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Was MtBE a Costly Mistake? The Evidence from Maine

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INTRODUCTION

MtBE History & Characteristics

The energy politics of New England have provided a natural experiment on how the gasoline additive methyl *tertiary* butyl ether (MtBE) affects the contamination and remediation of groundwater. The Clean Air Act of 1990, in an effort to reduce ground-level ozone and other volatile organic compounds, mandated the use of oxygenated gasoline. As a result, areas that exceeded ambient carbon monoxide levels began using reformulated gasoline (RFG), which contained MtBE as the oxygenate. Maine's seven southern counties opted into the RFG program in 1991, and mandated the use if RFG in 1994, which increased the volume of MtBE in gasoline to at least 11% (MEDHS, 1995). In the mid-1990s, water quality surveys nationwide began detecting MtBE in groundwater without the usual other gasoline components (Squillace et al, 1999; Nielsen and Peckenham, 2000). In response to these numerous cases of MtBE contamination, Maine carried out a statewide survey, in 1998, and found that 16% of groundwater supplies were contaminated with MtBE, including areas that were not in the RFG program (MEDHS, 1998). As a result, Maine opted out of the RFG program in March 1999, and into a low-value MtBE blend. This policy change set up a unique opportunity to study how changing MtBE content from about 15% to 2% MtBE by volume in fuel affects the quality of water resources and the costs of spill remediation.

MtBE has been used in gasoline since the late 1970s as a replacement for tetra-ethyl lead, and became the oxygenate of choice following the Clean Air Act due to its low production costs and gasoline blending properties. Although there is evidence that oxygenated gasoline has improved air quality in non-attainment areas, MtBE has posed a problem when the chemical reaches water resources. MtBE is an ether that is mobile in water and recalcitrant to remediation (USEPA, 1999). MtBE has a half-life of months to years in groundwater, compared its 3-day half-life in the gas phase (UCD, 1998). The following are characteristics that explain why MtBE is so environmentally persistent:

1) Readily dissolves in water (saturation solubility ~40,000 ppm)
2) Moves at a rate similar to water itself (low retardation)
3) 2 to 5 times more soluble than other ether oxygenates
4) Resistant to biodegradation

The U.S. Environmental Protection Agency (USEPA) has determined that MtBE poses potential health concerns, both acute and chronic (chronic exposures are much lower, Maine MEG is 35 ppb), when MtBE reaches levels of 100 parts per billion (ppb) (1997). USEPA has designated MtBE a potential carcinogen, although there are no studies yet to confirm whether MtBE is indeed a carcinogen, nor are there studies to confirm any health effects associated with long-term exposure to low concentration levels of MtBE. However, due to its relatively low taste and odor threshold (i.e. as low as 2 ppb), it clearly poses an aesthetic concern (Williams et al, 1998,). Although aesthetic drinking water concerns do not necessarily pose a public health concern, they do pose a use concern, in that if water is not aesthetically pleasing, individuals will find alternative sources of drinking water. USEPA has set an advisory standard limit between 20 ppb (odor) and 40 ppb (taste), while Maine has set its standard at 35 ppb.

The Project

Maine's goal in opting out of the RFG program was to quickly decrease MtBE concentrations in its water resources. Maine now uses gasoline that contains 0 to 2% MtBE, as well as tert-Amyl Ether (TAME), ethtyl tert-butyl ether (ETBE), tert-butyl alcohol (TBA), methanol, and ethanol. We examine the persistence of MtBE concentrations, over space and time, in Windham, Maine. Over a period of six years (1998-2003), we collected groundwater samples periodically from 19 monitoring wells distributed over a sand and gravel aquifer. It is important to note that no large gasoline spills were reported.

