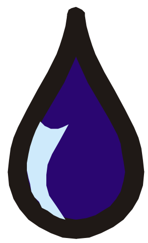
The Presence of MTBE and Other Gasoline Compounds in Maine's Drinking Water



A Preliminary Report

October 13, 1998

Bureau of Health
Department of Human Services

Bureau of Waste Management & Remediation
Department of Environmental Protection

Maine Geological Survey
Department of Conservation

Presence of MTBE and other Gasoline Compounds in Maine's Drinking Water Supplies – A Preliminary Report

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SUMMARY

This report presents the preliminary findings from a study of the statewide occurrence of MTBE and other gasoline constituents in Maine's drinking water. Water samples were obtained from 951 randomly selected household wells and other household water supplies (e.g., springs and lakes) and 793 of the 830 regulated nontransient public water supplies. Water samples were analyzed for the occurrence and concentration of the following five gasoline constituents: MTBE, benzene, toluene, ethyl benzene, and xylenes.

Results for Household Wells and Other Private Household Water Supplies

- ✓ MTBE was detected in 150, or 15.8%, of the 951 sampled private wells.
- ✓ 1.1% of the sampled waters showed levels of MTBE above the Maine drinking water standard of 35 ppb. Extrapolated statewide, this represents an estimated 1400 - 5200 private wells in Maine with these levels.
- ✓ 92.3% of the sampled waters showed either MTBE levels that were not detectable or below 1ppb; and 6.6% were between 1ppb and 35ppb.
- ✓ Compared to MTBE, other gasoline compounds were infrequently detected, and levels of BTEX compounds detected were well below health-based standards.
- ✓ Assessed factors which were found *not* to be associated with MTBE detection included: a) recollection on a questionnaire of a noticeable water odor or taste, b) recollection on a questionnaire of a recent nearby gasoline spill, c) type of well or water supply, and d) proximity to gasoline storage tanks (such as a gas station).
- ✓ Location of the water supply in areas with required RFG use as well as with high population density were both associated with detectable MTBE levels. Since RFG use is often required in places of high population density, these two factors are difficult to tease apart from each other. However, further data analysis shows that both seem to be separate risk factors.
- ✓ The risk of required RFG use:
  - In areas of high population density (greater than 180 people per square mile), the risk of MTBE detection was 1.3 times higher in areas where RFG use is required compared to other areas;
  - In areas of low population density (less than 180 people per square mile), the risk of MTBE detection was 2.0 times higher in areas where RFG use is required compared to other areas.
- ✓ The risk of high population density:
  - In areas where RFG use is required, the risk of MTBE detection was 1.4 times higher in areas of high population density compared to other areas;
  - In areas where RFG use is not required, the risk of MTBE detection was 2.1 times higher in areas of high population density compared to other areas.

Results for Public Water Supplies

- ✓ MTBE was detected in 125, or 16% of the 793 tested public water supplies.
- ✓ No samples were found to have MTBE levels above 35ppb.
- ✓ 93.9% of the samples showed levels that were either not detectable or below 1ppb; and 6.1% were between 1ppb and 35ppb.
- ✓ Toluene was found in 13.1% of public water supplies - higher than seen in private water samples. However, concentrations of toluene were quite low, mostly less than 1ppb and well below the drinking water standard of 1000ppb. With this exception of toluene, very few public water supplies detected BTEX compounds compared with MTBE.
- ✓ Assessed factors that were found *not* to be associated with MTBE detection included: type of well or water supply and proximity to gasoline storage tanks.
- ✓ Type of water use establishment was found to be associated with MTBE detection. Public water supplies that were businesses or mobile home parks were 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 as well as with high population density were both associated with detectable levels of MTBE. Population density itself was a significant risk factor within areas where RFG use was required. However, unlike the private water data, population density was not a significant risk factor in areas where RFG is not required.
- ✓ The risk of required RFG use:
  - In areas of high population density, the risk of MTBE detection was 4.1 times higher in areas where RFG use is required compared to other areas;
  - In areas of low population density, the risk of MTBE detection was 1.7 times higher in areas where RFG use is required compared to other areas.
- ✓ The risk of population density:
  - In areas where RFG use is required, the risk of MTBE detection was 1.6 times higher in areas of high population density compared to other areas;
  - In areas where RFG use is not required, population density appeared to not be a risk factor.

INTRODUCTION

Methyl tertiary-butyl ether (MTBE) is a gasoline additive that has been used as an octane enhancer since 1979. Conventional gasoline has MTBE in amounts of a few percent by volume or less, while some premium blends can contain as much as 9 percent MTBE. MTBE has also been used to meet the oxygenate requirement under the federal reformulated gasoline program that is directed at reducing air pollution. Reformulated gasoline contains 11 percent MTBE. Maine, following the lead of other northeast states, opted into the reformulated gasoline (RFG) program in 1991. As a result, the sale of RFG as the primary automotive fuel is required in seven southern Maine counties.

MTBE is very water soluble, and very persistent in ground water. In recent years, there has been increasing concern over the potential threat to ground water quality posed by widespread use of gasoline containing higher levels of MTBE (e.g., Andrews, 1998). This concern has been propelled by: (1) studies demonstrating MTBE has carcinogenic activity; (2) studies demonstrating MTBE has very low odor and taste detection thresholds; (3) and studies indicating the potential for frequent though low-level detection of MTBE in ground water.

By the mid 1990s, several animal studies were completed demonstrating that MTBE possesses carcinogenic potential by both inhalation and oral routes of exposure (Chun et al., 1992; Burleigh-Flayer, 1992; Belpoggi et al., 1998). The United States Environmental Protection Agency (USEPA) has tentatively designated MTBE as a possible human carcinogen. USEPA has yet to establish a federal standard for permissible levels in public water supplies under the Safe Drinking Water Act. Maine recently established an enforceable health-based drinking water standard of 35 ppb, currently the lowest among the three states that have thus far promulgated such standards. California has proposed a public health goal of 14 ppb for public water supplies.

Several studies of the ability of people to detect low levels of MTBE in water in laboratory settings have now been completed (ARCO, 1993; API, 1993, Young et al., 1996; Dale et al., 1997). These studies have collectively demonstrated that MTBE has very low odor and taste detection thresholds, with some individuals able to detect its presence at concentrations below 15 ppb in controlled studies. In December 1997, USEPA issued a drinking water advisory recommending MTBE levels be kept at 20 – 40 ppb or below to protect consumer acceptance of the water resource. California Department of Health has proposed an enforceable secondary drinking water standard of 5 ppb for protection of odor or taste detection.

Maine Department of Environmental Protection (DEP) has been confronting MTBE as a ground water contaminant associated with gasoline spills since 1984. Most of this experience was related to spills associated with leaking under ground and above ground gasoline storage tanks. At these releases MTBE was the gasoline constituent that reached the drinking water supply first, usually to be followed by benzene, toluene, ethylbenzene, xylenes and other gasoline constituents. Sometimes, at wells distant from the leak, small concentrations of MTBE would appear in the absence of any other gasoline constituent. Monitoring for MTBE in Maine public water supplies since 1997 by the Maine Bureau of Health (BOH), further supported the view that MTBE levels of concern (Maine DEP's 25 ppb action level for remediation) were usually the result of a leaking under ground or above ground gasoline tank; based on a detection limit of 1 ppb, MTBE was detected in 5 to 7% of Maine public water systems, with most levels less than 5 ppb. The one result in excess of 35 ppb was found to be associated with a leaking fuel tank.

In the early spring of 1998, several incidents clearly demonstrated that apparently small spills of gasoline unrelated to underground or above ground fuel storage tank leaks could significantly impact a water source. Gasoline leaked from an overturned car was the likely source responsible for the contamination of 24 domestic wells within 2,200 feet; 10 wells attained MTBE levels exceeding 100 ppb. A small gasoline spill at Whitefield elementary school requiring removal of 8 yards of contaminated soil resulted in peak MTBE water concentrations levels of 800 ppb, necessitating the discontinuance of the well for drinking water purposes. Furthermore, contamination of nearby wells from surface spills and tank overfills associated with modern, double-walled tanks at a convenience store located in Windham, underscored the vulnerability of ground water resources from spills at a facility constructed in compliance with current environmental controls. Most notable with all three of these spills, was the presence of only MTBE in contaminated water.

In response to these events, Maine Governor Angus King directed state health and environmental agencies to undertake a study of the occurrence and concentrations of MTBE in Maine's drinking water supplies by sampling 1000 private residential water supplies and all public water supplies. The interagency study was coordinated by Bureau of Health within the

Department of Human Services, and had strong involvement of hydrogeologists from the Department of Environmental Protection and Maine Geological Survey within the Department of Conservation.

Purpose and Scope

This report presents the preliminary findings from a study of the statewide occurrence of MTBE and other gasoline constituents in Maine drinking water supplies. Water samples were obtained from 951 randomly selected residential water supplies and nearly all of the 830 regulated nontransient public water supplies. Water samples were analyzed for the occurrence and concentration of the following five gasoline constituents: MTBE, benzene, toluene, ethyl benzene, and xylenes (the latter four compounds are commonly referred to as BTEX compounds).

