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A Review of Literature for Methyl *tert*-Butyl Ether (MTBE) in Sources of Drinking Water in the United States

Open-File Report 01-322

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

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GALE A. NORTON, Secretary

U.S. Geological Survey

Charles G. Groat, Director

Rapid City, South Dakota: 2003

For additional information write to:

District Chief
U.S. Geological Survey
1608 Mt. View Road
Rapid City, SD 57702

Copies of this report can be purchased from:

U.S. Geological Survey
Information Services
Building 810
Box 25286, Federal Center
Denver, CO 80225-0286

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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FIGURE

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CONVERSION FACTORS

Multiply	By	To obtain
mile	1.609	kilometer
million gallons per day	0.04381	cubic meter per second
square mile	2.590	square kilometer
ton (short)	0.90718	ton (metric)

A Review of Literature for Methyl *tert*-Butyl Ether (MTBE) in Sources of Drinking Water in the United States

By Gregory C. Delzer *and* Tamara Ivahnenko

ABSTRACT

The American Water Works Association Research Foundation is currently (2001) sponsoring an assessment of methyl *tert*-butyl ether (MTBE) in the Nation's drinking-water supplies. The assessment is being conducted by Metropolitan Water District of Southern California, U.S. Geological Survey, and Oregon Health & Science University and is scheduled for completion in fall 2002. One part of this national assessment included a literature review of MTBE in public and private drinking-water supplies, which is the focus of this report. An exhaustive review of literature conducted in 1997 for MTBE in water concluded that it was not possible to characterize MTBE in sources of drinking water due to limited data available at that time. As such, reviewed literature for this report focused on those assessments completed after the 1997 review. Specifically, this literature review focused on public and private water-supply assessments that were national, regional, or statewide in scope. Overall, 3 national, 2 regional, and 13 statewide assessments were reviewed.

Inconsistencies among assessments reviewed include different objectives, reporting levels, and different water types sampled such as ambient water and treated and untreated drinking water. This usually made comparisons among assessments difficult, if not impossible, to achieve. Regardless, results of this literature review indicate that MTBE has been detected in public and (or) private drinking-water supplies in 36 States with concentrations ranging from 0.1 to 17,800 µg/L (micrograms per liter). However, when median detected concentrations were available, they were typically low—less than 5.0 µg/L. In addition, the reviewed assessments collectively indicated that: (1) MTBE occurred in public drinking-water systems supplied by ground and surface water, and concentrations generally were less than 20 µg/L; (2) population density and reformulated gasoline use were significant factors for MTBE detection in water supplies; and (3) type of well, water supply, and proximity to gasoline storage tanks did not seem to be associated with MTBE detection.

INTRODUCTION

The Clean Air Act (CAA) Amendments of 1990 mandate seasonal or year-round use of oxygenated compounds (oxygenates) in gasoline in specific parts of the United States. Oxygenates are added to gasoline to increase the oxygen content, which enhances combustion and decreases vehicular carbon monoxide emissions. Oxygenates also reduce the need for benzene and other ozone-forming, aromatic compounds in gasoline. Methyl *tert*-butyl ether (MTBE) is the most commonly used oxygenate, followed by ethanol. Oxygenates are added to gasoline during the winter months in areas where winter concentrations of carbon monoxide exceed established air-quality standards. This gasoline is called oxygenated (OXY) gasoline, and contains oxygenates at 2.7 percent by weight (15 percent by volume for MTBE). In select areas, oxygenates are added to gasoline year round to abate

ozone pollution during the summer months as well as carbon monoxide pollution during the winter months. This gasoline is called reformulated gasoline (RFG), and contains oxygenates at 2 percent by weight (11 percent by volume for MTBE). MTBE also has been added to gasoline as an octane enhancer since the late 1970's.

MTBE production and use have increased substantially during the 1990's resulting from the implementation of the CAA Amendments. For example, MTBE went from the 39th highest produced organic chemical in the United States in 1970 to the fourth highest in 1998. During that period, MTBE had an aggregate production of 60 million metric tons. In 1998, 10.5 million gallons per day were used in the United States, 40 percent of which was used in California alone (Johnson and others, 2000). The majority of MTBE use is associated with RFG. MTBE is used in only about 3 percent of OXY gasoline whereas MTBE is used in about 85 percent of all RFG (Wigglesworth, 1999). As of 2000, 10 areas in 9 States are involved in an OXY gasoline program, and 11 areas in 17 States are involved in an RFG program (fig. 1).

Chemical properties of MTBE, such as high solubility in water, a low Henry's law constant, low soil-sorption properties, and recalcitrant nature in ground water, may cause contamination of public and private drinking-water sources. MTBE also is a possible human carcinogen, and at concentrations as low as 15 µg/L (micrograms per liter) can affect the taste and odor of water, causing it to become non-potable.

Because of the chemical characteristics of MTBE and its presence in source water, some cities have already lost substantial amounts of drinking-water supplies. For example, in Santa Monica, California, 75 percent of the drinking-water wells are unusable due to MTBE; in South Lake Tahoe, California, one-third of the city's 34 drinking-water wells have been shut down because of MTBE contamination; and Los Angeles, San Francisco, Santa Clara Valley, and Sacramento in California all have wells affected by MTBE (Bourelle, 1998; City of Santa Monica, 1999; California Department of Health Services, 2001). Other cities with affected drinking-water supplies include Windham, Maine, and La Crosse, Kansas, where officials have taken steps to remediate the problem rather than to remove the wells from service (Maine Bureau of Health, 1998; Hattan, 2000).

Although isolated instances of MTBE contamination have been observed, the overall extent of MTBE occurrence in the Nation's drinking-water supplies has not been evaluated. The Interagency Assessment of Oxygenated Fuels (Zogorski and others, 1997) attempted to address the national occurrence of MTBE in drinking-water supplies, but was unable to do so due to insufficient data. As a result, additional assessments were recommended.

One such assessment was initiated by the American Water Works Association Research Foundation (AWWARF), an organization that sponsors numerous research projects for the benefit of the drinking-water community. In March 1998, AWWARF solicited a request for proposals to study MTBE in the Nation's drinking-water supplies. In response to this request, the Metropolitan Water District of Southern California, the U.S. Geological Survey (USGS) National Water-Quality Assessment (NAWQA) Program, and the Oregon Health & Science University collectively prepared and submitted a proposal to assess not only MTBE but also 65 other volatile organic compounds (VOCs), including other ether oxygenates and ether oxygenate degradation by-products, in public drinking-water supplies. The complete list of compounds included in this proposal also included 13 VOCs that are on the U.S. Environmental Protection Agency's (USEPA's) Contaminant Candidate List (CCL). The CCL is a list of contaminants not currently regulated by a National Primary Drinking Water Standard. Additional data on these compounds are needed before a regulatory determination can be made. The proposal for a national assessment of MTBE and other VOCs was accepted by AWWARF in September 1998.

The national assessment of MTBE and other VOCs in sources of public drinking-water supplies is currently (2001) underway and scheduled to be completed by fall of 2002. This assessment is being accomplished by a two-phase approach: (1) reviews of available literature and (2) the collection of new drinking-water-quality data. Specific information on the design for the collection of new drinking-water-quality data is presented in Ivahnenko and others (2001). There are two literature reviews associated with this assessment. One review focused on MTBE taste and odor threshold concentrations and their relevance to aesthetic effects and possible water-treatment requirements. The second review, which is the focus of this report, concentrated on the occurrence of MTBE in public and private drinking-water supplies reported by national, regional, or statewide assessments.

