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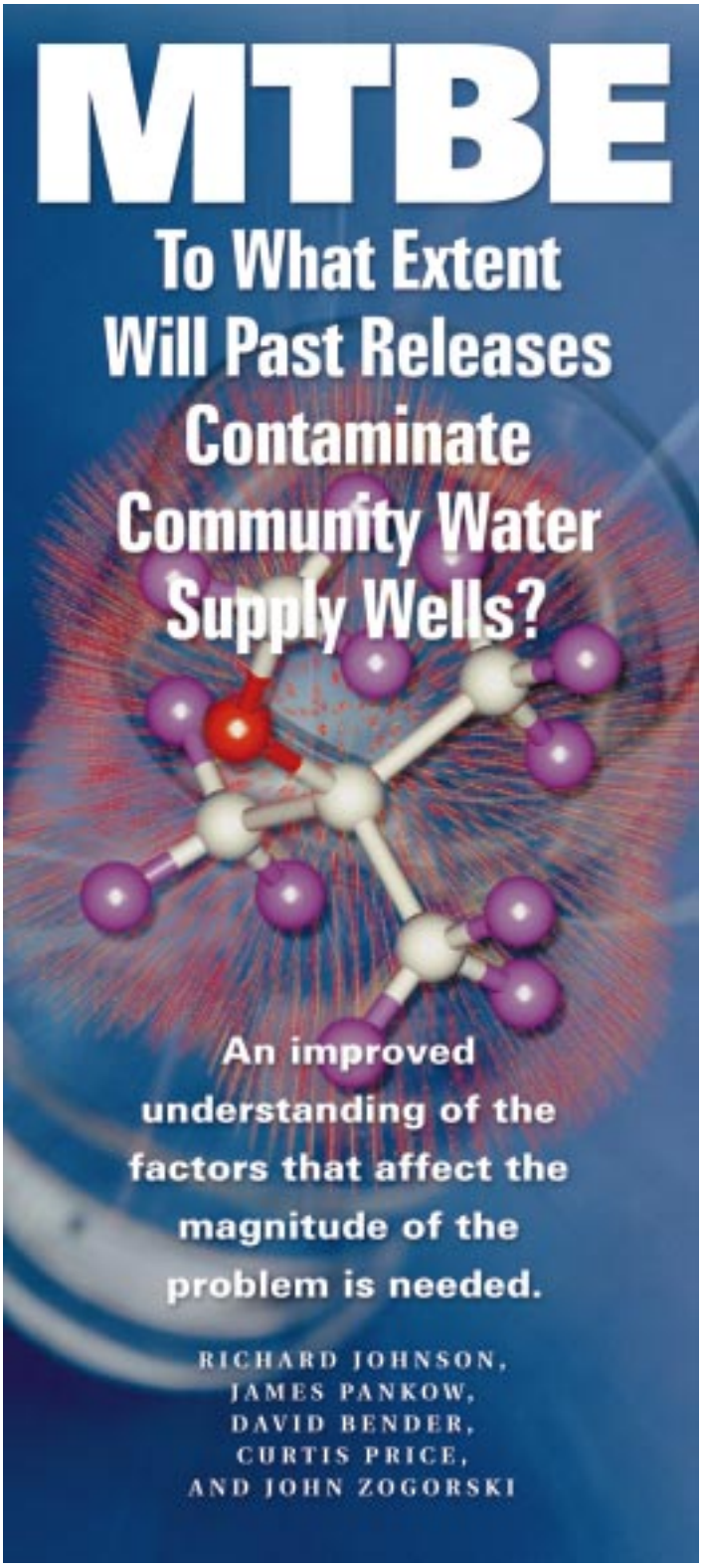


The increasing frequency of detection of the widely used gasoline additive methyl *tert*-butyl ether (MTBE) in both ground and surface waters is receiving much attention from the media, environmental scientists, state environmental agencies, and federal agencies. At the national level, the September 15, 1999, *Report of the Blue Ribbon Panel on Oxygenates in Gasoline* (*1*) states that between 5 and 10% of community drinking water supplies in high MTBE use areas show at least detectable concentrations of MTBE, and about 1% of those systems are characterized by levels of this compound that are above 20 µg/L. In Maine, a desire to determine the extent of MTBE contamination led to a 1998 study (*2*) that revealed that this compound is found at levels above 0.1 µg/L in 16% of 951 randomly selected household wells and in 16% of the 793 community water systems tested in that state (37 wells were not tested). The study also suggested that between 1400 and 5200 household wells may have levels above 35 µg/L, although no community water supplies were found to be above that concentration. For comparison, Maryland, New Hampshire, New York, and California have set MTBE remediation "action levels" at or below 20 µg/L, and EPA has set its advisory level for taste and odor at 20–40 µg/L (*3*).