To investigate possible predisposing risk factors for gasoline contamination of drinking water, a variety of additional information on water sources was obtained by either questionnaire, visual inspection by field staff, or use of existing databases. Risk factors evaluated included: (1) distance from known under ground and above ground gasoline storage tanks; (2) type of water source (e.g., drilled bedrock well, drilled sand and gravel well, dug well, well point, spring, lake); (3) perception of an odor or taste associated with water consumption; (4) recollection of any gasoline spills on or nearby the property of a water supply; (5) location of a water supply in an area with required RFG use; and (6) location of a water supply in an area of high population density.

Description of Study Population

Private Residential Water Supplies: The 951 residential water supplies sampled in this study were recruited based on a random sample of households with a published Maine telephone listing. A simple random sample design was selected for two reasons: 1) to allow statistical inferences to be made statewide from the study population and 2) to maximize the ability to detect potentially rare small and localized spills. Table 1 describes the distribution of private water sources by county, type of water supply source, and surrounding population density. Map 1 illustrates the geographical distribution of sampled water supplies.

Public Water Supplies: There are approximately 830 regulated nontransient public water supplies. MTBE and BTEX data were obtained for 793 (96%) of these sources. These regulated sources, referred to as "community and noncommunity/nontransient" water supplies, include: community water supplies, schools, mobile home parks, apartment buildings, businesses having their own water source and more than 25 employees, nursing homes and hospitals. An important distinction between public water sources and private residential sources is that with the former, two or more water sources may belong to a common system (e.g. water district). Sources located within a system may be more alike in characteristics relevant to gasoline contamination (e.g., common water source, wellhead protection). Hence, sources belonging to a common system may not necessarily be truly independent observations. Table 2 describes the distribution of sampled public water sources by type of water use establishment, type of water source, and surrounding population density.

Table 1. Distribution of sampled residential water supplies by county, water source type, and population density.

County	**Number**	**Percent**
Androscoggin	44	4.7%
Aroostook	77	8.1%
Cumberland	133	14.1%
Franklin	36	3.8%
Hancock	60	6.3%
Kennebec	89	9.4%
Knox	37	3.9%
Lincoln	53	5.6%
Oxford	51	5.4%
Penobscot	75	7.9%
Piscataquis	22	2.3%
Sagadahoc	32	3.4%
Somerset	42	4.4%
Waldo	33	3.5%
Washington	31	3.3%
York	131	13.9%
Water Source	**Number**	**Percent**
Drilled Bedrock Well	704	74.1%
Drilled Sand & Gravel Well	37	3.9%
Dug Well	143	15.0%
Well Point	35	3.7%
Spring	23	2.4%
Other	9	0.9%
Population Density	**Number**	**Percent**
< 40 people/square mile	208	28.5%
40 - < 80 people/square mile	160	21.9%
80 - < 180 people/square mile	178	24.4%
> 180 people/square mile	184	25.2%

Table 2. Distribution of sampled public water sources by water use, water source type and population density.

Water Use	Number	Percent
Community water systems	217	27.4%
Schools	268	33.5%
Mobile Home Parks	153	19.3%
Businesses	70	8.3%
Apartments	42	5.3%
Other	45	5.6%
Water Source	**Number**	**Percent**
Drilled Bedrock Well	569	71.8%
Drilled Sand & Gravel Well	100	12.6%
Dug Well	17	2.1%
Spring	10	1.3%
Lake or Pond	57	7.2%
Mixed or Other	40	4.5%
Population Density	**Number**	**Percent**
< 40 people/square mile	217	33.5%
40 - < 80 people/square mile	120	18.6%
80 - < 180 people/square mile	122	18.9%
> 180 people/square mile	188	29.0%

STUDY METHODS

Recruitment of Private Residential Water Supplies

Homeowners or tenants with private residential water supplies were recruited into the study by telephone solicitation. Telephone numbers were obtained from Survey Sampling, Inc., who generated a random sample drawn from all Maine telephone numbers having a full line listing, excluding those exchanges totally included within census blocks identified as not having private water supplies based on the 1990 Census TIGER database files for Maine. Individuals were recruited as volunteers after confirming presence of a private water supply. Of the 1,872 individuals successfully contacted by telephone and who indicated they owned a private water supply, 57% agreed to participate in the study. The low acceptance rate for study participation is unlikely to affect the representativeness of the sampled household wells and other household water supplies, provided household members were unlikely to know if gasoline compounds were present in their water. Lack of knowledge of MTBE in household water seems likely, based on the absence of an association between either perception of a water odor or taste or knowledge of a recent gas spill and MTBE detection frequency (to be discussed below).

A total of 1067 volunteers were initially recruited into the study. 951 households had their water successfully sampled; 946 households had both water sampled and water supply location mapped. Of the 116 wells that were not sampled, 34 were subsequently found to be ineligible for participation in the study (e.g., on public water, could not obtain a water sample according to the study protocol). The remaining 82 were individuals dropped out of the study for a variety of reasons (e.g., inability to schedule sampling of water, loss of interest in the study, objections to surveying well location).

Water Sampling

Samples obtained from private residential water supplies were of raw “untreated” water. Water samples were collected from either a sink faucet (when water treatment systems were absent) or from a tap located at the pressure tank (when sampling to avoid a treatment system). Prior to collecting a sample, water systems were purged by running the tap or faucet at near full flow for 20 minutes. In addition, water temperature was monitored to assure that water was being drawn directly from the well. The flow rate was then adjusted to give a laminar stream of no more than 400 ml per minute (0.1 gallons/minute). When it was not possible to obtain such a laminar flow, a brass flow reducer with attached Teflon tubing was connected to the tap. Water samples were collected in 40-mL clear glass VOA vials containing 0.1 mL of pre-added 6 N hydrochloric acid (HCl), as an acid preservative to prevent microbial decomposition of gasoline constituents. The sample vial was held at an angle while filling to minimize aeration of water that can result in loss of the more volatile organic compounds. The vial was allowed to slightly overfill creating an inverted meniscus at the top of the vial, then capped, inverted, and tapped to check for air bubbles. The sample vials were immediately placed in coolers and chilled with ice until delivery to the laboratory for chemical analysis.

Samples obtained from public water systems were collected as described above with the following exceptions. Purging of the water systems was decreased when it was determined that large quantities of water had recently been pumped. In such cases, purging was only needed to flush water from plumbing that was part of the main water line. Water samples were collected regardless of whether it was possible to obtain a raw water sample. Water samples were obtained as close to raw water as possible. The presence of any treatment systems prior to the sample collection point was recorded.

As part of the quality assurance plan, field personnel were instructed to avoid self-refueling of cars on sampling days, and if unavoidable, thoroughly wash hands prior to handling any sampling equipment. A new pair of latex gloves was worn with the collection of each sample. A back-up sample was always collected to protect against accidental sample loss.

Chemical Analysis of Water Samples

All water samples were analyzed at the State Health and Environmental Testing Laboratory (HETL). Analyses were performed using purge and trap capillary gas chromatography/mass spectrometry. (GC/MS), following modified USEPA method 524.2 with the target list of compounds: MTBE, benzene, toluene, ethylbenzene and total xylenes. Rather than using cryogenic cooling on columns less than 0.32 mm bore, 0.25 mm split columns without cryogenic cooling were used in sample analyses. This modification has been shown to result in flow rates of 1 ml per minute, well within the range acceptable for flow rates as described in method 524.2.

The detection limit for all analytes except total xylenes was 0.1 μg/L; for total xylenes the detection limit was 0.3 μg/L. These detection limits reflect a 10-fold drop in past detection limits used by HETL in routine analysis of volatile organic compounds (VOCs) in water samples. The lower detection limit was used to obtain data that could be compared with detection limits reported in recent studies by the U.S. Geological Survey (USGS).

All samples were stored at 4°C until the time of analysis. In accordance with the quality assurance plan developed for the study, the maximum holding time of acid preserved samples was 14 days. Only two samples were held beyond the 14-day period (16 & 19 days). The average holding time was six-days for private residential water supplies and four-days for public water supplies. Samples were rejected if received with an air bubble greater than 6 mm in diameter.

Quality Control Samples

To assess the reliability (accuracy and precision) of measured concentrations of analytes within this study, several different types of quality control samples were obtained and analyzed. To assess accuracy, calibration checks at 0.1, 0.5 and 5 ppb MTBE were performed with each set of samples (30-samples per set) on each of the two GC/MS instruments used for analysis. Mean MTBE percent recoveries were 130 and 180% (at 0.1 ppb), 120 and 130% (at 0.5 ppb), and 93 and 101% (at 5 ppb) for the two instruments, respectively. Relative standard deviations associated with the mean MTBE percent recoveries were 23 and 39% (at 0.1 ppb), 27 and 29% (at 0.5 ppb), and 20 and 21% (at 5 ppb) for the two instruments, respectively. Low concentration data were only used to indicate detection of MTBE or frequency of detection within the 0.1 to 1 ppb range. Therefore, the high observed positive bias associated with 0.1 ppb MTBE for one of the two GC/MS instruments used in this study is unlikely to compromise the results to be discussed below.