The economics component of this project evaluates the costs of using and remediating MtBE to safe-levels. MtBE increases the cost of ground water remediation, as compared to conventional gasoline (U.C. Davis, 1998). In Maine, great efforts have been taken to mitigate the effects of MtBE through remedial activities, from complete remediation to replacing water supplies. We analyzed economic data to determine whether reducing MtBE concentration in gasoline has affected remediation cost. This is accomplished by comparing the cost and effectiveness of various remedial techniques implemented to reduce MtBE contamination across Maine. Remediation cost data is compared with water sample data and spill characteristic data from across Maine to determine whether the change from pre-RFG to RFG, and to post-RFG has led to changes in the cost of remediation.

METHODS

Ground-water

An existing network of shallow wells, installed by the USGS and distributed throughout the ground water flow system in the Windham aquifer, are used for this study (Nielsen and Peckenham, 2000). These wells are completed in different types of glacial outwash. Samples were collected in July and August 1998 in 31 wells; subsequent sampling rounds in November and December 1998, April and May 1999, and August 2001 and 2003, used a slightly smaller number of wells. Well depths ranged from 19 to 132 feet (5.8 to 40 m), with screened interval depths ranging from 8 to 130 feet (2.4 to 39.6 m). Screened intervals were mostly 5 or 10 feet (1.5 to 3.0 m) long, with a few wells having longer screens, up to 30 feet (9.1 m). Depth to water in the wells at the time of sampling ranged from 4.5 to 61.1 feet (1.37 to 18.6 m). All the wells are completed in unconfined parts of the aquifer; the sampling points range from water-table position to more than 110 feet (33.5 m) below the water table. Seven pairs of nested wells were sampled to evaluate vertical distributions of MtBE. The dominant land cover near each well was determined from the NLCD land-cover classification: urban, undeveloped, or low-density residential.

USGS National Water Quality Assessment protocols for sampling ground-water wells (Koterba et al., 1995) were followed in sample handling, quality assurance/quality control (QA/QC), sampling equipment, and cleaning. The USGS protocols were modified, however, to follow the USEPA low-flow (minimal drawdown) sampling procedures (Puls and Barcelona, 1995). A small number of wells did not yield enough water to meet the minimum drawdown requirements. These wells were pumped dry and sampled the next day.

The sampling equipment setup was simplified from USGS protocols to reflect what was necessary for the small number of constituents sampled in this study. Flow rates were generally within the range of 0.026 to 0.11 gal/min (100 mL/min to 400 mL/min). Samples for analysis of VOCs, including benzene, toluene, ethyl benzene, xylene, and MtBE, were collected. The collection method was modified in 2001 to use disposable materials instead of decontaminating in-well materials in order to minimize cross-contamination. Samples were kept on ice and shipped within 24 hours to the USGS or contract laboratories for analysis for the 1998, 1999 and 2003 samples, and the Mitchell Center laboratory at the University of Maine for the 2001 samples.

Quality assurance samples consisted of equipment blanks (15 percent of all samples), trip blanks, spiked samples, source-solution blanks, and ambient blanks (trip blank vials opened and exposed to the ambient air during sampling, then closed and shipped for analysis). In all, 26 percent of all the samples analyzed were QA/QC samples. During the initial round of sampling, deionized water created in the district laboratory was used for rinsing; this presented a problem, however, in that the water was later found to be contaminated with very low concentrations of VOCs. An additional round of samples was collected for all the environmental samples with VOC detections in the first round to eliminate the rinse water as a source of VOCs to the samples. Purchased distilled water was used for all additional sampling, and all sampling equipment and supplies were stored in a clean environment.

Detections of MtBE in the first round of samples (11 detections) were recorded as a "less than" value larger than the observed analytical result. For example, a detection in the first round of 0.42 µg/L would have been recoded to <0.5 µg/L, to make sure that the database did not contain detections of MtBE from potentially compromised samples. MtBE was also detected in subsequent sampling rounds in 9 of the 11 wells assigned an elevated detection limit.

