)	0	0	0	0	100	0	0
1,2,4-Trimethylbenzene (4)	0	0	0	0	0	0	0
Vinyl chloride (1)	100	100	100	100	100	ND	100
o-Xylene (6)	0	0	0	0	0	0	0
m-, *p*-Xylene (7)	0	0	0	0	0	0	0

Appendix 3. Co-occurrence of volatile organic compounds (VOCs) in source-water samples for the Random Survey with VOC detections—Continued

Volatile organic compound (number of detections)	Co-occurrence, in percent						
	Ethyl-benzene	Ethyl *tert*-butyl ether	Isopropyl-benzene	Methylene chloride	Methyl ethyl ketone	Methyl *tert*-butyl ether	Naphthalene
Benzene (3)	0	0	0	0	0	100	0
Bromodichloromethane (61)	0	0	0	0	0	10	0
Bromoform (32)	0	0	0	0	0	9.4	0
Bromomethane (2)	0	0	0	0	0	0	0
n-Butylbenzene (1)	0	0	0	0	0	100	0
Carbon tetrachloride (7)	0	0	0	0	0	14	0
Chlorobenzene (1)	0	0	0	0	0	100	0
Chlorodibromomethane (52)	0	0	0	0	0	9.8	0
Chloroethane (1)	0	0	0	0	ND	0	0
Chloroform (120)	0.8	0	0.8	0	0.8	13	0
Chloromethane (3)	0	0	0	0	0	33	0
Dibromomethane (2)	0	0	0	0	0	0	0
1,2-Dichlorobenzene (1)	0	0	0	0	0	100	0
1,4-Dichlorobenzene (3)	0	0	0	0	0	33	0
Dichlorodifluoromethane (4)	0	0	0	0	0	25	0
1,1-Dichloroethane (11)	0	0	0	0	0	**36**	0
1,2-Dichloroethane (3)	0	0	0	0	0	33	0
1,1-Dichloroethene (8)	0	0	0	0	0	25	0
cis-1,2-Dichloroethene (12)	0	0	0	0	0	**33**	0
1,2-Dichloropropane (1)	0	0	0	0	0	0	0
Diisopropyl ether (2)	0	0	0	0	0	100	0
Ethylbenzene (5)	--	0	20	0	40	20	0
Ethyl *tert*-butyl ether (1)	ND	--	0	0	0	100	0
Isopropylbenzene (2)	50	0	--	0	50	50	0
Methylene chloride (2)	0	0	0	--	0	0	50
Methyl ethyl ketone (5)	50	0	25	0	--	20	0
Methyl *tert*-butyl ether (81)	1.2	1.2	1.2	0	1.2	--	0
Naphthalene (2)	0	0	0	50	0	0	--
n-Propylbenzene (1)	100	0	100	0	100	100	0
Styrene (5)	80	0	20	0	40	40	0
tert-Amyl methyl ether (2)	0	0	0	0	0	100	0
Tetrachloroethene (27)	0	0	0	0	0	**26**	0
Toluene (10)	10	0	0	0	10	**40**	0
1,1,1-Trichloroethane (10)	0	0	0	0	0	**30**	0
Trichloroethene (22)	0	0	0	0	0	14	0
Trichlorofluoromethane (5)	0	0	0	0	0	20	0
1,2,3-Trichloropropane (1)	0	0	0	0	0	0	0
1,1,2-Trichloro-1,2,2-trifluoroethane (1)	0	0	0	0	0	100	0
1,2,4-Trimethylbenzene (4)	33	0	0	0	25	0	0
Vinyl chloride (1)	0	0	0	0	0	100	0
o-Xylene (6)	100	17	17	0	33	33	0
m-, *p*-Xylene (7)	71	0	14	0	29	14	0

Appendix 3. Co-occurrence of volatile organic compounds (VOCs) in source-water samples for the Random Survey with VOC detections—Continued