To assess possible false positives from sample contamination during transport, trip blank samples were collected for every set of field samples delivered to HETL. Trip blanks are sample vials filled in the laboratory with water previously determined to have undetectable concentrations of the analytes of interest, capped, and transported into the field (always kept capped) along with sample collection vials. Trip blanks provide a check on sample contamination resulting from any diffusion of volatile compounds across the silicon septum sealing the vial either in the field or laboratory, and also provide a check on any carry-over contamination during GC/MS analyses. Of the 85 trip blank samples collected while sampling the private residential water supplies, one trip blank sample had detectable MTBE concentrations (0.3 ppb). Of the 111 trip blank samples collected while sampling the public water supplies, 4 had detectable levels (0.1 – 0.2 ppb).

To assess precision (reproducibility) in analytical results, approximately 41 sets of duplicate samples were obtained. There were two types of duplicate samples; one in which the field person was blinded that a duplicate was obtained (via analysis of back-up samples), and one in which the lab chemist was blinded the sample was a duplicate (collection of two sample sets at a single location). Because of the expected low detection frequency for MTBE, duplicate samples were only obtained for sampling sites where prior knowledge indicated the likely presence of MTBE. The average percent difference among laboratory blinded duplicates was 12%. The average percent difference among field person blinded duplicates was 20%.

Mapping Location of Water Sources

Location of both private residential and public water supplies was obtained by Global Positioning System (GPS) technology operated to achieve 3-5 meter accuracy by trained personnel. As a quality control check on the private residential water supply location coordinates obtained by the GPS receivers, water sampling field staff were required to provide a copy of a USGS 1:24,000 topographic map with their best estimate of the water supply location. GPS data were imported into Environmental Systems Research

Institute (ERSI), Inc. ARC/INFO geographic information system software to generate a 1:24,000 scale check plot of the GPS location that included roads, rivers, streams, and town lines. These plots were visually compared to the topographic map locations provided by the field samplers. If the estimated mapped location was more that 0.5 miles from the GPS location, field staff were required to resolve the discrepancy. As an additional quality control check, 32 locations with varying degrees of discrepancy between GPS located coordinates and estimated mapped location, were rechecked. In all instances, the GPS located coordinates were found to be accurate. Consequently, a very high degree of confidence is placed in the location of the private water supplies included in the survey.

Estimating Population Density for a Water Supply.

After the locations of the private and public water supplies were checked, the point locations were combined with a coverage of census blocks derived from the U.S. Census Bureau 1990 TIGER database files for Maine. This census block coverage included a calculated population density in people/square mile. ESRI's ARC/INFO geographic information software was used to attach the population density associated with the census block to points that fall within the census block. The water supply identification number and population density were then exported for use in subsequent statistical analysis.

Estimating Distance of a Water Supply from Under Ground and Above Ground Gasoline Tanks

The distance from a sampled public or private water supply and known gasoline storage facility was calculated using the coordinates obtained from the ARC/INFO water supply point coverage and a point coverage of gasoline storage facilities obtained from the Maine DEP. Using a water supply location as a starting point, the gasoline storage facility point coverage was searched to find the closest active storage facility. The straight-line distance was then calculated from the known coordinates.

This is the closest distance from the water supply to the gasoline storage facility. Without some knowledge of ground-water flow directions, however, it is not possible to say whether it is even realistic that MTBE or other petroleum products from a spill at this closest storage facility could travel to the water supply.

Statistical Analyses

Because most data reflect observations below analytical limits of detection (and hence can only be reported as less than the detection limit), analysis of data with statistical methods for continuous variables was not performed. Rather, only categorical methods were used to perform statistical analyses with groups of data. Contingency-table tests were used to compare the frequency of detection of MTBE among a variety of groupings of the data. Whenever significant differences were found in multi-way contingency table, separate 2 by 2 tables were computed for all possible pairwise comparisons. Exact probability determinations were made any time a contingency table cell included less than 10 observations.

If we sampled every water supply in Maine, we would be able to compute exact frequencies of MTBE detection. A sample, such as the 946 household wells and other household water supplies, provides an estimate of the true statewide frequencies of MTBE detection. The larger the size of the sample, the higher the degree in confidence that the sample estimate is close to the true statewide number. Throughout the results and discussion, we use the 95 percent confidence (95%CI) to describe the uncertainty surrounding our sample estimate of the true statewide value.

All statistical analyses were performed using Stata Ver. 4.0. A statistical test was judged significant for $p < 0.05$, and marginally significant for $p < 0.1$.

RESULTS

Results for Private Residential Water Supplies

Occurrence and Concentrations of MTBE and BTEX Compounds: MTBE was the most frequently detected gasoline constituent found in private residential water supplies (see Figure 1). At a detection limit of 0.1 ppb, MTBE was detected in 15.8% (N=150) of the 946 tested private water supplies. The 95 percent confidence interval (95%CI) around this estimate of the statewide frequency of detection was 13.5 – 18.2%. Toluene was the next most frequently detected gasoline compound, occurring in 2.1% of water samples. Benzene, ethylbenzene and xylenes were all detected in less than 1% of samples.

Figure 2 illustrates the frequency distribution for MTBE concentrations observed in sampled private residential water supplies. 92.3% of the observations were less than 1 ppb. MTBE was the only compound detected at concentrations exceeding a health-based standard or guideline; 1.1% (95%CI = 0.5 – 1.9%) of water samples exceeded Maine's 35 ppb maximum contaminant level (MCL) for MTBE.

Map 2 shows where detectable concentrations of MTBE were found in the state. MTBE was detected in household water supplies located in every county, though differences in frequency of detection by county were readily apparent from visual inspection.

Risk Factors for MTBE Contamination: The term "risk factor" is being used here to refer to any attribute common to a group of water supplies and that can be shown to be associated with higher frequencies of MTBE detection than groups of water supplies not having the attribute. The following potential risk factors were evaluated: (1) perception of odor or taste with water or knowledge of a recent gasoline spill on or nearby the household water supply; (2) type of water supply; (3) proximity of a water supply to a known gasoline storage tank; (4) location of a water supply in a county with required RFG use; and (5) population density.

1. Perception of a water odor or taste / Knowledge of a nearby gasoline spill

Because of the low odor and taste detection thresholds for MTBE, household members were asked whether they believed that their water had a noticeable taste or odor. Of primary interest was the reliability of odor and taste as a marker for low level MTBE contamination. Individuals were also asked if they were aware of a gasoline spill (small or large) on their property or nearby. Results are presented in Table 3.

Table 3. Frequency of MTBE detection in private water supplies by taste and odor perception and by knowledge of a nearby gasoline spill.

Risk Factor	Percent MTBE Detects	95 Percent Confidence Interval
Water odor or taste		
Yes (181)	14.4%	10-20%
No (765)	16.1%	14-19%
Recent nearby gasoline spill		
Yes (57)	15.8%	7-28%
No (889)	15.7%	13-18%

No significant difference was found in frequencies of MTBE detection among individuals answering yes versus no regarding presence of a water odor or taste ($p < 0.1$). Only 2 of the 10 households discovered to have water with > 35 ppb MTBE reported a noticeable odor or taste with their water. No difference in the frequency of odor/taste perception was found when the data were grouped by above and below 5, 10, 25 or 35 ppb MTBE (results not shown).

No difference in MTBE detection frequencies was observed for knowledge of a recent nearby gasoline spill ($p < 0.1$).

2. Type of Water Supply Source

Different water supply sources may reflect different hydrogeological conditions, and possibly different vulnerability to contamination from a small gasoline spill. Consequently, frequency of MTBE detection was evaluated by type of water supply source (Table 4). No type of water supply source was found to have significantly higher frequency of MTBE detection compared to others.

To test for a possible effect of well depth and construction, the surficial well types (sand & gravel wells, dug wells and well points) were grouped into a single category and compared to the generally deeper bedrock wells. Frequency of MTBE detection among bedrock wells (15%; 95%CI=13-19%) was not significantly different from surficial wells (14%; 95%CI = 9-19%).

Table 4. Frequency of MTBE detection in private water supplies by water supply source.

Type of Water Supply Source (number of sources)	Percent MTBE Detects	95 Percent Confidence Interval
Drilled Bedrock Well (668)	15.9%	13-19%
Drilled Sand & Gravel Well (36)	11.1%	3-26%
Dug Well (139)	13.7%	8-21%
Well Point (34)	17.7%	7-35%
Spring (22)	22.7%	8-45%
Other (9)	11.1%	<1-48%

Pearson tests for independence, Chi2(5) = 2.11 Pr = 0.88
Type of water source could not be determined on 21 water supplies.