Economics

We collected data from the Maine Department of Environmental Protection (MEDEP). MEDEP is divided into 4 regions, Augusta, Bangor, Portland, and Presque Isle. Each region is managed by a MEDEP regional office (Bangor and Presque Isle are maintained by the Bangor regional office). We collected data for the Augusta, Bangor and Presque Isle regions. The Portland region was left out of the analysis due to access difficulty within the timeframe of this project.

MEDEP maintains a "groundwater database" of spills that have impacted, or have the risk of impacting, drinking water and is composed of water sample data. MEDEP also maintains an electronic database of all spills, in Maine, with information on spill type, volume, and location. We collected all gasoline related spills from this dataset in order to identify sites with MtBE contamination. We then extracted general characteristics of spills from spill reports and files for spills that had MtBE documentation. We matched these spills with MEDEP's electronic database of costs for all spills in Maine. The costs are recorded by spill and are disaggregated, within the context of this study, among up to 22 categories, for example geologic activities, excavation and sampling.

We used an ordinary least squares regression to test hypotheses about relationships between explanatory variables and the dependent variable, total cost associated with a spill, for 57 observations. We are in the process of collecting additional data to increase the reliability of our results.

RESULTS

Groundwater

The results reveal that MtBE is still detectable up to 2003 despite Maine's decision to opt out of the RFG program in 1999 (Table 1). While some wells show a decrease in MtBE concentrations, the patterns of reductions is not even, and two wells, CW1985 and CW 2003, show increases in concentrations.

Table 1- Summary of Sample Locations & Analytical Results from 1998 to 2003) Frequency from 1998 to 2003

Well Identification	MtBE (ug/L)				
	Summer 1998	Winter 1998	Spring 1999	Summer 2001	Summer 2003
CW 1971	<0.2		<0.2	<0.1	<1
CW 1979	<0.2		0.20	0.50	0.18
CW 1980	<0.2			0.49	
CW 1985	<0.5	<0.2	E0.10	<0.1	0.42
CW 1987	<0.2		<0.2	<0.1	
CW 1990	<0.2		0.23	E0.01	<1
CW 1992	<0.2		<0.2	<0.1	<1
CW 1993	<0.2		<0.2	<0.1	<1
CW 1999	<0.2		<0.2	<0.1	<1
CW 2000	<0.4	0.46	0.35	0.16	<1
CW 2001	<0.8	<0.2	<0.2	<0.1	<1
CW 2003	<1.0	0.72	0.47	E0.05	0.22
CW 2004	<0.7	3.1	0.60	38.7	0.34
CW 2005	<1.8	2.7	1.5	4.2	0.73
CW 2008	<0.2		<0.2	5.7	0.38
CW 2009	<0.2		<0.2	<0.1	<1
CW 2010	<0.2		1.9	0.33	<1
CW 2012	0.370	4.0	14.0	6.6	4.6
CW-2011	<0.4	<0.2	<0.2	<0.1	<1

Surprisingly, of the 19 wells consistently tested from 1998 to 2003, at least half of the wells had detectable concentrations of MtBE (Figure 1). In 1998, 71% of the wells had detectable levels of MtBE. The number of wells with detectable concentrations decreased to 50% in 1999, increased to 53% in 2001, and maintained a 53% frequency in 2003.