In California, concern regarding MTBE reached statewide levels in 1996 when seven wells supplying 50% of the water for the city of Santa Monica were removed from service because of MTBE at concentrations as high as 600 µg/L. For the city's Charnock well field, an initial review of known and suspected petroleum spill sites identified about 10 potential sources that lay within 1 km of the well field, lay above the hydrologic unit accessed by the well field, and were created after MTBE use began in the state (*4*). At the time that contamination of the wells was discovered, pumping of the Charnock well field was at 5 million gallons/day (mgd). This aggressive pumping was approximately twice the total natural flow of water moving into the aquifer. Despite the presence of a protective aquitard in the system, the pumping had dewatered a significant portion of the upper aquifer, caused water to flow toward the well field from all directions, and had greatly increased the likelihood that the community water supply (CWS) wells in Santa Monica would in fact become contaminated by one or more persistent organic pollutants such as MTBE.

Besides leaking underground fuel tanks (LUFTs) and leaking pipelines, other sources of MTBE in groundwater include tank overfilling and faulty construction at gas stations, spillage from vehicle accidents, and homeowner releases. In Maine, it is pos-


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sible that many of the cases of domestic well contamination by MTBE were caused by homeowner releases (*2*). For the Santa Monica wells, the scale of contamination found there seems consistent only with large releases (e.g., LUFTs).

## Unprecedented growth in use

Use of MTBE as a gasoline additive began in the United States in the late 1970s when it was introduced as a means of maintaining adequate octane ratings during the phaseout of alkyl lead additives. MTBE use expanded dramatically in the mid-1990s with the implementation of the Clean Air Act Amendments of 1990, which mandated efforts to reduce carbon monoxide emissions, as well as ozone levels in urban air. For carbon monoxide, MTBE was selected by some gasoline producers as a means of producing "oxygenated fuel" (oxyfuel) that allowed the more complete combustion of gasoline hydrocarbons. For ozone, MTBE has been used to produce "reformulated gasoline" (RFG), which is low in the potent human carcinogen benzene and other aromatic compounds; use of RFG lowers the emissions of unburned aromatic compounds and therefore the formation of ozone in urban air. Alternative oxygen-containing compounds for the formulation of oxyfuel and RFG include ethanol, ETBE, TAME, and DIPE (see box above); usage of the last three has been relatively small. Currently, 19 areas in 13 states are involved in the oxyfuel program, with MTBE used in 3% of all oxyfuel at levels of 10–15% by volume. A total of 29 areas in 18 states are involved in the RFG program, with MTBE used in 85% of all RFG at levels of 11–15% by volume (*5*).

The growth in the use of MTBE has been unprecedented. In 1970, MTBE was the 39th-highest produced organic chemical in the United States. By 1998, it had become fourth-highest (see Figure 1, (*6–11*)), with an aggregate production of about 60 million metric tons over that period. And, the production of MTBE is exceeded only by that for the monomers used to make polyethylene, polypropylene, and polyvinyl chloride. In 1998, more than 10.5 mgd of MTBE were used in the United States, with 4.2 mgd used in California alone (*12*). These production numbers are far larger than those for the chlorinated solvent compounds, a group widely recognized as having caused extensive contamination of groundwater in urban and nonurban areas. Thus, regardless of what happens to MTBE use in the future (e.g., both Maine and California have stated that they intend to stop using MTBE, and the Blue Ribbon Panel on Oxygenates in Gasoline (*1*) has called for a substantial and rapid reduction in MTBE use in RFG areas), it is likely that significant amounts of this compound are already present in the subsurface.