3. Proximity to Gasoline Tanks

Given the potential for frequent small spills of gasoline while refueling and for any above ground or under ground gasoline tank to be a potential release point, proximity to a gas tank is a logical risk factor to evaluate. Comparisons were made among MTBE detection frequencies based on a water supply being located within a ¼ mile or ½ mile of a gas tank. Results are presented in Table 5. Though higher rates of MTBE detection were observed among wells located within either a ¼ mile or a ½ mile of a known gas tank relative to wells that were not, there were too few wells to show the difference as statistically significant. It is also noteworthy that only 2 of the 67 water supplies with MTBE levels > 1 ppb were located within ¼ mile of a gas station.

Table 5. Comparison of percent MTBE detection in private water supplies by distance from known under ground and above ground gasoline tanks.

Distance from Gas Tank Grouping (number of wells)	**Percent MTBE Detects**	**95 Percent Confidence Interval**
Located within ¼ mile		
Yes (36)	19.4%	8-36%
No (910)	15.6%	15-20%
Located within ½ mile		
Yes (88)	21.6%	14-32%
No (858)	15.2%	13–18%

Differences were not statistically significant at either p=0.05 or 0.1 levels.

4. Location in a County with Required RFG Use

RFG use is required in seven Maine Counties. As RFG contains considerably more MTBE than conventional gasoline by volume, it is logical to hypothesize that the frequency of detection of MTBE in water supplies located in counties where RFG use is required will be higher than in counties where RFG use is not required. Results of a comparison of MTBE detection frequencies among counties that differ in required RFG use are presented in Table 6. Detection frequencies were significantly different.

The ratio for frequency of MTBE detection for counties with and without required RFG use (referred to as the "risk ratio") was 1.84 (95%CI = 1.3-2.5). That is, the risk of having detectable levels of MTBE in a private residential water supply is nearly 2-times higher when the water supply is located in a county required to use RFG.

Table 6. Comparison of percent MTBE detection in private water supplies by presence in a county with required RFG use.

Required RFG Use Status (number of water supplies)	**Percent MTBE Detects**	**95 Percent Confidence Interval**
RFG Use Required		
Yes (427)	19.8%	17-24%
No (519)	10.7%	8-14%

Pearson tests for independence, Chi2(1) = 14.53 Pr = 0.0001

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5. Population Density

In principle, a water supply can become contaminated either by actions occurring on the property where the water source is located, or by actions of others located nearby. The more "others" there are the greater the opportunity for a water supply to become impacted by actions of others. As a test of this hypothesis, frequency of MTBE detection was compared across the four population density strata presented in Table 1. Results, presented in Table 7, indicate a higher frequency of MTBE detection in private residential water supplies at the higher population densities. On closer examination of the data, it was felt that a simple dichotomous split at 180 people per square mile was most appropriate. The risk ratio for frequency of detection of MTBE for a population density greater than 180 versus less than 180 people per square mile was 1.7 (95%CI = 1.3-2.3).

Table 7. Comparison of percent MTBE detection for different population densities.

Population Density (people per square mile)	**Percent MTBE Detects**	**95 Percent Confidence Interval**
< 40	13.6%	10-18%
40 - < 80	10.1%	6-15%
80 - < 180	15.7%	11-21%
> 180	22.7%	18-28%

Pearson tests for independence, Chi2(3) = 14.66 Pr = 0.002

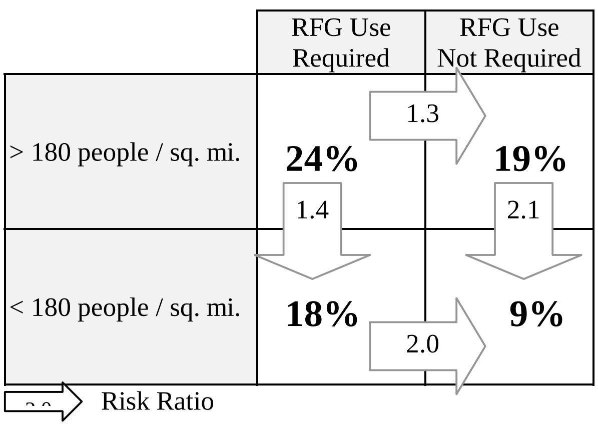
Population Density (people per square mile)	**Percent MTBE Detects**	**95 Percent Confidence .Interval**
< 180	13.3%	11-16%
> 180	22.7%	18-28%

Pearson tests for independence, Chi2(1) = 12.07 Pr = 0.0005

Stratified Analysis of RFG Use and Population Density**:** We have observed close to a 2-fold increased MTBE detection frequency at levels > 0.1 ppb by either living in a county with required RFG use or living in an area with population density > 180 people per square mile. It is also true, however, that counties with required RFG use tend to have higher population densities. Of the water supplies located in census blocks with >180 people per square mile, 70% are also located in a county required to use RFG. For census blocks with < 180 people per square mile, 50% are also in an RFG area. Because of the relationship between RFG use and population density, it is necessary to reexamine the relationship between frequency of MTBE detection in water supplies and RFG use after controlling for population density.

The results when stratifying by population density and RFG use are shown in Table 8. After controlling for one anther, both required RFG use and population density remain significant risk factors associated with higher frequencies of MTBE detection in domestic water supplies (i.e., both had statistically significant risk ratios after stratifying for the other). The highest frequency of MTBE detection was in the contingency table cell corresponding to both required RFG use and population density > 180 people per square mile. The lowest frequency of detection was observed in the cell corresponding to absence of required RFG use and population density < 180 people per square mile. Similar frequencies of MTBE detection were apparent in areas that have either higher population density absent required RFG use, or lower population density with required RFG use. There was some evidence that population density acts as an "effect modifier" on the relationship between RFG use and frequency of MTBE detection – that is, the relationship between required RFG use and detection of MTBE may be dependent on population density.

Table 8. Relationship between required RFG use and frequency of MTBE detection in private water supplies: Stratified by population density. Values in the cells of the 2 x 2 table are the observed frequency of MTBE detection



Confidence Intervals for Risk Ratios

Risk Factor (Stratified by)	Risk Ratio	95 Percent Confidence Interval
RFG Use (>180 people/sq.mi.)	1.3	0.7-2.2
RFG Use (<180 people/sq.mi.)	2.0**	1.3-2.9
Pop. density (RFG Required)	1.4*	1.0-1.9
Pop. density (RFG Not Required)	2.1**	1.2-3.8

* $p \leq 0.1$ ** $p \leq 0.05$

<u>Results for Public Water Supplies</u>

Occurrence and Concentrations of MTBE and BTEX Compounds: MTBE was the most frequently detected gasoline constituent found in public water supplies (see Figure 3). At a detection limit of 0.1 ppb, MTBE was present in 16.0% (95%CI = 13-19%) of the 793 tested public water supplies. Toluene was the next most frequently detected gasoline compound, occurring in 13.1% of water samples – considerably higher than that seen for private residential water supplies. Concentrations of toluene were quite low, generally less than 1 ppb and all observations were well below the maximum contaminant level (MCL) of 1000 ppb. Benzene, at a 2.0% (95%CI = 1-3%) occurrence, was also a more common contaminant among public versus private residential water supplies. The two public water supplies associated with benzene levels above the MCL of 5 ppb are currently Maine DEP remediation sites and reflect levels in water pre-filter treatment already in place to remove contaminants. Detection of ethylbenzene and xylenes were more common among public water systems, but detected levels were well below health-based standards and guidelines. MTBE was not detected above 35 ppb in any public water systems. Figure 4 illustrates the frequency distribution for MTBE concentrations observed in public water supplies.

The geographical distribution of public water supplies with detectable levels of MTBE is illustrated in Map 3. MTBE was detected in public water supplies in every county but Franklin. As with the domestic water supply data, differences in frequency of detection were apparent at the county level by visual inspection.

Predisposing Factors for MTBE Contamination: Exploratory analyses of possible risk factors for higher frequency of MTBE detection were also performed on public water supplies. Evaluations of proximity to a known gasoline tank has not yet been completed because of complications arising from the presence of multiple wells within some public systems, which in some cases are sampled as a combined source; hence ambiguity in determining distance to a gas tank. Preliminary analyses with data where such ambiguity does not exist indicate that neither factor was predictive of higher frequencies of MTBE detection. Other potential risk factors that have been evaluated are: (1) type of water source; (2) type of water supply establishment; (3) location in a county with required RFG use; and (4) population density.

1. Type of Water Source

Table 9 presents results from the evaluation of type of water supply source as a potential risk factor for higher rates of MTBE detection. None of the water supply source types were found to have significantly different frequencies of MTBE detection. It is nonetheless noteworthy that springs had the highest frequency of MTBE detection for both private residential wells and public water supplies.

Table 9. Comparison of percent MTBE detection in public water supplies by water supply source.