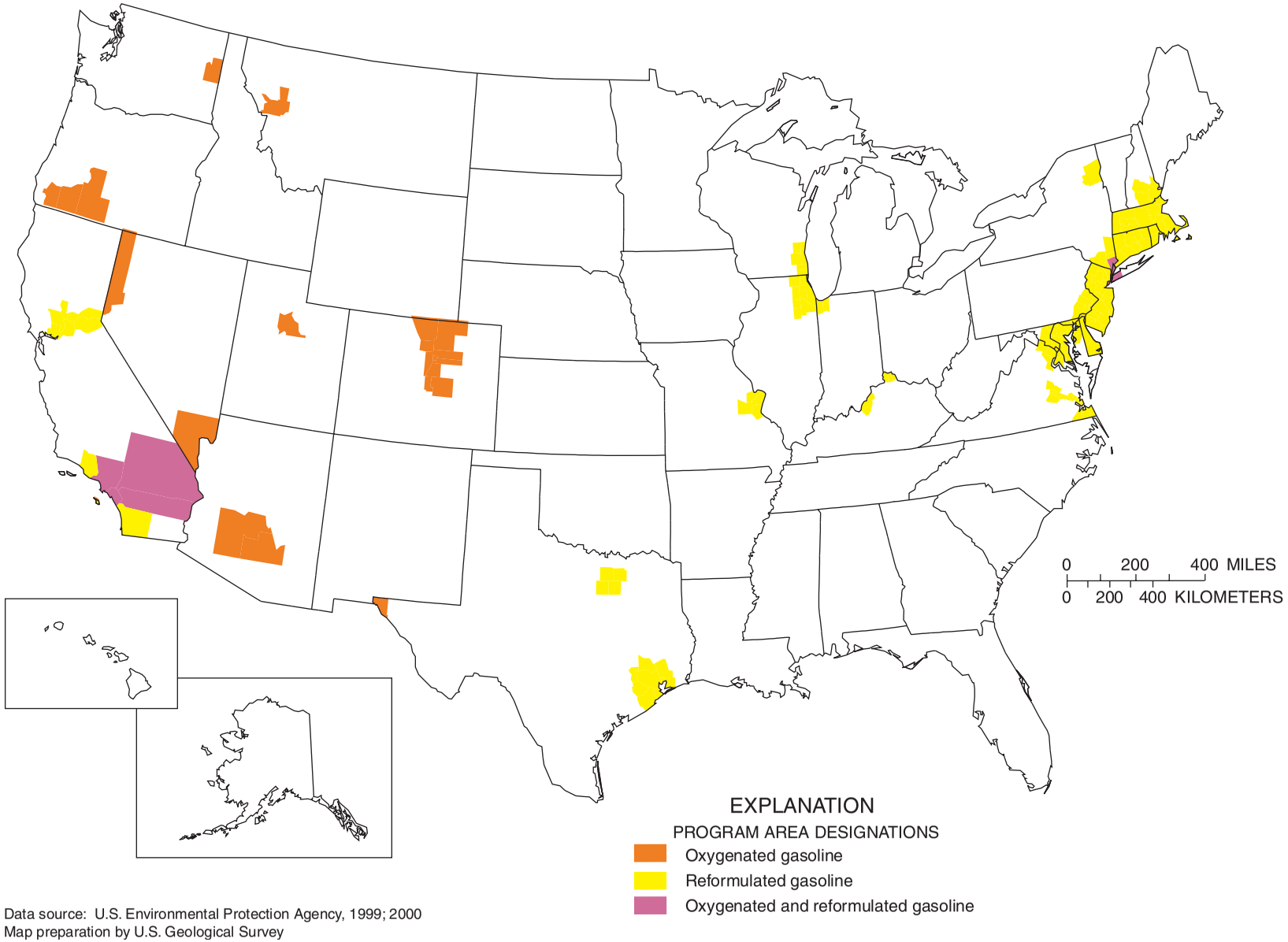

Figure 1. Location of current (2000) Federal oxygenated and reformulated gasoline program areas.

PURPOSE AND SCOPE

The literature review presented in this report provides information on the frequency of detection, concentration, and distribution of MTBE in sources of water used for drinking water and finished drinking water in the United States. The review focused on public and private water-supply assessments that were national, regional, or statewide in scope. Specifically, 3 national, 2 regional, and 13 statewide assessments were reviewed. In some cases, results are reported from summaries of information provided by States and are based on the State's normal compliance monitoring rather than a designated assessment. No additional large-scale MTBE drinking-water assessments are currently (2001) known to exist. Large-scale assessments were targeted for this literature review to provide a basis for comparison to the results obtained from the second phase of the national AWWARF assessment—the collection of new drinking-water-quality data.

SUMMARIES OF MTBE IN DRINKING WATER

The following summaries were obtained from assessments completed that were national, regional, or statewide in scope. The first national assessment, an Interagency Assessment of Oxygenated Fuels (Zogorski and others, 1997), reviewed all available scientific literature, data, and agency information with respect to all fuel oxygenates and their degradation by-products as of 1997. As such, this report serves as a comprehensive compilation of available information on ether oxygenates in drinking water up to the time of its completion. Additional assessments described herein were completed after the Interagency Assessment of Oxygenated Fuels report. An overall comparison of each assessment's findings is presented in table 1 in the "Summary" section of this report. However, direct comparisons of findings among assessments generally were not possible due, in part, to variable reporting limits and the types of water sampled (untreated drinking water, finished drinking water, and ambient water).

National Assessments

Three national assessments are summarized in this section, including the previously mentioned Interagency Assessment of Oxygenated Fuels. The other two national assessments that are summarized include an assessment of MTBE in rural domestic wells and an assessment of MTBE identified by State Leaking Underground Storage Tank (LUST) programs.

Interagency Assessment of Oxygenated Fuels

In June 1997, the Executive Office of the President's Office of Science and Technology Policy released a report summarizing an Interagency Assessment of Oxygenated Fuels (Zogorski and others, 1997). The purposes of this report were to provide a review of the scientific literature on oxygenated fuels and to assess the effects of the winter OXY gasoline program on air quality, water quality, fuel economy, engine performance, and public health.

As part of this assessment, two data sets were available to provide information on the occurrence of MTBE in drinking water. The first data set was collected by the USGS, mostly as part of the NAWQA Program (Gilliom and others, 1995), where MTBE was included on a list of analytes for ground-water samples collected in 20 major watersheds across the country during 1993-94. In addition, retrospective efforts of the NAWQA Program summarized MTBE occurrence data from a few State and regional ground-water assessment programs. The USGS data are a mixture of ambient ground-water data and drinking-water data. This is largely due to the NAWQA Program emphasis on resource assessments rather than characterizations of drinking water at that time.

The second data set was assembled while the Interagency Assessment of Oxygenated Fuels report was being prepared. The USEPA requested, through its 10 regional offices, information on drinking-water programs that have analyzed for MTBE. In response to this request, data were provided by seven States on the occurrence of MTBE in public drinking-water supplies derived from ground water, and four States provided data collected from domestic wells.

The USGS data indicated that MTBE was analyzed in samples collected from 1,516 wells and (or) drinking-water systems in 33 States with varying land uses. At least one detection of MTBE occurred in ground water in 14 of the 33 States surveyed. Overall, MTBE was detected in 5 percent (76 of 1,516) of the samples with a reporting level ranging from 0.2 to 1.0 µg/L. Most of the detections occurred in shallow ground water in urban areas (55 of 204 samples), whereas only about 1.3 percent (7 of 524) of the samples from wells in agricultural areas had detections

of MTBE. Of the 76 total detections of MTBE, 13 occurred in drinking-water supplies in six States—Colorado, Connecticut, Georgia, New York, Pennsylvania, and Washington. Eleven of these 13 detections occurred in domestic-water supplies, and two occurred in public water supplies. Concentrations detected in ground water and drinking water obtained from ground water (combined) ranged from 0.2 to 23,000 µg/L with a median of 0.6 µg/L. Concentrations detected in drinking water (domestic and public) generally were low and ranged from 0.2 to 2.2 µg/L with a median of 0.5 µg/L.