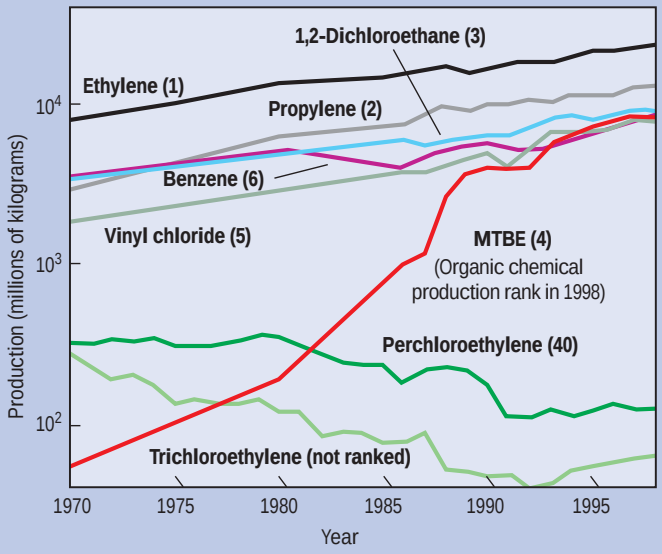
### Terms

| | |
|---|---|
| MTBE | methyl *tert*-butyl ether |
| ETBE | ethyl *tert*-butyl ether |
| DIPE | di-isopropyl ether |
| TAME | *tert*-amyl methyl ether |
| RFG | reformulated gasoline |
| oxyfuel | oxygenated fuel |
| BTEX | benzene, toluene, ethylbenzene, and xylenes |
| CWS"wells" | community water supply well |
| CWS | one or more CWS pumping wells that draw from the same portion of an aquifer |
| LUFT | leaking underground fuel tank |
| LUST | leaking underground storage tank |
| UST | underground storage tank |
| PCE | perchloroethylene (also called tetrachloroethene) |
| TCE | trichloroethylene (also called trichloroethene) |
| mgd | millions of gallons per day |
| UFT | underground fuel tank |

FIGURE 1

### Organic chemical production in the United States, 1970–1998

Production of MTBE has grown dramatically since 1970, and it now ranks fourth overall among organic chemicals.




## . . . and MTBE Is Very Soluble

Gasoline hydrocarbons are nonpolar compounds composed only of hydrogen and carbon. Of these, the compounds with the lowest drinking-water concentration limits are members of the BTEX group (benzene, toluene, ethylbenzene, and the xylenes). However, the relatively low water solubilities from gasoline mixtures of the BTEX group (see Table 1), combined with their high in situ biodegradabilities, greatly limit their migration from LUFT sites. These limitations have allowed "natural attenuation" processes to mitigate subsurface contamination at many sites where conventional gasoline has been released. The extent of contamination by BTEX compounds at most LUFT sites is typically less than 100 m (*12*), and ben-

TABLE 1

## Water solubilities of hydrocarbon compounds

The relatively low water solubilities from gasoline mixtures of the BTEX group (benzene, toluene, ethylbenzene, and xylenes) combined with their high in situ biodegradabilities, greatly limit their migration from LUFT sites. This situation differs greatly for alkyl ether compounds.

| Compound | Solubility | |
|---|---|---|
| | *Solubility (mg/L) at 20 °C* | |
| *Aromatic gasoline hydrocarbons* | *from conventional gasoline*[a] | |
| Benzene | 18 | |
| Toluene | 25 | |
| Ethylbenzene | 3 | |
| Xylenes (total) | 20 | |
| *Chlorinated solvent compounds* | | |
| *from the pure compound* | *Solubility (mg/L) at 20 °C* | |
| trichloroethylene (TCE) | 1440 | |
| perchloroethylene (PCE) | 240 | |
| | *Solubility (mg/L) at 20 °C* | |
| *Alkyl ether compounds* | *from RFG*[b] | *from oxyfuel*[c] |
| methyl *tert*-butyl ether (MTBE) | 4700 | 6300 |
| ethyl-*tert*-butyl ether (ETBE) | 1300 | 1750 |
| *tert*-amyl methyl ether (TAME) | 1400 | 1850 |
| di-isopropyl ether (DIPE) | 1200 | 1600 |

[a]Assumes release of a conventional gasoline containing 1% benzene, 5% toluene, 1.5% ethylbenzene, and 10% total xylenes.
[b]Assumes release of reformulated (RFG) gasoline containing 2.0% by weight oxygen, which would correspond to 11.1% MTBE, 12.9% ETBE, 12.4% TAME, or 12.9% DIPE (all by volume).
[c]Assumes release of oxygenated gasoline containing 2.7% by weight oxygen, which would correspond to 15.0% MTBE, 17.5% ETBE, 16.8% TAME, or 17.4% DIPE (all by volume).

## Blue Ribbon Panel on Oxygenates in Gasoline

Appointed by U.S. EPA Administrator Carol M. Browner in November 1998, the Blue Ribbon Panel was asked to "*investigate the air quality benefits and water quality concerns associated with oxygenates in gasoline and to provide independent advice and recommendations on ways to maintain air quality while protecting water quality*". The panel was composed of experts from the public health and scientific communities, automotive fuels industry, water utilities, and local and state governments.

zene has been detected only rarely in the community water systems of California (*13*) and across the nation in groundwater samples collected as part of the National Water-Quality Assessment Program of the U.S. Geological Survey (*14*).

MTBE is a relatively nonpolar ether that blends easily with gasoline hydrocarbons. If MTBE behaved like the gasoline hydrocarbons in all respects, the scale of its use would not by itself be a reason for concern. After all, the current numbers for gasoline production in the United States are about 40 times larger than those for MTBE, and 385,000 known releases of gasoline have already occurred at LUFT sites. Unfortunately, MTBE is very soluble in water and is therefore very mobile in groundwater systems. And, the absence of any carbon branches more than one carbon long on the MTBE molecule make MTBE very resistant to biodegradation. Thus, like the chlorinated solvent compounds TCE and PCE, MTBE has been found to persist in groundwater, and cases of MTBE plumes extending kilometer-scale distances in the subsurface have now been documented (e.g., Port Hueneme, CA; East Patchoque, NY; Spring Creek, WI; and Vandenberg AFB, CA).