Type of Water Supply Source (number of wells)	Percent MTBE Detects	95 Percent Confidence Interval
Drilled Bedrock Well (569)	16.2%	13-19%
Drilled Sand / Gravel Well (100)	13.0%	3-26%
Dug Well (17)	17.6%	8-21%
Spring (10)	30.0%	7-35%
Lake or Pond (57)	12.3%	8-45%
Mixed sources (25)	20.0%	7-40%

Pearson tests for independence, Chi2(6) = 3.25 Pr = 0.777

2. Type of Water Supply Establishment

Table 10 presents the frequency of MTBE detection for five types of public water systems. Pairwise statistical comparisons indicated that MTBE detection frequencies for mobile home parks differed significantly from those for schools and community water systems, but not with businesses and apartments. Similarly, businesses significantly differed from schools and community water systems but not from others. The risk ratio for MTBE detection in water supplies for mobile home parks relative to community water systems was 1.8 (95%CI = 1.1-2.8), and relative to schools was 2.4 (95%CI = 1.5-3.8). Similar risk ratios were obtained when public supplies classified as businesses were compared with community and school sources. High detection frequencies were suggested for apartment water sources, though statistical comparisons were not significant at the p<0.1 level.

Table 10. Comparison of percent MTBE detects among different types of public water use.

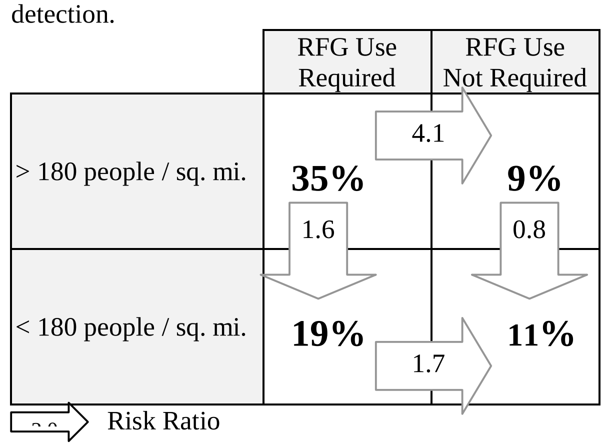
Type of Water Supply Establishment	Percent MTBE Detects	95 Percent Confidence Interval
Community water systems	13.1%	9-18%
Schools	9.8%	7-14%
Mobile Home Parks	23.5%	17-31%
Businesses	34.6%	22-49%
Apartments	19.0%	9-34%

Pearson tests for independence, Chi2(3) = 14.66 Pr = 0.002

3. Required RFG Use and Population Density

The unadjusted (crude) risk ratio for frequency of MTBE detection conditional on required RFG use status was 2.4 (95%CI = 1.7-3.4), indicating more than a 2-fold higher rate of MTBE detection for public water systems located in areas with required RFG use. The unadjusted risk ratio for frequency of MTBE detection conditional on a population density of greater than or less than 180 people per square mile was 1.5 (95%CI = 1.1-2.1). There was also a positive relationship between RFG use and population density; 48% of areas with population density > 180 people per square mile are also RFG required use areas versus 35% the lower population density strata. Thus, as with private residential water supplies, population density was found to be associated with both frequency of MTBE detection and required RFG use. Consequently, evaluation of the risk ratio for required RFG use required adjusting for population density effects. Results from stratifying based on population density are presented in Table 11.

Table 11. Relationship between required RFG use and frequency of MTBE detection in public water supplies: Stratified by population density. Values in the cells of the 2 x 2 table are the observed frequency of MTBE detection.



Risk Factor: (Stratified by)	Risk Ratio	95 Percent Confidence Interval
RFG Use: (>180 people/sq.mi.)	4.1**	2.1-8.2
RFG Use: (<180 people/sq.mi.)	1.7**	1.1-2.7
Pop. density: (RFG Required)	1.6**	1.1-2.5
Pop. density: (RFG Not Required)	0.8	0.4-1.6

* p ≤ 0.1 ** p ≤ 0.05

Results presented in Table 11 indicate that required RFG use is an important risk factor for higher frequencies of MTBE detection among public water supplies. Required use of RFG was a strong risk factor for higher frequency of MTBE detection at both population density strata. The picture is less clear for population density as an independent risk factor, as there was no apparent difference in frequency of MTBE detection across population strata in areas where RFG use is not required. Population density clearly acted to modify the risk ratio for frequency of MTBE detection as a function of required RFG use.

As noted above, schools tend to have lower frequencies of MTBE detection relative to mobile home parks, and schools constitute a disproportionately higher fraction of the total public water supplies within the <180 people per square mile population stratum. Mobile homes constitute a disproportionately higher fraction of the total water supplies within the >180 people per square mile stratum. Consequently, it will be important to explore potential confounding by type of water use establishment in future analyses.

DISCUSSION

Comparison of Results with Those of Other Studies

The USGS has performed four studies in the northeast on the occurrence and concentration of MTBE and other volatile organic compounds in ground water, as part of the ongoing National Water Quality Assessment program. One study sampled wells in southeastern Pennsylvania (USGS, 1996). A second study sampled wells located in the Connecticut, Housatonic and Thames River basins, with wells located in NH, VT, MA, and CT (USGS, 1997a). A third study sampled wells in the Glassboro area of southern NJ (USGS, 1997b). The fourth study sampled wells in the Hudson River basin of New York (USGS, 1998). Combined, the four studies represent a total of 376 wells.

It should be noted that the USGS studies reflect a mixture of well types; 52% are domestic wells, 41% are monitoring wells, and 27% others. There can be important differences between monitoring wells and domestic wells. Monitoring wells are not routinely used, and consequently will not create their own ground water flow field that can act to draw contaminated water from more distant sources toward a well. It is also likely that the annulus seals of USGS monitoring wells are constructed with more care than the typical domestic well.

At the request of the Maine Bureau of Health, scientists in the Water Resources Division at the USGS South Dakota District office reanalyzed data from these studies using a detection limit of 0.2 ppb, which was the lowest detection limit common to all studies. They additionally performed a set of evaluations of the significance of RFG use and population density on frequency of MTBE detection for comparison with identical evaluations performed with data from the Maine study. Results, provided as written communication (Zogorski et al., 1998), are discussed below.

Table 12 compares the frequency distribution for MTBE concentrations observed in the Maine and USGS studies. The frequency distributions are quite similar. While the Maine data are suggestive of higher MTBE detection frequencies for concentrations greater than 5 ppb, the small number of observations in these ranges prevents any firm conclusions (e.g., note considerable overlap in 95 percent confidence intervals).

Comparisons of overall detection rates are more meaningful when first normalized to population density, because of the potential differences in population density across the northeast states. Detection frequency by population density is shown in Table 13. Noteworthy is the higher frequencies of MTBE detection observed in the Maine study for the lower population densities. However, again the small number of observations for low population density strata in the USGS study resulted in very broad confidence intervals. As a consequence, it is difficult to draw any strong conclusions about differences between the studies at the lower population densities.

Table 12. Comparison of frequency distributions for MTBE concentrations for the Maine and USGS studies.

Concentration Range (ppb)	**Maine Privates** N=946 (95%CI)	**Maine Publics** N=793 (95%CI)	**USGS Studies** N=376 (95%CI)
< 0.2 ppb	85.0% ….	85.1% ….	82.2% ….
0.2 – 5 ppb	12.0% (10-14%)	13.6% (11-16%)	16.2% (13-20%)
5 – 35 ppb	1.9% (1.1-2.3%)	1.3% (0.6-2.3%)	1.0% (0.3-2.7%)
> 35 ppb	1.1% (0.5-1.9%)	0.0% (0.0-0.5%)	0.5% (0.06-1.9%)

Table 13. Comparison of frequencies of detection by population density for USGS studies and Maine studies with private residential and public water supplies.

Population Density (people/square mile)	**Maine Privates** (95%CI)	**Maine Publics** (95%CI)	**USGS Studies** (95%CI)
< 40	13.3% (9-18%)	8.3% (5-13%)	3.2% (<1-17%)
40 – 80	9.2% (6-14%)	13.6% (8-21%)	6.5% (1-18%)
80 – 180	14.4% (10-20%)	20.3% (14-28%)	11.1% (6-20%)
180 – 1000	20.9% (16-27%)	24.0% (14-26%)	24.5% (18-32%)
> 1000	28.1% (14-47%)	24.2% (11-42%)	27.6% (17-41%)

USGS (1997a) reported much higher MTBE detection frequencies for wells located within a quarter mile of a gasoline station (70%). We observed only a small difference in MTBE detection frequencies for wells located within a quarter mile radius of a gas tank relative to wells that were not, and detection frequencies were considerably lower (20%). Confounding of the relationship between proximity to a gas tank and MTBE detection frequency by population density may be an explanation for these different findings.