The USEPA request to States resulted in information on MTBE occurrence in public water systems voluntarily provided by seven States—Colorado, Illinois, Iowa, New Jersey, Rhode Island, Texas, and Wisconsin. Indiana, Missouri, Rhode Island, and Texas also provided information on domestic wells. The information provided was mostly specific to MTBE occurrence in public drinking-water supplies derived from ground water. However, Rhode Island and Wisconsin reported MTBE data for surface water as a source of drinking water.

Findings from the USEPA request indicated that MTBE was detected at least once in public water systems supplied from ground water in six of the seven States. MTBE was detected in 51 public drinking-water systems in Colorado, Iowa, Illinois, New Jersey, Rhode Island, and Texas. Of the 51 public drinking water systems with MTBE detections, 35 (68.8 percent, representing approximately 1,300 samples) were in New Jersey, whereas seven were in both Illinois and Texas (13.7 percent representing an unknown number of samples and 15,352 samples, respectively), and one was in Colorado and Iowa (2 percent representing five samples and an unknown number of samples, respectively) (Zogorski and others, 1997). When detected, the concentrations of MTBE generally were low and almost always less than 20 µg/L. However, concentrations as high as 63 µg/L in Iowa and 770 µg/L in Illinois were reported. In addition, MTBE was detected in all four States that provided data for domestic wells: Indiana, Missouri, Rhode Island, and Texas. Samples from five domestic wells from Indiana and Missouri had MTBE concentrations exceeding 200 µg/L, and one had a concentration of 40 µg/L. It is important to note, however, that domestic well samples were collected in response to consumer complaints. Thus, the MTBE concentrations in domestic wells generally were high in comparison to public water-supply information. In general, the public water-supply findings also may be biased toward high concentrations because a number of sampling programs were conducted when contamination from a nearby point source was known or suspected.

In addition to the information provided by States on MTBE occurrence in drinking water derived from ground water, Rhode Island and Wisconsin provided data on drinking water derived from surface water. In Rhode Island, an unknown number of surface-water samples were analyzed for MTBE, and one detection of MTBE occurred at a system that used surface water as a source. The detection occurred in a sample collected in January 1994 with a concentration of 1 µg/L. Two drinking-water systems were sampled during April 1995 in Wisconsin, and MTBE was not detected.

Assessment of MTBE in Rural, Domestic Wells

The results of an assessment to characterize the occurrence, distribution, and levels of 55 VOCs in untreated, self-supplied water from rural, domestic wells in the United States were reported by Moran and others (2002). Wells were considered to be in rural areas if the population density around the well was less than 386 people per square kilometer. One of the 55 VOCs assessed was MTBE. Data used in this assessment were compiled from two sources. The first source was a compilation of VOC data collected from wells by the NAWQA Program during 1993-99. Some of these wells also were included in Zogorski and others (1997). The second source was a compilation of VOC data collected and analyzed as part of ambient ground-water or source-water-quality monitoring programs by local, State, and other Federal agencies during 1986-99. All wells included in these analyses were at least 1 kilometer away from each other to avoid overlapping data, and only one sample from each well was included.

MTBE data from a total of 1,335 domestic wells located in 39 states were evaluated. At a reporting level of 0.2 µg/L, MTBE was detected in 2.2 percent of samples (30 of 1,335) in eight States. Typically, detections were associated with areas where the RFG program was Federally mandated and in areas near larger cities that opted for voluntary participation in the RFG program. The States in which MTBE was detected in domestic wells included: Arkansas (8.3 percent, 1 of 12 wells), Colorado (5.6 percent, 3 of 54 wells), Connecticut (25 percent, 3 of 12 wells), Georgia (9 percent, 2 of 22 wells), Illinois (1.9 percent, 1 of 52 wells), Massachusetts (33 percent, 2 of 6 wells), New Jersey (16.4 percent, 12 of 73 wells), and Pennsylvania

(3.7 percent, 6 of 164 wells). Concentrations ranged from 0.2 to 30.2 µg/L with a median of 0.7 µg/L.

Summary of State Leaking Underground Storage Tank Programs

The University of Massachusetts, with support from the USEPA, Office of Underground Storage Tanks, developed a mail questionnaire to characterize the effect of MTBE on State leaking underground storage tank (LUST) programs and to identify and evaluate any effective methods for dealing with MTBE that States have developed (Hitzig and others, 1998). State LUST programs were surveyed, allowing respondents to choose very general responses to increase the response rate for the survey. Questions included whether or not MTBE was required to be analyzed and, if so, how frequently was it detected at LUST sites. However, the generalized responses limited the ability to obtain specific data. As such, these data are not presented in table 1 in the "Summary" section of this report. Responses from LUST programs came from 48 States and the District of Columbia. Only California and Indiana did not respond.

In addition to the LUST site questions, programs also were asked to estimate the number of MTBE-contaminated drinking-water wells reported in their State or territory. Of all the LUST programs, 25 had reports of private drinking-water wells contaminated with MTBE. The total number of private wells contaminated with MTBE was estimated to range from 2,256 to 2,663. The largest number of contaminated domestic wells occurred in New York and was estimated to be at least 546 on the basis of responses from only four of New York's nine regions (Robert Hitzig, U.S. Environmental Protection Agency, Office of Underground Storage Tanks, written commun., 1998). States reporting MTBE contamination in 1 to 10 private drinking-water wells included Alabama, Idaho, Massachusetts, Minnesota, Montana, Oregon, and South Carolina. States reporting MTBE contamination in 11 to 20 private drinking-water wells included Delaware, Florida, North Carolina, and West Virginia. No States reported MTBE contamination in the 21- to 30-well range; however, Michigan and Wisconsin reported contamination in the 31- to 40-well range. Connecticut, Kansas, Maine, Maryland, New Hampshire, New Jersey, New Mexico, New York, Rhode Island, Tennessee, Vermont, and Virginia each reported contamination in more than 40 private drinking-water wells.

Nineteen LUST programs identified public drinking-water wells contaminated with MTBE. The total number of contaminated public wells was estimated to range from 251 to 422. States reporting estimated MTBE contamination in 1 to 10 public drinking-water wells include Connecticut, Florida, Michigan, Missouri, North Carolina, Rhode Island, South Carolina, Virginia, and West Virginia. States reporting estimated contamination in 11 to 20 public drinking-water wells include Maine, Maryland, New York, and Wisconsin. Kansas, Massachusetts, and New Mexico estimated 21 to 30 contaminated public drinking-water wells, and New Hampshire and Vermont reported between 31 and 40 contaminated public drinking-water wells. New Jersey estimated 65 contaminated public drinking-water wells (Robert Hitzig, U.S. Environmental Protection Agency, Office of Underground Storage Tanks, written commun., 1998).

Very limited data on MTBE concentrations were provided; however, when available, the vast majority of concentrations in public drinking-water wells was less than 10 µg/L. This assessment indicated that MTBE detections by State programs were common and that MTBE contamination may occur at diesel fuel storage sites or unexpected locations due, in part, to surface dumping of small amounts of gasoline.

Regional Assessments

Two regional assessments were reviewed and are summarized in this section. These assessments include a survey of MTBE in sources of drinking water by the American Water Works Company and an assessment of MTBE in finished drinking water from community water supplies in the northeast and Mid-Atlantic regions of the United States.

American Water Works Company Assessment of MTBE in Drinking Water

Gullick and LeChevallier (2000) summarized the results from a MTBE survey of ground- and surface-water supplies used for drinking water in the American Water System of the American Water Works Company. The system is large and comprises wholly owned utility subsidiaries in 23 States that serve more than 7 million people in 879 communities. A total of 1,349 groundwater samples representing 342 wells from 17 States were analyzed from 1997 to 1998 using a reporting level of 0.5 µg/L. Raw water was sampled from 270 of these wells, and treated water was sampled from 72 wells.