Some MTBE plumes have originated from very small spills, as from the gasoline in the tank of a single overturned auto. Ten gallons of a gasoline that is 11% by volume MTBE will contain 3 kg of MTBE. If such an amount were to reach the water table (either by direct seepage of the gasoline or as assisted by infiltration of precipitation), subsequent dissolution and transport could lead to the contamination of millions of liters of water at the tens of µg/L level. The potential for rapid and extensive transport of MTBE through the subsurface is especially large when spills reach fractured rock where porosities may only be a few percent. For example, a spill resulting from a single automobile accident in Standish, ME, led to MTBE transport through more than 0.7 km of fractured rock and to the contamination of more than 20 domestic wells (*15*).

### 250,000 LUFT releases of MTBE?

Because MTBE has been used so widely (as an octane enhancer, as a component of RFG, and/or as a component of oxyfuel), most underground gasoline tanks in use after 1979 in the United States probably contained this compound at some point in time. For example, in Kansas, where neither RFG nor oxyfuel use was required, MTBE has been found at 88% of 818 leaking underground storage tanks (LUSTs) (*16*). In California, MTBE was found at 75% of 9000 LUFT sites (*17*). Therefore, of the approximately 385,000 confirmed LUFT releases of gasoline nationwide (*18*), perhaps some 250,000 of these spills involved MTBE. And, recent evidence from California suggests that spills and leaks continue to occur, even at upgraded UFT facilities (*1*). Therefore, because approximately 90 million people in the United States obtain a portion of their drinking water from CWS wells, EPA has been advised to work with its state and local water supply partners to

> . . . coordinate the Source Water Assessment program in each state with federal and state Underground Storage Tank Programs using geographic information . . . systems to determine the location of drinking water sources and to identify UST sites within source protection zones.
>
> Blue Ribbon Panel on Oxygenates in Gasoline (*1*)

Thus, specific information is greatly needed regarding the areal density and distribution of UST sites and other significant sources in the areas surrounding CWS wells and also the hydrogeological and pumping information for these wells.

Once this information is in hand, vulnerability as-

sessments based on common sense, as well as detailed hydrogeological modeling can be carried out to determine what steps, if any, are needed to ensure the protection of a given CWS well. While these data are being gathered, it will be very useful to identify the factors that will determine the likelihood that individual CWS wells will be adversely affected by local sources. It will also be important to estimate the number of CWS wells nationwide that ultimately may be affected by MTBE, as well as by other persistent organic compounds. There are three scales to this problem: a temporal scale, a site-dependent local scale, and a national scale. Each will be considered here.

## Temporal scale for CWS wells

Subsurface contamination has the potential to threaten local CWS wells for tens to hundreds of years. This is because LUST sources can persist for decades and because it can take tens to hundreds of years for groundwater to flow from source areas to a CWS well. The actual time frame that MTBE from a given source has the potential to appear in a CWS well at problematic concentrations will depend on the size of the source, the concentration leaving the source, and how attenuation mechanisms act to reduce the concentration as the contaminant moves from the source toward the well. Experience indicates that most large LUFT-MTBE sources have lifetimes of greater than 10 years, and that the concentrations of MTBE in groundwater leaving such sources are frequently a few hundreds of milligrams per liter. Some states have established maximum allowed concentration values of a few tens of micrograms per liter (or less) for MTBE in drinking water. This suggests that an *overall reduction factor* on the order of 10,000 may be necessary to bring groundwater concentrations coming from CWS wells down to the maximum allowed values.

Three primary mechanisms can reduce the concentration of MTBE as it moves toward and into a CWS well: dilution, dispersion, and degradation. Substantial dilution can occur when a groundwater plume is drawn into a CWS well. In the example involving a 1-mgd well (see sidebar at right), the *well dilution factor* is about 250. If the required overall reduction factor is 10,000, then an additional *in situ reduction factor of about 40 would be required to reduce the concentration in the CWS to an acceptable level. (Note that in this analysis, the overall reduction factor = in situ reduction factor × well dilution factor.)*

The magnitude of the in situ reduction factor for a nonsorbing contaminant such as MTBE will be determined by the dispersion and degradation that occurs as the contaminant moves in the subsurface. Although dispersion can play an important role in determining the shape of a groundwater plume, when an MTBE source lies within the "capture zone" of a well, dispersion will, in general, not be strong enough to remove much MTBE from the flow paths leading to the well (see sidebar at right). Thus, in most cases, degradation followed by dilution at the well will control the MTBE concentrations found in CWS wells.