Evaluation of Risk Factors and Misclassification Error

Misclassification error occurs when observations are incorrectly assigned to groupings used in statistical comparisons. For contingency table analyses of the type used in this report, misclassification error tends to bias results toward the null (i.e., not finding a statistical difference when one is present). For several of the risk factors evaluated in this report, misclassification error was likely present, and thus must be considered as a possible explanation of the lack of statistical significance.

The presence of iron and manganese in drinking water can impart an unpleasant taste, and both elements are routinely found in private water supplies. This was not controlled for in our analysis of a relationship between perception of odor and taste with MTBE detection frequency. Thus, it is possible that our inability to find any relationship between MTBE detection frequency and perception of odor and taste was in part a consequence of misclassification error.

Misclassification error may also have occurred in assessing knowledge of a recent gas spill. The ability to recall past events is always subject to error, and again in most circumstances will bias results toward the null.

Admittedly, "Required RFG Use" is a crude measure of RFG use, with an opportunity for misclassification of status. In Maine, required RFG use occurs at the county level. However, it is known that RFG is sold to varying extents over much of Maine. Clearly, use is highest in those southern counties required to use RFG. Current knowledge, though imprecise and somewhat anecdotal, suggests that the western counties of Maine have the lowest use of RFG fuels, while northern and downeast counties have intermediate use. It is noteworthy that tabulation of MTBE detection rates by county, as shown in Map 4, agrees well with the current conventional wisdom regarding RFG use: detection rates tend to be the lowest in the western counties, highest in the southern counties with required RFG use, and intermediate in the northern and downeast counties,

To the extent that RFG use status is subject to some degree of misclassification error, the statistically significant relationship observed between RFG use and MTBE detection frequency may be more pronounced than that reported. While the observed relationship between RFG use and MTBE detection frequency is logically consistent with our expectation, given the higher content of MTBE in RFG, it needs to be noted that a statistical association in and of itself does not prove causation.

Statewide Inferences

Approximate one-half of Maine residents obtain their drinking water from their own private water supply. Therefore, one of the primary purposes for using a random sample study design for selection of private residential wells, was to allow for predictions statewide based on the sample. According to the 1990 Census data tapes for Maine, there were 245,831 households in Maine with drilled or dug wells as their water supply. Another 28,915 households were on other sources of private water supplies (e.g., lake or spring water), for a total of 274,746 households with a private water supply. Estimates of the number of private residential wells in Maine with detectable levels of MTBE (> 0.1 ppb), levels > 20 ppb, and levels > 35 ppb were made assuming 275,000 households with private water supplies and using the 95 percent confidence interval on frequency of detection of MTBE at the several different concentrations. Results are presented in Table 14. Most noteworthy is the estimate of 1400 to 5200 Maine households expected to have MTBE concentrations in drinking water above the state standard of 35 ppb.

Table 14. Statewide predictions of number of private residential water supplies with MTBE contamination.

MTBE Concentration Range (95%CI)*	Significance of Reference Concentration	Estimated Number of Water Supplies Statewide
> 0.1 ppb (13.5-18.2%)	Detection Limit	37,000 to 50,000
> 20 ppb (0.8-2.5%)	USEPA's Advisory Level for Odor and Taste Acceptance	2,200 to 6,900
> 35 ppb (0.5-1.9%)	Maine Drinking Water Standard (MCL)	1,400 to 5,200

*** 95 percent confidence interval for MTBE detection frequency**

It is of interest to compare these statewide estimates with recent estimates of number of domestic wells nationwide that are currently known to be contaminated with MTBE. Based on a survey of Leaking Underground Storage Tank (LUST) programs in 48 states, a study funded by USEPA estimated the total number of private wells with MTBE contamination to range from 2256 to 2663 (Hitzig et al., 1998). Presumably, these private wells with MTBE contamination were wells known to be impacted by a leaking underground storage tank. The study additionally indicated that there could be 300 "mysterious" MTBE sites around the country (i.e., sites that cannot be linked to a known source). We estimate between 2200 and 6900 domestic wells above 20 ppb MTBE in Maine alone.

Public Health Implications

For all concentrations of MTBE observed in this study, the primary health concerns are associated with long-term repeated exposure. The concentrations of MTBE reported in this study reflect a snapshot in time and do not provide any information regarding how levels may change over a period of months or years. This lack of information about how concentrations might vary over time complicates attempts to assess potential public health impact. As a conservative assumption, one can assume that observed concentrations remain constant over a lifetime. Under such a scenario, using a cancer potency factor for MTBE derived from the study of Belpoggi et al. (1995), and following standard cancer risk assessment practices for drinking water, the excess cancer risk from lifetime consumption of the highest concentration of MTBE detected among 946 tested domestic water supplies (i.e., 260 ppb) is conservatively estimated to be 2-in-100,000. For the vast majority (~99%) of water supplies with MTBE levels less than 35 ppb, the estimated lifetime cancer risk would be approximately 10-fold or more lower, or no more than 3-in-1,000,000.

The assumption that the higher levels of MTBE will remain constant over time is likely to be overly pessimistic. The experience of Maine DEP field staff responding to gasoline spills that are not associated with a significant point source such as a leaking fuel tank, has been a tendency to observe initially high concentrations decreasing substantially in the course of a year of follow-up monitoring. Therefore, the above estimates of cancer risk assuming constant exposure may be overly conservative.

Water Resource Issues

MTBE is generally unpleasant in taste and odor, increasingly so as concentrations increase. Individuals vary considerably in their ability to detect low level MTBE in water. Based on controlled taste and odor studies (referred to as organoleptic studies), some individuals can correctly identify water containing less than 5 ppb MTBE, though for many individuals the detection thresholds are likely to be considerably higher. USEPA (1997) recently issued a drinking water advisory that recommends "keeping levels of MTBE contamination in the range of 20 to 40 ppb or below to protect consumer acceptance of the water resource." We estimate that between 1650 and 5600 Maine households currently have water exceeding the 20 ppb advisory limit.

Future Work

This report presents the preliminary findings from analysis of data from the study of gasoline compounds in Maine drinking water. Additional analyses are planned over the next few months to further explore risk factors for MTBE contamination and refine the analysis of interactions between RFG use, population density and MTBE detection frequency. A full technical report is planned for January 1999.

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Map 1: Private water supplies sampled for MTBE study

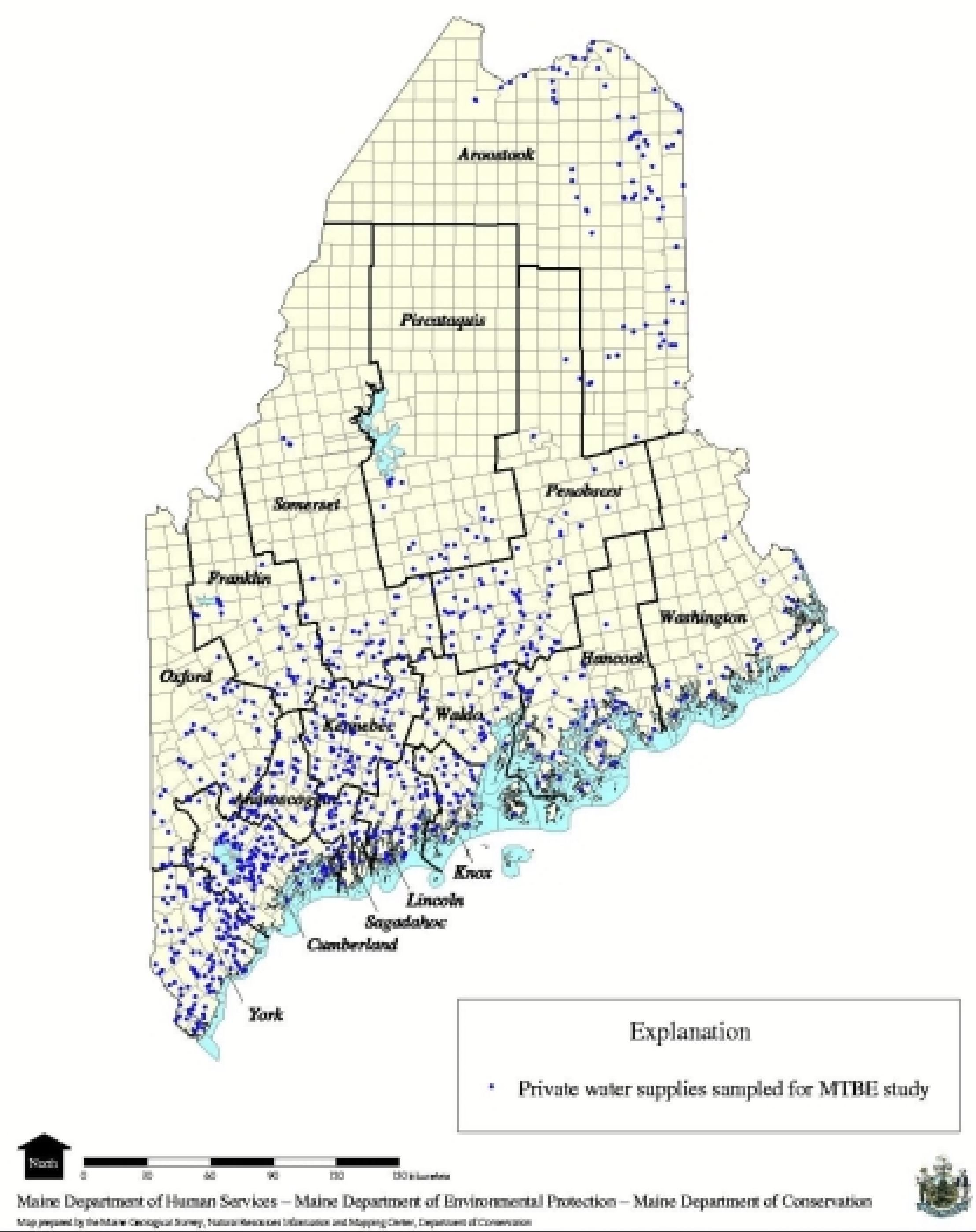


Figure 1. Occurrence and concentration of gasoline compounds in sampled household wells and other household water supplies.