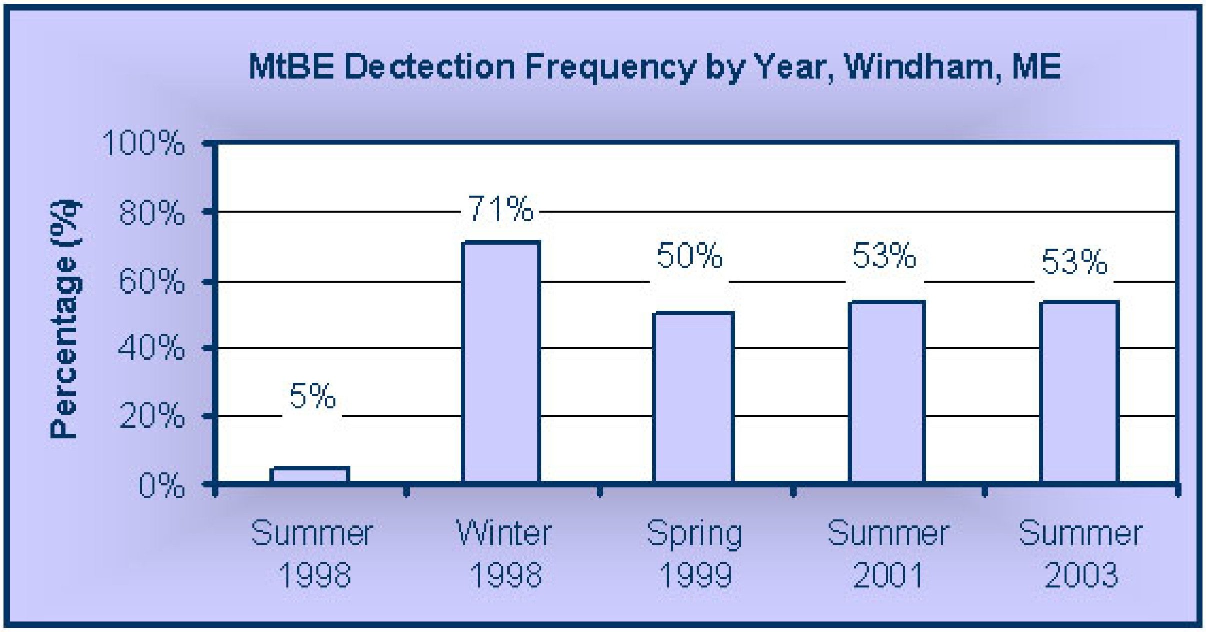

Figure 1- MtBE Detection Frequency from 1998 to 2003

MtBE was detected at a mean sample of 0.37 µg/L (Figure 2) in the summer of 1998, 2.2 µg/L in winter of 1998, 2.4 µg/L in 1999, 7.1 µg/L in 2001, and 0.98 µg/L in 2003 (these values exclude the samples that were recorded as "less thans").