If degradation occurs as a first-order process (i.e., the passage of each degradation half-life ($t_{1/2}$) brings a factor of 2 concentration reduction), a 40-fold concentration reduction will require between five and six half-lives. For BTEX compounds released from LUFT sources, degradation in groundwater is relatively fast, with a typical half-life of two to three months. In contrast, based on a limited number of field data (e.g., (*19*, *20*)), it has been noted that

> [in] studies to date, in situ biodegradation of MTBE has been minimal or limited at best, which is significantly less (by at least one order of magnitude) when compared to benzene.
>
> Blue Ribbon Panel on Oxygenates in Gasoline (*1*)

## Mechanisms that can reduce the concentration of MTBE arriving at a CWS well

**Dilution by mixing in a CWS well**

Dilution by mixing with uncontaminated water in a community supply well can be calculated by comparing the groundwater flow rate through the source zone (assumed to be in the capture zone for the well) with the pumping rate for the well. For example, the dimensions for a LUFT source zone might be 30 m wide × 5 m thick. If the groundwater velocity is 0.3 m/day and the porosity is 0.33, the volume of water flowing through the source will be 15 $m^3$/day. For a community supply well pumping at 4000 $m^3$/day (1 mgd), this would result in a dilution factor of about 250, *regardless of the distance between the source zone and the well.*

**Dispersion**

Dispersion can occur both perpendicular ("transverse") to groundwater flow and in the direction of the flow ("longitudinal"). Neither means of dispersion will provide much net reduction in the flux of MTBE as it moves toward a CWS well. Studies of chlorinated solvent plumes in capture zones indicate that transverse dispersion is rarely strong enough to move significant contamination outside the capture zone of a pumping well. This means that transverse dispersion cannot, by itself, help much to reduce the concentration of MTBE in the water produced by a CWS well. For longitudinal dispersion, because MTBE sources are persistent and MTBE is relatively long-lived in groundwater, once such a plume becomes established and longitudinal concentration gradients dissipate, the amount of concentration reduction at the well head that can occur by longitudinal dispersion will be small.

**Degradation**

Degradation of MTBE by subsurface microorganisms is generally slow. Abiotic degradation is negligible. Field studies of MTBE spills can be used to compute apparent first-order rates of decay and corresponding half-lives, $t_{1/2}$, (in years) for biodegradation. Data obtained from actual spills indicate that MTBE has a half-life in most natural groundwater systems of at least two years, although significant uncertainty exists with these numbers.

**Required Degradation Time, $t_d$**

The required degradation time is defined here as the time required for the flux of contaminants from a source to be reduced by degradation to the point at which they no longer pose a threat to the CWS well. It is a function of source size and strength, groundwater flow rate, and pumping rate, as well as the in situ biodegradation rate. As discussed in the text, a value of 10 years has been assumed for the analysis presented here.

FIGURE 2

## Modeling well vulnerability to MTBE contamination

By making assumptions about the location of MTBE sources and using numerical models, the vulnerability of wells to contamination by MTBE can be assessed and expressed as the size of an area around a well that is at risk.

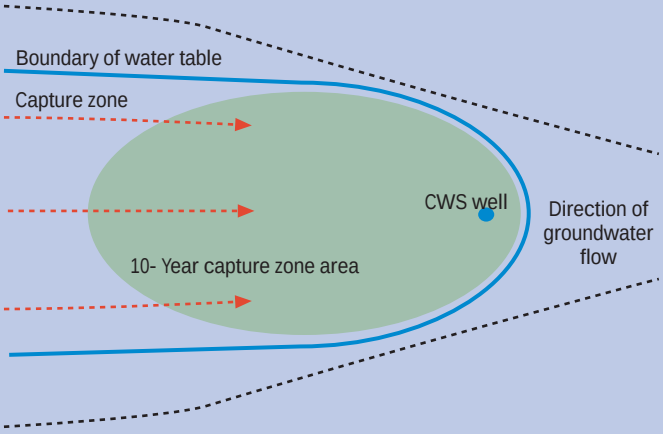
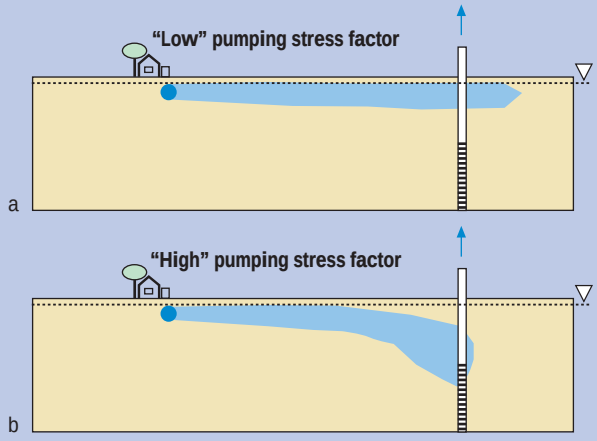



FIGURE 3

## The effect of pumping intensity on well contamination

The intensity of the pumping at a well influences the likelihood that MTBE will be drawn up into the well: (a) effect of a low pumping stress factor and (b) effect of a high pumping stress factor on contaminant intrusion.