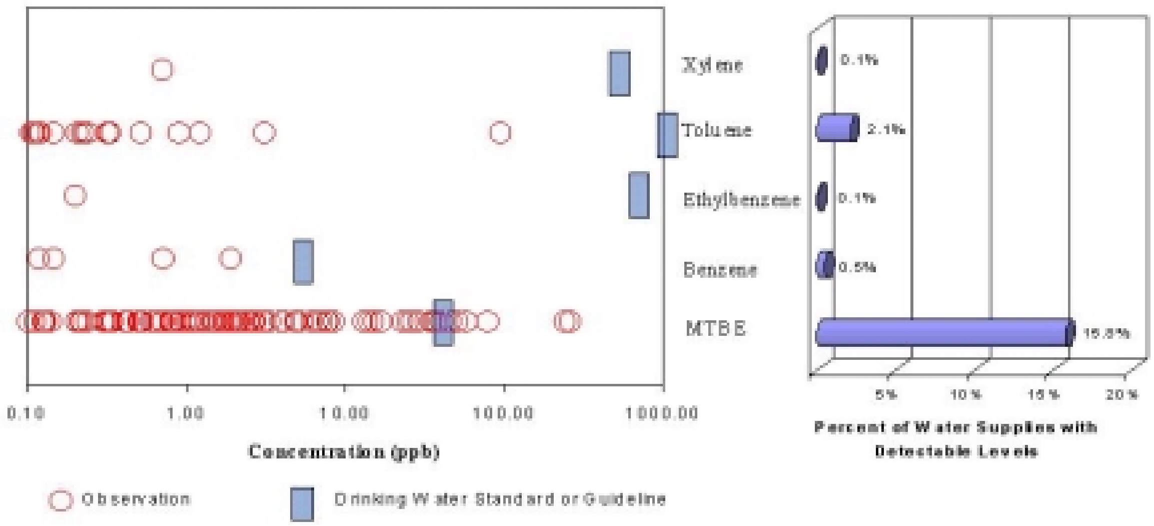
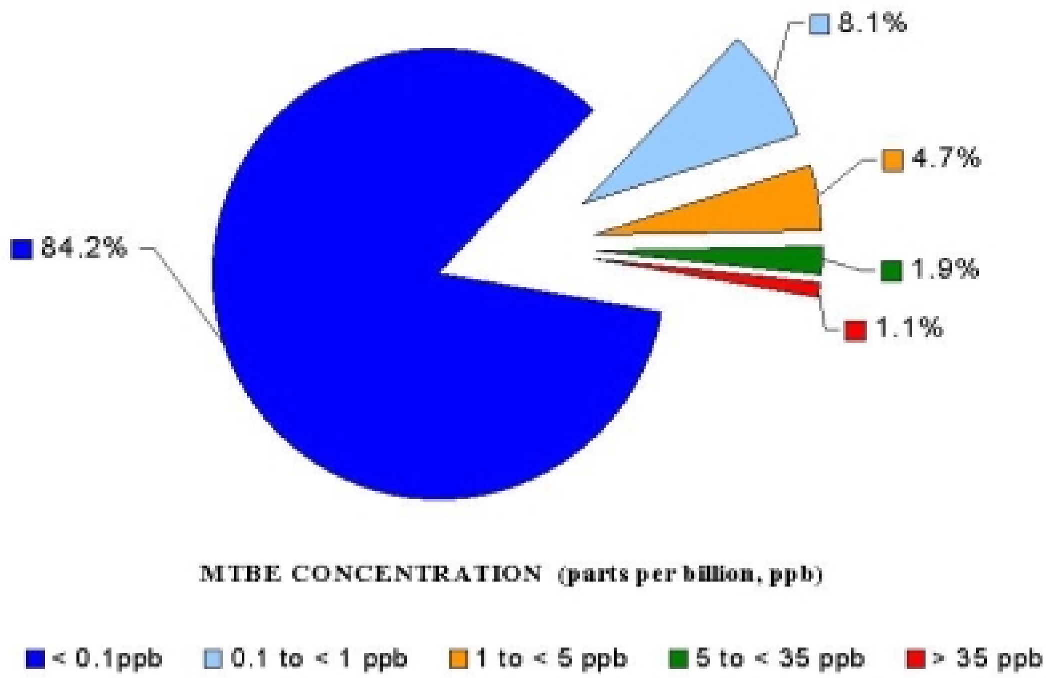


Figure 2. Frequency distribution of MTBE concentrations observed in sampled private residential water supplies.



Map 2: Preliminary MTBE concentrations in private water supplies sampled in study

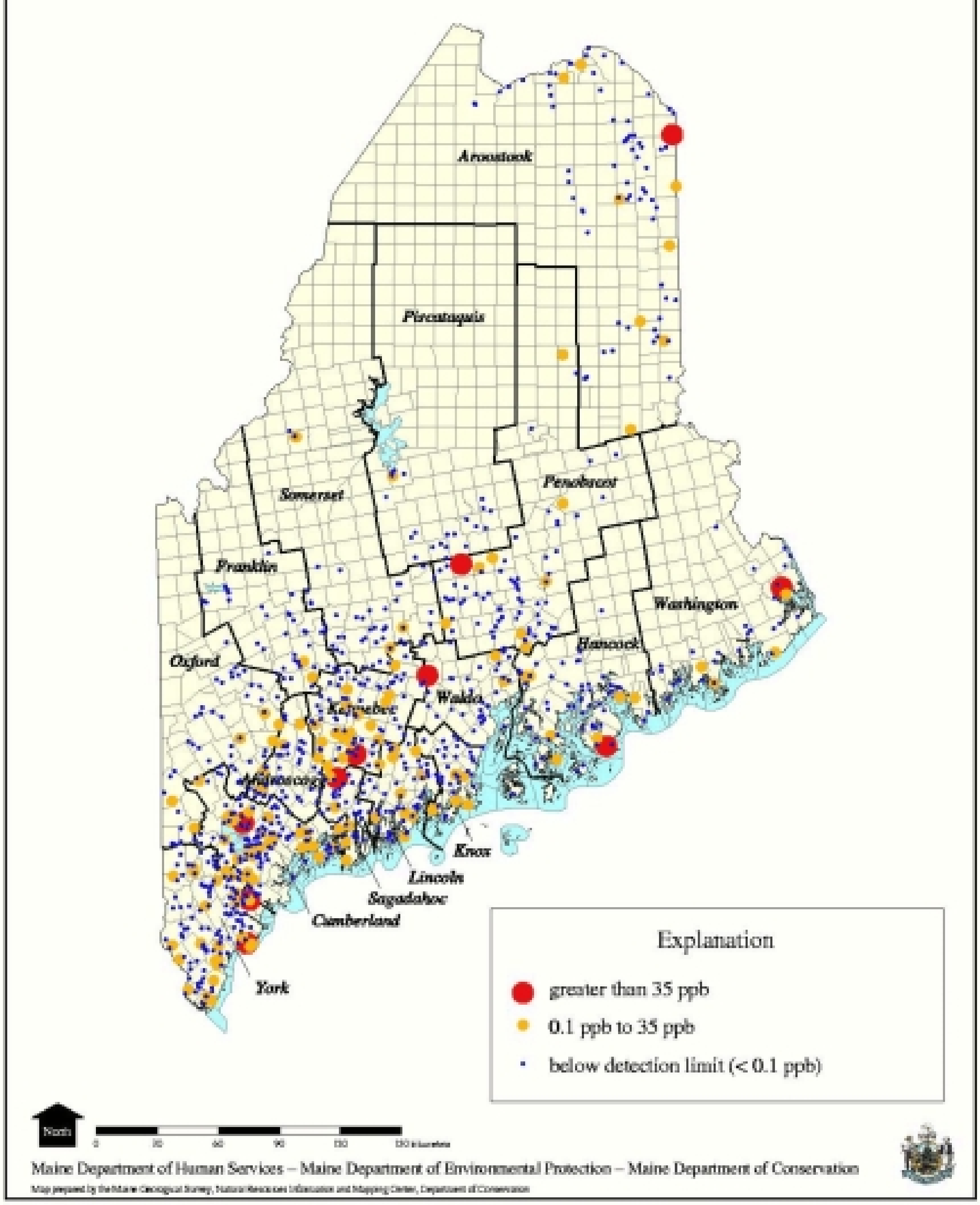


Figure 3. Occurrence and concentration of gasoline compounds in sampled public water supplies.