MTBE was detected in wells in eight States at a frequency of 8.8 percent (30 of 342). The highest concentration detected was 14.1 µg/L. The States in which MTBE was detected included Connecticut (50 percent, 5 of 10 wells), Indiana (1 percent, 1 of 99 wells), Maryland (50 percent, 1 of 2 wells), Massachusetts (38 percent, 5 of 13 wells), New Hampshire (9.1 percent, 1 of 11 wells), New Jersey (13 percent, 12 of 92 wells), Pennsylvania (100 percent, 4 of 4 wells), and West Virginia (50 percent, 1 of 2 wells). MTBE was detected in treated water in Massachusetts (50 percent, 2 of 4 samples) and New Jersey (9.1 percent, 4 of 44 treated water samples).

A total of 200 surface-water samples representing 92 sampling sites in 12 States also was analyzed. MTBE was detected at 8 of 92 sites (8.7 percent) in three States. The highest concentration detected was 25.1 µg/L. States in which MTBE was detected in surface water included New Jersey (25 percent, 4 of 16 sites), New York (17 percent, 3 of 18 sites), and Pennsylvania (11 percent, 1 of 9 sites).

Characterization of MTBE in Finished Drinking Water in the Northeast and Mid-Atlantic Regions

Grady and Casey (2001) characterized the occurrence and distribution of MTBE and other VOCs in finished drinking water from community water systems (CWSs) in the Northeast and Mid-Atlantic regions of the United States from 1993 to 1998. These regions were selected for assessment because of their large populations, extensive urban and industrial development, and widespread use and release of many VOCs. In addition, these regions comprise the largest contiguous area, outside of California, where the gasoline additive MTBE is used to meet requirements of the CAA Amendments of 1990. The assessment area included the six New England States plus Delaware, Maryland, New Jersey, New York, Pennsylvania, and Virginia.

This assessment was designed to provide statistically representative data for each of the 12 States. A random selection of 20 percent (2,110) of the 10,479 active CWSs in the assessment area (as of December 1, 1997) was made to represent the actual distribution of CWSs in the area. The resulting distribution of randomly selected CWSs included 1,690 systems supplied exclusively by ground water, 270 supplied exclusively by surface water, and 150 systems with both ground- and surface-water sources. About 65 percent of the selected CWSs were small, serving fewer than 500 people, 20 percent served 501 to 3,300 people, 13 percent served 3,301 to 50,000 people, and 2 percent served more than 50,000 people. The number of systems selected from within each State was proportional to the size of the population within that State and ranged from 30 CWSs in Rhode Island to 538 CWSs in New York.

Chemical analyses, as well as supporting documentation, were provided for each of the randomly selected CWSs by each respective State. Data obtained from States varied significantly in format, constituents analyzed, reporting levels, and period of record. As such, MTBE was not analyzed at each of the randomly selected CWSs; a total of 5,510 analyses of MTBE from 1,194 CWSs were provided. MTBE data were not available from Delaware or Pennsylvania, however. Reporting levels ranged from 0.5 to 10.0 µg/L. At any reporting level, MTBE was found to occur in 6.2 percent (343 of 5,510 analyses) of the samples and 8.9 percent (106 of 1,194) of the CWSs. Further examination of these data by applying censoring levels of 20, 10, 5, 2, 1, and 0.5 µg/L resulted in frequencies of detection of 0.8, 1.4, 2.0, 4.6, 7.8, and 12.2 percent, respectively. It should be noted that 4,427 of the 5,510 analyses at 865 of the 1,194 CWSs were included using a reporting level of 0.5 µg/L. Thus, only about 20 percent of the data set had a reporting level higher than 0.5 µg/L.

MTBE was detected in drinking water from all 10 States in the two regions that had analytical data. MTBE concentrations ranged from 0.26 to 210 µg/L; however, most MTBE concentrations were less than 5.0 µg/L, and 0.8 percent of CWSs reported MTBE concentrations equal to or greater than 20 µg/L. Two percent of the CWSs reported MTBE concentrations equal to or greater than 5 µg/L.

Although MTBE concentration data were not available on a State-by-State basis in the report by Grady and Casey (2001), the frequency of detection in randomly selected CWSs varied substantially from State to State at a reporting level of 1.0 µg/L. MTBE was detected most frequently in New Jersey (about 22 percent) and least frequently in Virginia (1.3 percent). MTBE was found to occur in Connecticut and Rhode Island approximately 17 percent of the time. MTBE also was found to occur at frequencies of approximately 12, 11, 10, 9, 4, and 2 percent in New Hampshire, Massachusetts, Maine, New York, Vermont, and Maryland, respectively. The States with the highest MTBE detection frequencies— New Jersey,

Rhode Island, and Connecticut—are the three States with the highest population density. MTBE occurrence was shown to be statistically related to population density using a contingency-table test (p-value less than 0.0001).

Statewide Assessments

Statewide assessments of MTBE have been conducted in 13 States by various entities and are summarized in this section. The reporting level, if given, varied between studies as did the types of water sampled (sources of drinking water, finished drinking water, and ambient water). Currently, CWSs are not required by the USEPA to monitor drinking water for MTBE. However, certain States (including in part, California, New Jersey, New Hampshire, and New York) have required monitoring and assembled data sets and set State MTBE MCLs.

Alabama

Due to concern of MTBE contamination and based in part on the results of the national and regional assessments just discussed, the Alabama Department of Environmental Management (ADEM), Water Division (2001) conducted an assessment to determine if the sources of water used by public water-supply (PWS) systems in Alabama have been affected by MTBE. MTBE has been and continues to be present in gasoline sold in Alabama at levels typically between 1 to 2 percent and occasionally as high as 4 percent by volume.

There are 575 PWS systems in Alabama that use surface water, springs, and wells to meet water-supply demands. Sixty percent of all the water supplied comes from surface water. In calendar year 2000, each of the 575 PWS systems was sampled for MTBE. Efforts were made to sample each potable water source prior to treatment at each PWS system. As a result, 1,053 water sources were sampled during the study, including 87 surface-water sources, 27 springs, and 939 wells.

Most surface-water sources were sampled four times; once during March to April, once during May to June, once within 3 days following the Fourth of July, and once within 4 days of Labor Day. This sampling strategy accounted for some temporal fluctuations of MTBE in surface water due to lake turnover, rainfall, runoff, and periods of high recreational use. The wells and springs were sampled once, however, MTBE will be analyzed on a routine basis in the future, as it is currently on the standard State VOC analyte list. Samples were analyzed by the Tennessee Valley Authority or an ADEM-approved certified laboratory. As such, reporting levels ranged from 0.5 to 2.0 µg/L depending on the laboratory used.

MTBE was not detected in any of the 87 surface-water sources. Five of 939 wells (0.53 percent) contained MTBE with concentrations ranging from 0.74 to 8.39 µg/L. Twenty-seven springs were sampled and analyzed for MTBE, all results were below the detection limit. ADEM staff are currently (2001) conducting follow-up investigations to try to determine the source of MTBE in the five contaminated wells.

California

California State Senate Bill 521, which became effective January 1, 1998, called for the University of California to perform an assessment of the benefits and risks associated with the uses of MTBE in California. The assessment reported by Keller and others (1998) addressed, in part, current effects of MTBE in drinking-water sources from surface water and ground water. Data were obtained from the Department of Health Services, Local Primacy Agencies, and Regional Water Quality Control Boards within California.

A total of 245 surface-water sources, including reservoirs, lakes, and rivers, were identified as drinking-water sources. Data were available for 105 of these surface-water sources. About 3,000 samples were collected and analyzed voluntarily during 1996-97; however, the vast majority of samples were from 25 of the 105 surface-water sources and were collected on multiple days at several different locations within each water body. MTBE was not detected in 56 (53 percent) of the 105 water bodies sampled; 49 (46.7 percent) of the 105 water bodies did contain MTBE. Twenty-six (53 percent) of these 49 water bodies were found to have MTBE concentrations greater than 5 µg/L, and 13 (26 percent) of the 49 water bodies were found to have MTBE concentrations greater than 14 µg/L in at least one sample.