**Local aquifer yield**
Local aquifer yield is defined here as the rate that water flows through the 1-km-wide cross section of the aquifer containing the CWS well ***in the absence of pumping.***

**Pumping stress factor**
Pumping stress factor = CWS pumping rate/local aquifer yield.

Thus, it is appropriate to assume that the degradation half-life for MTBE in plumes from LUFT sources is at least two years. As a result, a required degradation time, $t_d$, of five to six half-lives will probably correspond to at least 10 years (see sidebar on previous page). Significant numbers of MTBE releases may therefore continue to reveal themselves as problematic sources of contamination for the nation until at least 2010.

## Local scale: Sources near CWS wells

For any specific CWS well, if the hydrogeologic conditions and the locations of contaminant sources near the well are known in sufficient detail, then the movement of contaminants to the well can be assessed using numerical modeling. Although the data exist to do this in certain specific locations, this information is not available for most CWS wells. Therefore, to begin to understand the scale of the threat to CWS wells posed by MTBE sources, an approach is needed that can provide a general measure of the likelihood of contamination at wells when the specific locations of sources relative to the wells are not known.

One approach is to assume that MTBE sources are randomly distributed around CWS wells and use numerical modeling to calculate the likelihood that contaminated water will reach CWS wells under specific sets of conditions. If it is further assumed that MTBE sources occur only near the water table, then the first step in this approach will be to determine the size of the area from which groundwater at the water table is capable of reaching the well before the required degradation time, $t_d$, needed to achieve the in situ reduction factor can elapse. If, as has been assumed here, $t_d$ is 10 years, then the *10-year capture zone area* (see Figure 2) can be determined through a straightforward application of groundwater flow modeling techniques.

The second step is to determine the *areal density of significant sources* in the vicinity of the well. The third step is to multiply that density by the 10-year capture zone area for that well to obtain the *number of sources*, $n_s$, that will, on average, contaminate the well water at a concentration above tolerable levels. It should be noted that $n_s$ is a probabilistic parameter and is not the number of sources that will impact that specific well. (For example, this analysis cannot determine if a specific well with $n_s = 0.5$ will be impacted by zero, one, two, or more sources. However, a group of CWS wells all with $n_s = 0.5$ will, on average, be impacted by 0.5 sources per well.)

Three simple, yet instructive, hydrogeological examples will be examined here: a *"base" case*, consisting of a CWS well in a slightly stratified aquifer; an *aquitard case*, in which a continuous low permeability layer lies above the inlet to the well and helps protect the well; and an *infiltration case*, in which the infiltration of precipitation contributes to the downward movement of contaminated groundwater. To better generalize these cases, it is useful to express the magnitude of the pumping rate as a fraction of the rate at which groundwater would flow naturally through some relevant width of the aquifer (e.g., 1 km) in the vicinity of the well. This fraction is a measure of the intensity of the pumping, and as a result, it will be referred to here as the *pumping stress factor* (see Figure 3 for definitions).

When the pumping stress factor is low, even an MTBE plume flowing directly toward a well can pass over it without being drawn down to the well inlet (see Figure 3a). The 10-year capture zone area will therefore remain zero until some minimum pumping rate is reached, at which point water from sources at the water table will begin to be drawn into the well inlet (see Figure 3b).

In the base case, the well begins to capture water table sources when the pumping stress factor reaches ~0.4 (see Figure 4). As the pumping stress factor increases to 1.0, the 10-year capture zone area rises to 0.9 $km^2$.

When an aquitard is present, significant protection of a CWS well can be afforded. For the aquitard case considered here, the pumping stress factor must rise to about 1.3 before contaminated water at the water table begins to be captured by the well. In contrast, when the base case is modified to include infiltration, the 10-year capture zone area becomes nonzero when the stress factor is only about 0.2.

As was discussed above, for Santa Monica's Charnock well field, initial modeling by Brown and colleagues (*4*) indicates that at the time that MTBE contamination was discovered, the pumping rate corresponded to about twice the total natural flow through that 2-km-wide aquifer, and as a result, 100% of the water in the aquifer within 1 km of the wells was moving toward the well field. Because for such conditions the pumping stress factor would have been about 4, it would be of considerable interest to model the Charnock case to determine how many of the local LUFT-MTBE sources were inside the 10-year capture zone area.