Volatile organic compound (number of detections)	Co-occurrence, in percent						
	n-Propyl-benzene	Styrene	*tert*-Amyl methyl ether	Tetrachloro-ethene	Toluene	1,1,1-Trichloro-ethane	Trichloro-ethene
Benzene (3)	0	0	0	33	33	0	0
Bromodichloromethane (61)	0	0	0	1.6	0	1.6	1.6
Bromoform (32)	0	0	0	3.1	0	0	3.1
Bromomethane (2)	0	0	0	0	0	0	0
n-Butylbenzene (1)	0	0	0	0	0	0	0
Carbon tetrachloride (7)	0	0	0	0	0	0	0
Chlorobenzene (1)	0	0	0	100	0	100	100
Chlorodibromomethane (52)	0	0	0	1.9	0	0	0
Chloroethane (1)	0	0	0	0	0	0	0
Chloroform (120)	0.8	0.8	0	4.2	0.8	4.2	3.3
Chloromethane (3)	0	0	0	33	0	33	33
Dibromomethane (2)	0	0	0	0	0	0	0
1,2-Dichlorobenzene (1)	0	0	0	100	0	100	100
1,4-Dichlorobenzene (3)	0	0	0	33	0	33	33
Dichlorodifluoromethane (4)	0	0	0	75	0	25	75
1,1-Dichloroethane (11)	0	0	0	**46**	0	**46**	**50**
1,2-Dichloroethane (3)	0	0	0	67	0	67	67
1,1-Dichloroethene (8)	0	0	0	38	0	62	38
cis-1,2-Dichloroethene (12)	0	0	0	**83**	0	**33**	**91**
1,2-Dichloropropane (1)	0	0	0	100	0	100	100
Diisopropyl ether (2)	0	0	50	50	0	50	50
Ethylbenzene (5)	20	80	0	0	25	0	0
Ethyl *tert*-butyl ether (1)	0	ND	0	0	ND	0	0
Isopropylbenzene (2)	50	100	0	0	0	0	0
Methylene chloride (2)	0	0	0	0	0	0	0
Methyl ethyl ketone (5)	20	50	0	0	33	0	0
Methyl *tert*-butyl ether (81)	1.2	2.5	2.5	8.6	5.1	3.7	3.7
Naphthalene (2)	0	0	0	0	0	0	0
n-Propylbenzene (1)	--	100	0	0	ND	0	0
Styrene (5)	20	--	0	0	25	0	0
tert-Amyl methyl ether (2)	0	0	--	0	0	0	0
Tetrachloroethene (27)	0	0	0	--	0	15	**56**
Toluene (10)	0	10	0	0	--	0	0
1,1,1-Trichloroethane (10)	0	0	0	**40**	0	--	56
Trichloroethene (22)	0	0	0	**68**	0	**23**	--
Trichlorofluoromethane (5)	0	0	0	80	0	40	60
1,2,3-Trichloropropane (1)	0	0	0	100	0	100	100
1,1,2-Trichloro-1,2,2-trifluoroethane (1)	0	0	0	0	0	0	0
1,2,4-Trimethylbenzene (4)	0	33	0	0	67	0	0
Vinyl chloride (1)	0	0	0	100	0	100	100
o-Xylene (6)	17	80	0	0	25	0	0
m-, *p*-Xylene (7)	14	57	0	0	33	0	0

Appendix 3. Co-occurrence of volatile organic compounds (VOCs) in source-water samples for the Random Survey with VOC detections—Continued

Volatile organic compound (number of detections)	Co-occurrence, in percent						
	Trichloro-fluoro-methane	1,2,3-Trichloro-propane	1,1,2-Trichloro-1,2,2-trifluoro-ethane	1,2,4-Tri-methyl benzene	Vinyl chloride	*o*-Xylene	*m*-, *p*-Xylene
Benzene (3)	0	0	0	0	0	0	0
Bromodichloromethane (61)	0	0	1.6	0	0	0	0
Bromoform (32)	0	0	0	0	0	0	0
Bromomethane (2)	0	0	0	0	0	0	0
n-Butylbenzene (1)	0	0	0	0	0	0	0
Carbon tetrachloride (7)	0	0	14	0	0	0	0
Chlorobenzene (1)	100	0	0	0	100	0	0
Chlorodibromomethane (52)	0	0	1.9	0	0	0	0
Chloroethane (1)	0	0	0	0	0	0	0
Chloroform (120)	0.8	0.8	0.8	0	0.8	0.8	0.8
Chloromethane (3)	33	0	0	0	33	0	0
Dibromomethane (2)	0	0	0	0	0	0	0
1,2-Dichlorobenzene (1)	100	0	0	0	100	0	0
1,4-Dichlorobenzene (3)	33	0	0	0	33	0	0
Dichlorodifluoromethane (4)	50	0	0	0	25	0	0
1,1-Dichloroethane (11)	**27**	9.1	0	0	9.1	0	0
1,2-Dichloroethane (3)	33	33	0	0	33	0	0
1,1-Dichloroethene (8)	25	12	0	0	12	0	0
cis-1,2-Dichloroethene (12)	**25**	8.3	8.3	0	8.3	0	0
1,2-Dichloropropane (1)	0	100	0	0	0	0	0
Diisopropyl ether (2)	50	0	0	0	50	0	0
Ethylbenzene (5)	0	0	0	20	0	100	100
Ethyl *tert*-butyl ether (1)	0	0	0	0	0	100	ND
Isopropylbenzene (2)	0	0	0	0	0	50	50
Methylene chloride (2)	0	0	0	0	0	0	0
Methyl ethyl ketone (5)	0	0	0	25	0	50	50
Methyl *tert*-butyl ether (81)	1.2	0	1.2	0	1.2	2.5	1.3
Naphthalene (2)	0	0	0	0	0	0	0
n-Propylbenzene (1)	0	0	0	0	0	100	100
Styrene (5)	0	0	0	20	0	80	80
tert-Amyl methyl ether (2)	0	0	0	0	0	0	0
Tetrachloroethene (27)	15	3.7	0	0	3.7	0	0
Toluene (10)	0	0	0	**20**	0	11	**20**
1,1,1-Trichloroethane (10)	**20**	10	0	0	10	0	0
Trichloroethene (22)	14	4.6	0	0	4.6	0	0
Trichlorofluoromethane (5)	--	0	0	0	20	0	0
1,2,3-Trichloropropane (1)	0	--	0	0	0	0	0
1,1,2-Trichloro-1,2,2-trifluoroethane (1)	0	0	--	0	0	0	0
1,2,4-Trimethylbenzene (4)	0	0	0	--	0	33	67
Vinyl chloride (1)	100	0	0	0	--	0	0
o-Xylene (6)	0	0	0	17	0	--	100
m-, *p*-Xylene (7)	0	0	0	29	0	71	--