Of 13,919 public-supply wells within California, 2,988 were reported to have been sampled and analyzed for MTBE. Of these 2,988 wells, MTBE contamination was reported in 35 wells. This equates to 1.2 percent of all public supply wells tested for MTBE and 0.3 percent of all public-supply wells in counties where at least one well was tested. Through extrapola-

tion of these data using a 1.2 percent upper-boundary estimate, Keller and others (1998) estimated that between 60 and 160 public-supply wells may be contaminated with MTBE in the State of California.

A database of all MTBE samples collected from public supplies beginning October 1989 through the present was downloaded from the California Department of Health Services publications (2002), and analyzed. Data was truncated to September 2001 to represent a similar timeframe as the other States information. Data stored in the database is a combination of ground- and surface-water samples as well as results of analysis of MTBE in samples of raw and treated waters. A total of 50,748 samples were analyzed, with 535 MTBE detections. The lowest concentration detected was 0.15 µg/L with a maximum MTBE concentration of 610 µg/L.

Connecticut

The State of Connecticut Department of Public Health is required by law to provide an annual report on results of organic chemical testing by public water systems to the Governor of the State. One of the chemicals monitored is MTBE. Only the most recent report is summarized herein (State of Connecticut Department of Public Health, 2000).

In 1999, a total of 139 public water systems in 77 different towns contained organic chemicals. MTBE was detected in a total of 57 sources of public water supply in 40 of the 77 towns. Some detections within the same town were in more than one public water system. When detected, MTBE concentrations ranged from 0.7 to 110 µg/L with a median concentration of 2.7 µg/L.

Florida

The Florida Drinking Water Program has been sampling for MTBE as an unregulated contaminant since the early 1990's. The data have been stored in a database and are available on the referenced web site (Florida Department of Environmental Protection, 2001). This data set indicated that a total of 8,739 samples were analyzed from 1,692 public water supplies.

MTBE was detected in 4.9 percent of all samples (428 of 8,739) and 1.2 percent (20 of 1,692) of PWS systems tested. The majority (379) of MTBE detections occurred in two public water systems. The minimum, median, and maximum detected concentrations were 0.1, 1.4, and 166 µg/L, respectively.

Illinois

CWSs in Illinois routinely sample for VOCs under the Safe Drinking Water Act monitoring program. Under Illinois' CWS Laboratory Fee Program, analyses for MTBE have been reported as part of standard laboratory methods since 1994. Approximately 80 percent of the 1,200 CWSs that supply water participate in the program, and most (1,100 of 1,200) utilize ground water as the source of drinking water.

The results reported by the Illinois Environmental Protection Agency (2000) indicated that 26 active systems have had detections of MTBE. In addition, three CWSs have had to discontinue use of wells as a result of MTBE contamination. These CWSs were located in Kankakee County, Island Lake, and East Alton, Illinois. Although concentration data were not given, the Illinois Environmental Protection Agency (2000) did indicate that most of the concentrations were unlikely to cause adverse human health effects.

Iowa

In response to growing national concern over MTBE contamination in ground water and drinking-water supplies, the Iowa Comprehensive Petroleum Underground Storage Tank Fund and the Iowa Department of Natural Resources contracted with the University of Iowa's Hygienic Laboratory to conduct analyses of water samples from PWS wells located in Iowa's vulnerable bedrock regions. As part of the Risk-Based Corrective Action process, any municipal water-supply well located within a 1-mile radius of a LUST site that is in a vulnerable bedrock region must be sampled for chemicals of concern. MTBE was added to the list of analytes to be sampled on July 1, 1999.

A total of 530 samples were collected prior to any treatment from 235 PWS systems during the second and third quarters of 1999 and analyzed (Iowa Department of Natural Resources, 2000). Similarly, 518 samples were collected and analyzed during the fourth quarter of 1999. MTBE was not detected in any sample above the quantitation limit of 15 µg/L. However, MTBE was detected below the quantitation limit in eight samples.

MTBE also has been detected in Iowa CWSs, however, not as part of the bedrock project. Cities in which MTBE has been detected included Ida Grove,

Galva, and Alvord. These cites are located in northwestern Iowa. MTBE has been detected in Ida Grove's drinking-water supply each quarter since 1997. The highest concentration reported was 12 µg/L in 1998 after treatment but before blending with other source wells. MTBE was detected at a concentration of 18 µg/L in one sample from Galva's drinking-water supply in 1996, and concentrations as high as 63 µg/L in Alvord's supply were detected in 1994. Galva and Alvord have since abandoned their water-supply wells and are using a different source (Iowa Department of Natural Resources, 2000).

Kansas

News reports about MTBE in water supplies caused concern for residents of Kansas. This prompted the Kansas Department of Health and Environment (KDHE), which has routinely monitored MTBE in PWSs since 1996, to respond to these concerns (Kansas Department of Health and Environment, 2000).

From 1996 to January 2000, 27,935 water samples from 1,122 PWS wells were analyzed. MTBE was detected in 101 samples in 18 PWS wells. This equates to MTBE being detected in 1.6 percent of the 1,122 PWS wells. Concentrations ranged from 0.5 to 1,250 µg/L (Greg Hattan, Kansas Department of Health and Environment, written commun., 2002). In response to these findings, KDHE has installed three treatment systems at PWS wells where MTBE was detected at higher concentrations and plans to install a fourth treatment system.

Maine

In response to public awareness and concern for the presence of MTBE in Maine's water resources, Maine Governor Angus King directed State health and environmental agencies to undertake an assessment of the occurrence of MTBE in Maine's drinking-water supplies by sampling all (830) public and 1,000 private household water supplies. When completed, the assessment sampled 793 of the 830 regulated nontransient PWSs and 951 private household water supplies (Maine Bureau of Health, 1998).

MTBE was detected in 125 (16 percent) of the 793 PWSs that were sampled. All detected concentrations were less than Maine's Maximum Contaminant Level (MCL) of 35 µg/L. About 6 percent of the samples had detected concentrations between 1 and 35 µg/L, and in 93.9 percent of the samples, MTBE was either not detected or less than 1 µg/L. Public water supplies serving businesses or mobile home parks were found to be about twice as likely to have detectable levels of MTBE as compared with community water supplies and schools. Location of the water supply in areas with required RFG use and high population density were both associated with detectable levels of MTBE. Factors that were found not to be associated with MTBE detection included: (1) type of well or water supply, and (2) proximity to gasoline storage tanks.

Population density was a significant risk factor for PWSs within areas where RFG use was required. In areas of high population density (greater than 180 people per square mile), the risk of MTBE detection was 4.1 times higher in areas where RFG use was required compared to areas where it was not. In areas of low population density, the risk of MTBE detection was 1.7 times higher in areas where RFG use was required compared to areas where it was not.

MTBE was detected in 150 (15.8 percent) of the 951 private wells sampled. Ten (1.1 percent) of the 951 sampled wells contained MTBE at concentrations greater than the Maine MCL of 35 µg/L. Extrapolation of these findings indicates that an estimated 1,400 to 5,200 private wells may contain MTBE at concentrations greater than or equal to 35 µg/L. Sixty-three (6.6 percent) of the private wells contained MTBE at concentrations between 1 and 35 µg/L. Thus, about 92 percent of the wells did not contain detectable levels of MTBE or had concentrations less than 1 µg/L.

Population density was a significant risk factor for private household water supplies within areas where RFG use was required. In areas of high population, the risk of MTBE detection in private household water supplies was 1.3 times higher in areas where RFG use is required compared to areas where it was not. In areas of low population density, the risk of MTBE detection was 2.0 times higher in areas where RFG use was required compared to areas where it was not.