## National scale of the problem for CWS wells

To understand the issue of MTBE and CWS wells at the national scale, it would be useful to apply an approach such as the one just described to a number of sites to develop a histogram plot that presents the number of CWS wells as a function of the number of sources, $n_s$, that will, on average, impact those wells. That is, how many of the nation's CWS wells have low $n_s$ values, and how many have large $n_s$ values and are therefore at risk? As has been noted, the data required to prepare this plot are not currently available. However, two existing geographic information system databases can be useful in a first step toward that goal. The first is the Starview database (*21*), which has latitude and longitude information for many of the nation's LUST sites (most of which are LUFT sites). It is important to note that this database is known to have significant uncertainties in the locations of individual LUSTs. However, data from Happel and colleagues (*17*) indicate that the average distances between CWS wells and LUSTs are not biased, so the calculation of LUST densities based on those data is not expected to have significant errors. The second database, the EPA Safe Drinking Water Information System (SDWIS) (*22*), has CWS well location information for 31 states. (Several large states, including California and Texas, did not have location data available. The sites from the 31 states were filtered to remove multiple wells at the same location, resulting in a total of ~26,000 CWS wells.)

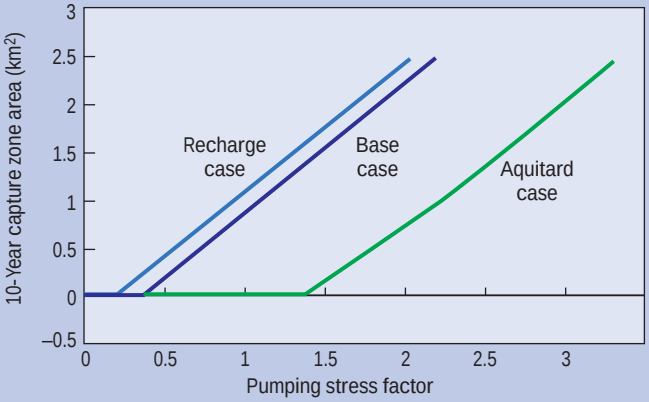
Overlaying these two databases allows the determination of a histogram plot of the number of CWS wells versus the number of LUSTs within 1 km of the CWS wells (see Figure 5a). Although it is likely that not every one of the LUSTs in the Starview database has created a significant source at the water table, this type of plot is useful in developing an understanding of how many CWS wells may be at risk of contamination.

When the distribution (see Figure 5a) is integrated to obtain the cumulative frequency distribution (see Figure 5b), we can see that approximately 35% of the CWS wells in the database are characterized by one or more LUST sites within a 1-km radius of the well. This corresponds to about 9000 CWS wells for the existing version of the 31-state SDWIS database.

FIGURE 4

### Factors affecting the capture zone area

Pumping rate, porosity, aquifer size, groundwater velocity, and other factors, as well as the presence of an aquitard and groundwater recharge, should be assessed in analyzing the relationship between pumping stress factor and capture zone area.




### Model assumptions

#### "Base" case

- 5400 m long × 3000 m wide × 60 m thick aquifer
- No-flow through 5400-m sides
- Groundwater velocity = 0.3 m/day maintained by constant heads at the upper and lower boundaries
- Porosity = 0.33
- Transmissivity = 6000 $m^2$/day (horizontal hydraulic conductivity = 100 m/day)
- Vertical hydraulic conductivity = 10 m/day
- Water table at 0-m depth at the upgradient boundary
- CWS intake depth interval of 30 to 60 m

#### Aquitard case

- 10-m-thick aquitard located below surface from 10 m to 20 m
- Hydraulic conductivity of aquitard = 0.1 m/day
- Transmissivity = 6000 $m^2$/day (horizontal hydraulic conductivity = 120 m/d above and below the aquitard)
- All other parameters as in base case

#### Recharge case

- 1/3 of total flow into the model domain occurs by recharge from the surface (6000 $m^3$/day)
- 2/3 of total flow into the model domain occurs as groundwater flow (12,000 $m^3$/day)
- All other parameters as in base case

**Note:** Hydrogeologic conditions in aquifers are highly variable. The conditions assumed here are typical of those found in many of the relatively shallow, unconsolidated aquifers in some of the systems most highly used to supply drinking water in the United States. Examples include a) basin-fill aquifers (e.g., those in the California Coastal Basins, the Central Valley of California, and the Puget-Willamette lowland); b) surficial aquifers of the Coastal Plain along the Atlantic and Gulf coasts; c) glacial-deposit aquifers in the Northeast and Midwest; d) large river-valley alluvial aquifers; and e) the shallow parts of large blanket-sand deposits (e.g., the High Plains aquifer).