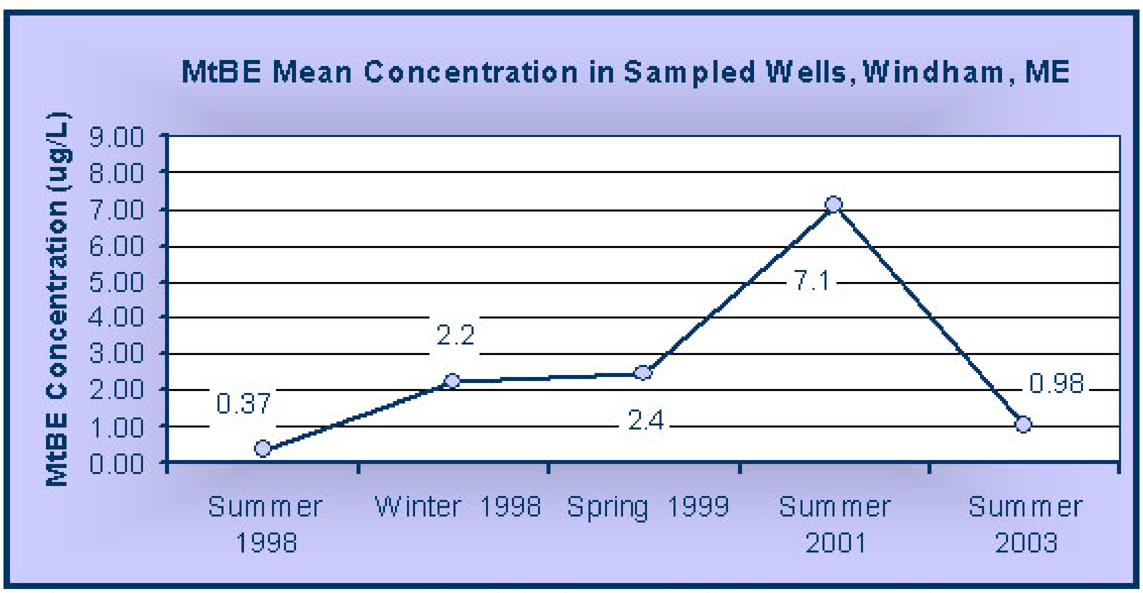

Figure 2- MtBE Mean Concentration (µg/L) in Sampled Windham Wells (1998 to 2003)

Three of the four highest concentrations detected, 14.0 µg/L in 1999, 6.64 µg/L in 2001, and 4.6 µg/L in 2003, were collected from the same well, CW 2012, and located in an urbanized area near a gasoline station. The single highest concentration, 38.7 µg/L in 2001, was detected in CW 2004, located in a light-industrial and commercial area.

Economic

We performed a correlation test to see how variables relate to each other. There are several variables for which correlation was significant. When the location of a spill is residential, there is negative correlation with the presence of underground storage tanks (USTs), compared to a positive correlation when the location is a gasoline terminal. This is most likely because most residential homes do not have USTs containing any volume of gasoline, while gas stations do. The highest concentration detected over the activity period for a spill positively correlates with the total cost associated with cleaning a spill. The number of properties affected also positively correlates with total cost. In other words, the more properties affected, the more costs will increase.

There is a negative correlation between the category for other causes of spills and the pre-RFG timeframe, whereas, the RFG timeframe has a positive correlation with other spill causes. These correlations could be explained by agencies paying more attention as more is known about contamination, and as technology and the concept of record keeping improves. The category for cause-by-accident correlates positively with pre-RFG time frame, but correlates negatively for the RFG timeframe. This change in accidents as the cause of a spill may be the result of education about the effects of spills and how to prevent spills from pre-RFG to RFG timeframe.

There is positive correlation between performing remediation and when the location of a spill is a terminal, while a negative correlation between remediation and when the location of a spill is a residence. This could be that terminal spills are generally much greater than spills that would occur at a residence, resulting in more extreme actions, such as extensive remediation. A residence may only require, for example, a point of entry system or quarterly monitoring program. There is a positive correlation between the category for large spills and the highest concentration detected over the timeframe of a spill. Larger spills will yield higher MtBE contamination levels.

We performed preliminary OLS regressions. The variables used appear to fit the model well, because the R-Square value averages 0.83. An indicator variable for the pre-RFG period is consistently significant and leads to higher total costs than either spills that were reported during RFG or post-RFG timeframe. The variable for the number of properties on some sort of monitoring program is also consistently significant and correctly demonstrates that the more properties tested the higher the total costs. Remediation estimate signifies that total cost decreases when remediation does not occur. Corrosion as cause of spill consistently comes up significant as a cause of spill that increases the total costs.

DISCUSSION

The economic and environmental effects of Maine’s policy change made the State of Maine a microcosm for assessing the impact of reduced MtBE content in gasoline. This study confirms MtBE’s temporal persistence in the environment, although the current detected concentrations are lower than in previous years for some samples. A key interpretation of these results is that reducing MtBE concentrations in gasoline is *not* sufficient to eliminate its occurrence in groundwater.

Continued work to improve the economic model will include incorporating additional variables, such as demographic data (mean household income, family size, education, and population) per census track with respect to spill location and average volume. The State of Maine now collects data on the volumes and concentrations of MtBE and other oxygenates in motor fuels entering the state.

The environmental costs of using MtBE in gasoline have been offset, in part, by better management to reduce the occurrence of spills and the development of more cost-efficient remediation techniques. The results of this project has the potential for providing information to allow other regions in Maine, the Northeast, and the rest of the U.S, to react to their specific situation with the appropriate understanding of MtBE persistence and associated costs for clean up.

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