Maryland

The Maryland Department of the Environment (2001) has been periodically monitoring public water systems, specifically community and nontransient noncommunity public water systems, for MTBE since 1995. MTBE was detected in 85 public water systems (7.8 percent) out of 1,084 sampled. Eleven of these systems contained MTBE concentrations greater than

20 µg/L, and 10 of the 85 systems now have alternative sources or the concentrations have since declined to levels below 20 µg/L.

In addition, all LUSTs that affect ground water are monitored within the State. At the time these data were obtained from the Maryland Department of Environment web site (June 8, 2001), 270 domestic wells had been affected by MTBE.

Michigan

In March 2000, the Michigan Department of Environmental Quality's (MDEQ) Storage Tank Division released a fact sheet summarizing MTBE specific information (Michigan Department of Environmental Quality, 2000). In 1996, Michigan began enforcing a low-vapor-pressure requirement in summertime fuel to control ozone levels for gasoline sold between June 1 and September 15. Rather than supplying RFG containing MTBE or ethanol, the refiners supplying gasoline during this timeframe opted to meet the low-vapor-pressure requirement by removing some of the more volatile compounds from the gasoline. The chemical composition of gasoline sold throughout the year is monitored by the Michigan Department of Agriculture. Gasoline samples are randomly collected and analyzed; however, the total number of samples collected each year is not known.

The results of the survey completed during 1998 indicated that 8 and 5 percent of the fuels sampled contained ethanol and MTBE, respectively. Concentrations of ethanol ranged from 9 to 10 percent by volume and a "very small fraction" contained MTBE in concentrations greater than 12 percent by volume. Low concentrations (less than 2.2 percent by volume) of MTBE were thought to be due to MTBE in the pipeline distribution system mixing with the next fuel to be transported. MTBE in gasoline at levels greater than 2.2 percent by volume was thought to be present as an octane enhancer.

Although MTBE was present in only about 5 percent of gasoline sold in Michigan, the MDEQ identified MTBE at several LUST sites. The Drinking Water and Radiological Protection Division (DWRPD) also detected MTBE in drinking water. The DWRPD has been analyzing samples for MTBE since 1987. From October 1, 1987, to September 30, 1999, 31,557 water samples from 18,046 community, non-community, and private water wells were analyzed by the DWRPD. Results indicated that MTBE was detected in 903 samples from 542 locations. This equates to 2.9 percent of all samples and 3.0 percent of the community, non-community, and private wells sampled. The reporting level used for these analyses was not presented but was assumed to be 1.0 µg/L for most analyses. For those samples in which MTBE was detected, 3.2 percent (29 of 903) contained MTBE at concentrations greater than 240 µg/L, 9.1 percent (82 of 903) contained MTBE at concentrations between 40 and 240 µg/L, and 87.7 percent (792 of 903) contained MTBE at concentrations between 1 and 40 µg/L (Michigan Department of Environmental Quality, 2000).

Missouri

In response to a request from State Senator David Klarich, the Missouri Department of Natural Resources (MDNR) reported their perspective on a State resolution that requires them to assess the extent of possible environmental contamination of MTBE (Missouri Department of Natural Resources, 2000). The MDNR has assessed MTBE in the environment since 1992 and has analyzed for MTBE in public drinking-water sources since 1994. There are approximately 1,685 public water supplies and non-transient community systems in Missouri, each of which are monitored at least once every 3 years for ground-water supplies or annually for surface-water supplies. Some water suppliers are required to analyze samples more frequently, such as in the St. Louis, Missouri, non-attainment area, whereas the larger systems do so voluntarily.

As of February 7, 2000, MTBE had been detected in two public water supplies. The MDNR indicated that the contamination was from underground tanks leaking premium-grade gasoline rather than RFG.

New Jersey

The continued interest in MTBE in the environment prompted the New Jersey Department of Environmental Protection (1999) to summarize and evaluate, in part, information on the use and occurrence of MTBE in New Jersey. Some of the information presented specifically related to the occurrence of MTBE in public and domestic water supplies.

The Bureau of Safe Drinking Water has been collecting data on MTBE in public water supplies since 1997. Results of samples collected from about 400 CWSs from July 1997 to September 1998 were presented. At a reporting level of 0.5 µg/L, results indicated that MTBE was detected in 59 (15 percent) of the

CWSs with a maximum concentration of 8.9 µg/L. The samples analyzed typically were finished drinking water.

The majority of information on MTBE in domestic wells was obtained in response to a potential or existing contamination problem associated with the well. As such, results from these wells would be biased high making it difficult to define the overall presence of MTBE in these types of wells. However, one assessment of domestic wells was completed in which the wells sampled were selected on a random basis. The wells were selected and ultimately sampled from four main areas of New Jersey: the New England physiographic province (Highlands); the Piedmont; the Kirkwood-Cohansey aquifer in southern New Jersey; and the crystalline rock aquifer surrounding Cranberry Lake in Sussex County. MTBE was detected in all four areas (reporting level of 0.1 µg/L). For all four areas combined, MTBE was detected in 35.6 percent of the domestic wells (37 of 104 wells sampled). Concentrations typically were low, with minimum and maximum detected concentrations of 0.1 and 30.2 µg/L, respectively.

Wisconsin

The State of Wisconsin has systematically analyzed for MTBE in ground water used as a source of drinking water since 1990. All results are entered into the Wisconsin Department of Natural Resources (DNR) Groundwater Retrieval Network (GRN) database.

In response to the national interest in MTBE in sources of drinking water, the DNR summarized MTBE data obtained from the GRN database (Wisconsin Department of Natural Resources Bureau for Remediation and Redevelopment, 2000). Results indicate that MTBE was detected in 99 (4.4 percent) of 2,271 wells sampled. Most (96) of the MTBE detections were found in private residential wells because municipal water-supply system purveyors in Wisconsin are not required to monitor for MTBE. Two wells that were described as "municipal-community" wells and one well that was described as "community, other than municipal" also had detected concentrations of MTBE. The statistical summary of MTBE concentrations were not reported by the DNR. However, the maximum concentration reported (1,700 µg/L) was from a private-residential well.

SUMMARY

In March 1998 the American Water Works Association Research Foundation solicited a request for proposals to assess methyl *tert*-butyl ether (MTBE) in the Nation's drinking-water supplies. In response, the Metropolitan Water District of Southern California, the U.S. Geological Survey, and the Oregon Health & Science University collectively prepared and submitted a proposal to assess MTBE and other VOCs in public drinking water. This proposal was accepted, and the assessment is currently (2001) underway and scheduled for completion in the fall of 2002.

One part of this national assessment includes a review of literature regarding MTBE in public and private drinking-water supplies, which is the focus of this report. Previously (1997), an exhaustive review of MTBE in water was completed as part of an Interagency Assessment of Oxygenated Fuels. Results of the Interagency literature review concluded that it was not possible to characterize MTBE in sources of drinking water due to limited data available at that time. As such, reviewed literature for this report focused on those assessments completed subsequent to the Interagency review.

Specifically, the review for this report focused on public and private water-supply studies that are national, regional, or statewide in scope. In some cases, results are reported from summaries of information provided by States that were based on the State's normal compliance monitoring rather than a designated assessment. Overall, three national, two regional, and 13 statewide assessments were reviewed.

A summary of the occurrence, frequency, and concentration of MTBE detected in drinking water is presented in table 1. It is important to note that it was usually not possible to compare findings between assessments, in part, due to different study objectives, different reporting levels, and different types of water sampled including untreated drinking water, finished drinking water, and ambient water. In addition, many samples reported in this literature review were collected in response to consumer complaints. This potentially results in detected concentrations that may be high in comparison to ambient levels. The inconsistencies among assessments studies further support the Interagency conclusion that an overall characterization of MTBE in drinking water was not possible on the basis of existing information and that further investigations, such as the AWWARF-sponsored assessment, were necessary.