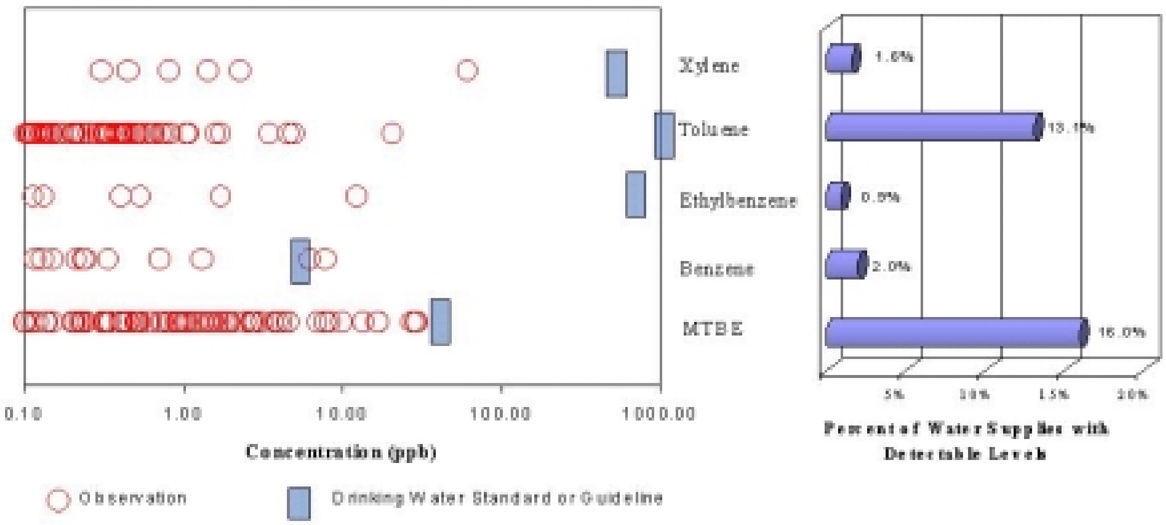
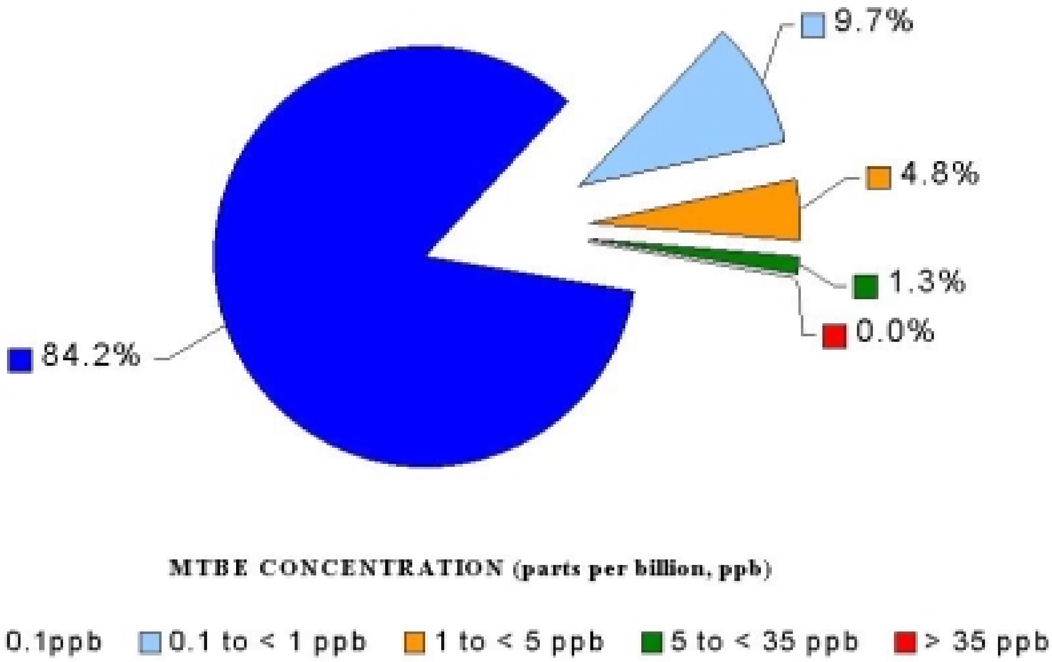
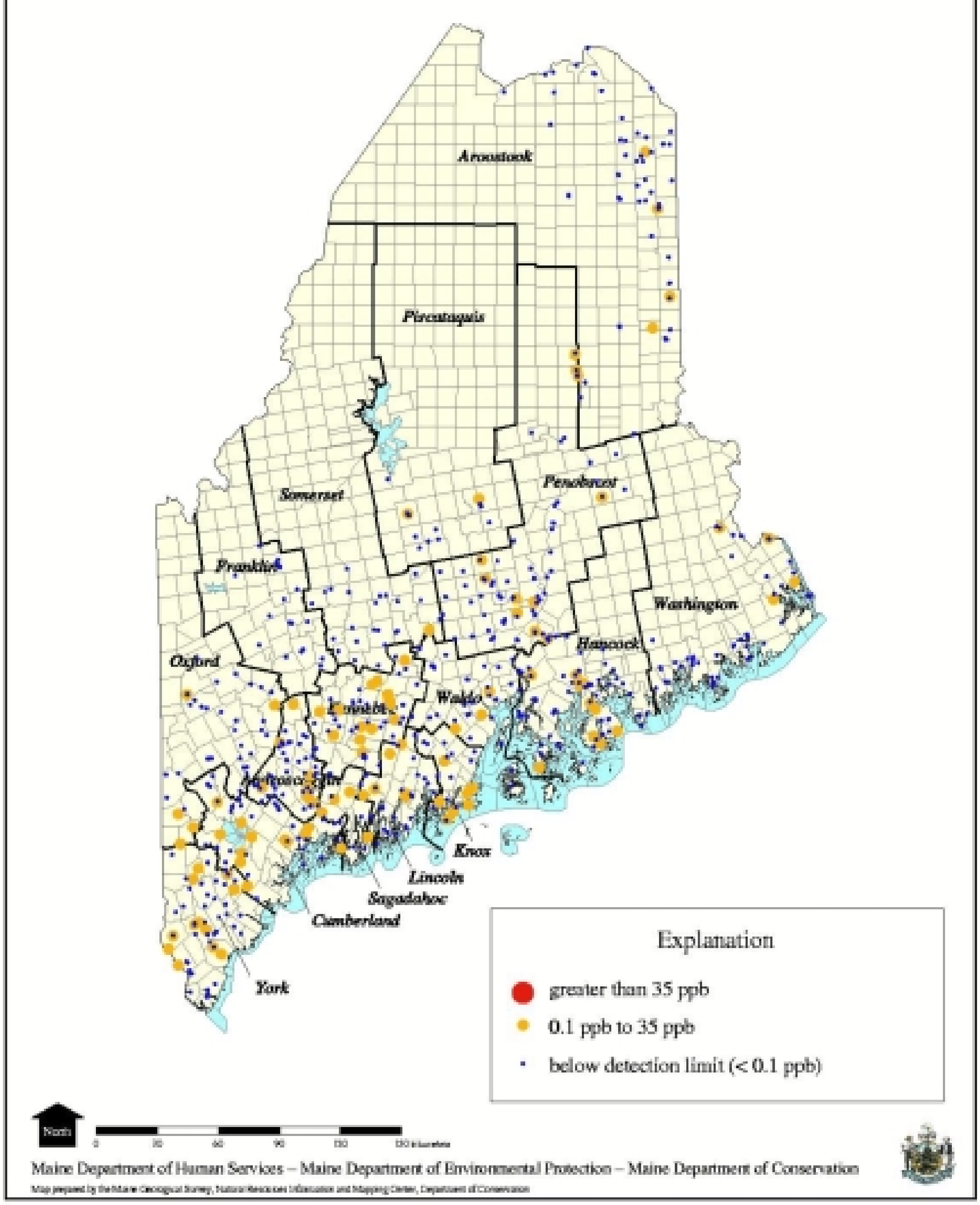


Figure 4. Frequency distribution of MTBE concentrations observed in sampled public water supplies.



Map 3: Preliminary MTBE concentrations in public water supplies



Map 4: Estimated percent of private water supplies with detectable levels of MTBE