Table 1. Summary of methyl *tert*-butyl ether (MTBE) in sources of drinking water reported in national, regional, and statewide assessments

[µg/L, micrograms per liter; NK, not known; ND, not detected; >, greater than; <, less than]

Reference	Type of water sampled	Number of samples collected	Reporting level (µg/L)	Number of MTBE detections	Detection frequency (percent)	Detected concentration (µg/L)		
						Minimum	Median	Maximum
		National Assessments						
Zogorski and others, 1997	Ground water and drinking water obtained from ground water[1]	1,516	0.2 – 1.0	76	5.0	0.2	0.6	[2]23,000
	Public ground-water supplies[1,3]	NK	.2 – 1.0	2	NK	.3	1.1	1.8
	Private ground-water supplies[1,3]	NK	.2 – 1.0	11	NK	.2	.5	2.2
	Public surface-water supplies[4]	NK	NK	1	NK	1.0	1.0	1.0
	Public ground-water supplies[4]	NK	NK	241	NK	.7	3.0	17,800
	Private ground-water supplies[4]	NK	NK	680	NK	1.0	27	17,000
Moran and others, 2002	Private ground-water supplies	1,335	.2	30	2.2	.2	.7	30.2
		Regional Assessments						
Gullick and LaChevallier, 2000	Public ground-water supplies	[5]1,349	.5	30	[6]8.8	.5	NK	14.1
	Public surface-water supplies	[7]200	.5	8	[8]8.7	.7	NK	25.1
Grady and Casey, 2001	Finished drinking water	[9]5,510	.5 – 10	106	[10]8.9	.26	NK	210
		Statewide Assessments						
Alabama Department of Environmental Management, 2001[11]	Public surface-water supplies	[12]87	.5 – 2.0	0	0	ND	ND	ND
	Public ground-water supplies	966	.5 – 2.0	5	0.5	.74	NK	8.39
Keller and others, 1998 (California)	Public surface-water supplies	[13]3,000	NK	NK	[14]46.7	NK	NK	[15]>14
	Public ground-water supplies	[16]2,988	NK	35	1.2	NK	NK	NK
California Department of Health Services, 2002	Public water supplies	50,748	NK	535	1.1	.15	3.6	610
State of Connecticut Department of Public Health, 2000	Public water supplies	NK	.5 – 2.0	57	NK	.7	2.7	110
Florida Department of Environmental Protection, 2001	Public water supplies	[17]8,739	NK	428	[18]1.2	.1	1.4	166
Illinois Environmental Protection Agency, 2000	Public water supplies	[19]960	.5 – 1.0	26	[18]2.7	NK	NK	NK
Iowa Department of Natural Resources, 2000	Public ground-water supplies	[20]1,048	15	NK	[21]NK	.46	NK	63
Kansas Department of Health and Environment, 2000	Public water supplies	[22]27,935	NK	101	[18]1.6	.5	NK	1,250
Maine Bureau of Health, 1998	Public water supplies	[23]793	.1	125	15.8	NK	NK	[24]<35
	Private ground-water supplies	[23]951	.1	150	15.8	NK	NK	[25]>35
Maryland Department of the Environment, 2001	Public water supplies	1,084	.5	[26]85	[27]7.8	.5	NK	[28]>20

Table 1. Summary of methyl *tert*-butyl ether (MTBE) in sources of drinking water reported in national, regional, and statewide assessments—Continued

[µg/L, micrograms per liter; NK, not known; ND, not detected; >, greater than; <, less than]

Reference	Type of water sampled	Number of samples collected	Reporting level (µg/L)	Number of MTBE detections	Detection frequency (percent)	Detected concentration (µg/L)		
						Minimum	Median	Maximum
Michigan Department of Environmental Quality, 2000	Public and private water supplies	[29]31,557	1.0	903	[6]3.0	1.0	NK	[30]>240
Missouri Department of Natural Resources, 2000	Public water supplies	[31]2,700	5	2	[6]7	NK	NK	NK
New Jersey Department of Environmental Protection, 1999	Public water supplies	[32]400	.5	59	14.8	NK	NK	8.4
	Private ground-water supplies	104	.1	37	35.6	.10	[33].48	30.2
Wisconsin Department of Natural Resources Bureau for Remediation and Redevelopment, 2000	Private ground-water supplies	2,271	12	[34]99	4.4	NK	NK	1,700

[1]Data provided by the U.S. Geological Survey for the referenced study.
[2]This concentration was detected in ambient ground water, not in a drinking-water supply.
[3]These data are a subset of the ground water and drinking water obtained from the U.S. Geological Survey ground-water category listed above.
[4]Data requested by and provided to the U.S. Environmental Protection Agency for the referenced study.
[5]1,349 samples were collected from 342 wells; 270 of the 342 wells were sampled before treatment, and 72 were sampled as treated water.
[6]Represents the number of wells with at least one detection of MTBE.
[7]200 samples were collected from 92 surface-water sites.
[8]Represents the percent of intakes with at least one detection of MTBE.
[9]5,510 samples were collected from 1,194 community water-supply systems.
[10]Detection frequency represents the number of community water systems (CWSs) with at least one detected concentration using reporting levels ranging from 0.5 to 10 µg/L.
[11]Efforts were made to sample all public drinking-water supplies in Alabama (701).
[12]Represents the number of surface-water sources sampled. Most were sampled quarterly, however, the number of samples collected is not known.
[13]About 3,000 samples (exact number is not known) were collected from a total of 105 surface-water sources. The majority of samples were collected at only 25 of the 105 sources.
[14]Represents the number of sources with at least one detection of MTBE.
[15]The maximum detected concentration was not presented. However, the report stated that 13 surface-water sources had concentrations greater than 14 µg/L.
[16]2,988 public-supply wells were sampled. It is unknown if any wells were sampled multiple times.
[17]8,739 water samples were collected from 1,692 public water systems.
[18]Represents the number of public water-supply systems with at least one detection of MTBE.
[19]960 is estimated based on 80 percent of 1,200 community water suppliers reported to participate in the study. Most (1,100 of 1,200) community water suppliers utilize ground water as the primary source of drinking water.
[20]1,048 samples were collected from 235 public water-supply systems. All wells were located within 1 mile of a leaking underground storage tank site.
[21]MTBE was detected in eight samples below the minimum reporting level.
[22]27,935 water samples were collected from 1,122 public water supplies. MTBE was detected in 18 of the public water supplies.
[23]Individual wells were sampled once.
[24]All detected concentrations were less than 35 µg/L, however, the maximum concentration was not presented.
[25]1.1 percent of the sampled wells contained concentrations that were greater than 35 µg/L, however, the actual concentrations were not presented.
[26]MTBE was detected in 85 systems. It is not known how many total samples were collected or how many samples contained MTBE.
[27]According to the data on the web site, a total of 1,084 systems were sampled.
[28]11 systems were found to contain MTBE at concentrations greater than 20 µg/L. The maximum concentration detected was not presented.
[29]31,557 water samples were collected from 18,046 community, non-community, and private wells.
[30]The maximum detected concentration of MTBE is not known, however, it was presented to be greater than 240 µg/L.
[31]Approximately 2,700 samples were collected from about 20 public water supplies. Two were found to contain MTBE.
[32]Actual number of samples is unknown; samples were submitted from approximately 400 CWSs.
[33]Represents the average median concentration from four sampling areas.
[34]Actual number of samples with MTBE detected is unknown. This represents the number of wells rather than number of samples.

Overall, results of this literature review indicate that MTBE has been detected in public and (or) private drinking-water supplies in 36 States, which are listed in table 2. Detected concentrations of MTBE ranged from 0.1 to 17,800 µg/L. In some cases, maximum concentrations were reported only as greater than a certain concentration. Thus, it is not known what those maximum concentrations were. Many times, it was not possible to determine median detected concentrations because only minimum and maximum concentrations were reported. However, when median detected concentrations were available, they were typically low—less than 5.0 µg/L. Similarly, the number of samples collected or the number of systems from which samples were collected was not always known. Thus, it was not always possible to determine or calculate detection frequencies. Regardless, these assessments did indicate that: (1) MTBE occurred in public drinking-water systems supplied by both ground and surface water, and concentrations generally were less than 20 µg/L; (2) population density and RFG use were significant factors for MTBE detection in water supplies; (3) type of well and proximity to gasoline storage tanks did not seem to be associated with MTBE detection; and (4) more data are needed before the extent of MTBE in drinking water and its resulting importance as a route of human exposure can be determined.

Table 2. States with detected concentrations of methyl *tert*-butyl ether in public and (or) private drinking-water supplies

Alabama	Kansas	North Carolina
Arkansas	Maine	Oregon
California	Maryland	Pennsylvania
Colorado	Massachusetts	Rhode Island
Connecticut	Michigan	South Carolina
Delaware	Minnesota	Tennessee
Florida	Missouri	Texas
Georgia	Montana	Washington
Idaho	New Hampshire	West Virginia
Illinois	New Jersey	Wisconsin
Indiana	New Mexico	Vermont
Iowa	New York	Virginia

REFERENCES CITED

Alabama Department of Environmental Management, Water Division, 2001, Evaluation of MTBE—Contamination of Drinking Water Sources in Alabama: accessed June 8, 2001, at URL http://www.adem.state.al.us/EduInfo/PressReleases/3dwsafe.htm

Bourelle, Andy, 1998, MTBE—A real concern for South Lake Tahoe: Tahoe Daily Tribune, accessed August 28, 1998, at URL http://www.tahoe.com/tribune/stories.8.28.98/news/ mt28Aug1347.html

California Department of Health Services, 2001, MTBE in California drinking water: accessed December 6, 2000, at URL http://www.dhs.cahwnet.gov/ps/ddwem/chemicals/ MTBE/mtbeindex.htm

———2002, MTBE in California drinking water, drinking water program download page: accessed March 26, 2002, at URL http://www.dhs.ca.gov/ps/ddwem/publications/ library.htm

City of Santa Monica, 1999, MTBE issue featured on "60 Minutes": accessed December 12, 2001, at URL http://epwm.santamonica.org/epwm/watquality/1999report/waterweb/news05.htm

Florida Department of Environmental Protection, 2001, MTBE (methyl tertiary-butyl ether) occurrence in Florida drinking water systems: accessed June 8, 2001, at URL http://www.dep.state.fl.us/water/wf/dw/mtbe.htm

Gilliom, R.J., Alley, W.M., and Gurtz, M.E., 1995, Design of the National Water-Quality Assessment Program—Occurrence and Distribution of Water-Quality Conditions: U.S. Geological Survey Circular 1112, 33 p.

Grady, S.J., and Casey, G.D., 2001, Occurrence and distribution of methyl *tert*-butyl ether and other volatile organic compounds in drinking water in the northeast and Mid-Atlantic regions of the United States, 1993-1998: U.S. Geological Survey Water-Resources Investigations Report 00-4228, 123 p.

Gullick, R.W., and LeChevallier, M.W., 2000, Occurrence of MTBE in drinking water sources: American Water Works Association, v. 92, no. 1, p. 100-113.

Hattan, Greg, 2000, MTBE treatment systems in Kansas: Association of State and Territorial Solid Waste Management Officials, MTBE and Fuel Oxygenates Workgroup Newsletter, v. 3, no. 1, 31 p.

Hitzig, Robert, Kostecki, Paul, and Leonard, Denise, 1998, Study reports LUST programs are feeling effects of MTBE releases: Soil and Groundwater Cleanup, August/September, p. 15-19.

Illinois Environmental Protection Agency, 2000, MTBE—Good news/bad news additive, good news for air quality is not-so-good news for groundwater, Spring 2000: accessed on April 10, 2001, at URL http://www.epa.state.il.us/environmental-progress/v25/nl/ mtbe.html

Iowa Department of Natural Resources, 2000, Methyl tertiary-butyl ether (MTBE) occurrence in Iowa, a report for the 2000 session of the 78th general assembly: Des Moines, Iowa Department of Natural Resources, Underground Storage Tank Section, 32 p.

Ivahnenko, Tamara, Grady, S.J., and Delzer, G.C., 2001, Design of a national assessment of MTBE and other volatile organic compounds in sources of drinking water: U.S. Geological Survey Open-File Report 01-271, 36 p.

Johnson, R.L., Pankow, J.F., Bender, D.A., Price, C.V., and Zogorski, J.S., 2000, MTBE—To what extent will past releases contaminate community water supply wells: Environmental Science & Technology, v. 34, no. 9, p. 2A-9A.

Kansas Department of Health and Environment, 2000, Testimony presented to Senate Committee on Energy and Natural Resources: Topeka, Kansas, Division of Environment, 7 p.

Keller, A.K., Froines, John, Koshland, Catherine, Reuter, John, Suffent, Irwin, and Last, Jerold, 1998, Health and environmental assessment of MTBE—Summary and recommendations, v. 1: Santa Barbara, Calif., University of California, 64 p.

Maine Bureau of Health, 1998, The presence of MTBE and other gasoline compounds in Maine's drinking water, preliminary report: State of Maine, Department of Human Services, 15 p.

Maryland Department of the Environment, 2001, MTBE update: accessed June 8, 2001, at URL http://www.mde.state.md.us/was/mtbe.htm

Michigan Department of Environmental Quality, Storage Tank Division, 2000, MTBE (methyl tertiary butyl ether) fact sheet: accessed June 12, 2001, at URL http://www.deq.state.mi.us/std/MTBE.pdf

Missouri Department of Natural Resources, 2000, Report on inter-agency meetings on MTBE: accessed October 2, 2001, at URL http://www.pstif.org/apps/mtbe_report.pdf

Moran, M.J., Lapham, W.W., Rowe, B.L., and Zogorski, J.S., 2002, Occurrence and status of volatile organic compounds in ground water from rural, untreated, self-supplied domestic wells in the United States, 1986-99: U.S. Geological Survey Water-Resources Investigations Report 02-4085, 51 p.

New Jersey Department of Environmental Protection, 1999, MTBE in New Jersey's Environment: accessed October 2, 2001, at URL http://www.state.nj.us/dep/dsr/mtbe/mtbe-conclusion.htm

State of Connecticut Department of Public Health, 2000, Report per section 25-39a of the Connecticut general statutes monitoring, health risks, and treatment costs for organic chemicals in public drinking water for the Year 1999: Hartford, State of Connecticut, 25 p.

U.S. Environmental Protection Agency, 1999, Winter oxygenated fuels program: Office of Mobile Sources, accessed June 16, 1999, at URL http://www.epa.gov/oms/fuels.htm

———2000, List of reformulated gasoline program areas: Office of Transportation and Air Quality, accessed Jan. 5, 2001, at URL http://www.epa.gov/omswww/rfgarea.htm

Wigglesworth, Terry, 1999, MTBE—A watertight case: Chemistry and Industry, no. 10, p. 408.

Wisconsin Department of Natural Resources Bureau for Remediation and Redevelopment, 2000, MTBE in Wisconsin groundwater: RE News, v. 10, no. 2, p. 1-3.

Zogorski, J.S., Murduchowitz, A.M., Baehr, A.L., Bauman, B.J., Conrad, D.L., Drew, R.T., Korte, N.E., Lapham, W.W., Pankow, J.F., and Washington, E.R., 1997, Fuel oxygenates and water quality—Current understanding of sources, occurrence in natural waters, environmental behavior, fate, and significance—Final report: Washington, D.C., Office of Science and Technology Policy, The Executive Office of the President, p 2-1 to 2-80.