FIGURE 5

## A national-scale view of MTBE threats to wells

Available national databases concerning LUST and well locations information can be used to evaluate the proximity of these wells to LUST sites: (a) Overlaying the databases suggests the number of CWS wells compared to the number of LUSTs within 1 km of the wells; (b) integration of the distribution in Figure 5a provides an estimate of the cumulative frequency distribution.

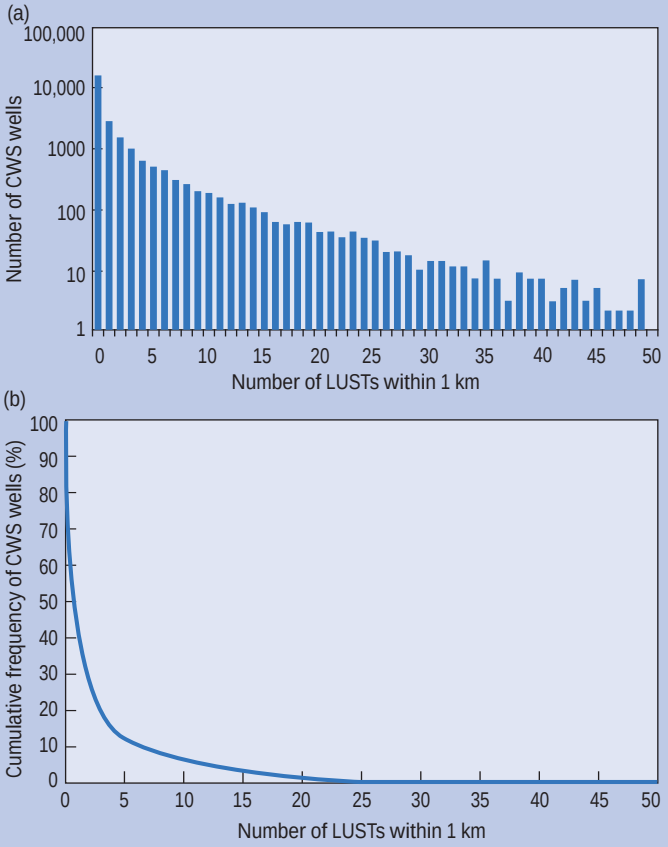
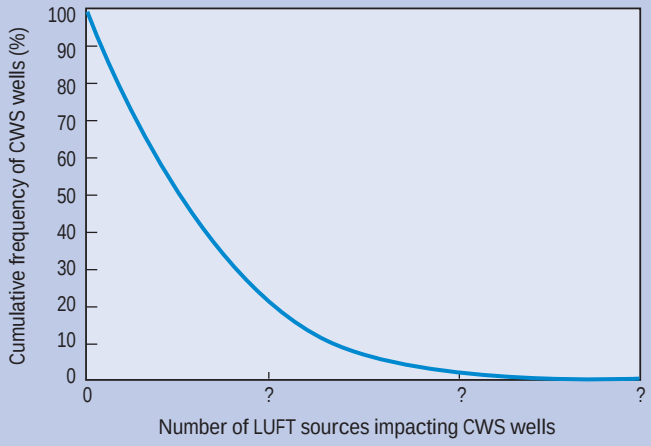



FIGURE 6

## LUSTs and well contamination: Data needed

Missing data, such as information concerning pumping rates, well characteristics, local aquifer yield, and other important well–aquifer data currently prevent determination of the 10-year capture zone areas for CWS wells and ultimately production of a figure in which the cumulative frequency of CWS wells versus the number of sources is shown.




Of course, not all LUSTs are LUFTs, not all LUFT sites will be contaminated with MTBE, and not all LUFT MTBE sites will be significant sources of MTBE. However, more than 90% of all LUSTs are LUFTs, perhaps 65% of all LUFTs are associated with MTBE contamination, and a large percentage of all LUFT MTBE sources is likely to have caused significant contamination by MTBE. Therefore, although the figure of 9000 CWS wells in the 31 states is undoubtedly an overestimate of the number of wells in those states with at least one significant LUFT-derived MTBE site, the number 9000 is so large that the actual number may well be worrisome.

As noted previously, information on pumping rates, well characteristics, local aquifer yield, and other important well/aquifer data is not available in a database for all the nation's CWS wells, or even for a random subset of those wells. Thus, the lack of this information currently prevents determination of the 10-year capture zone areas for CWS wells and ultimately production of a figure in which the cumulative frequency of CWS wells versus $n_s$ is plotted. A conceptual version of that plot, with no numerical labels on the $x$ axis, is given in Figure 6.

## Next steps

Although the large number of MTBE-LUSTs in the immediate vicinities of CWS wells may represent a significant threat to drinking water over at least the next decade, the data to determine the magnitude of that threat are simply not available at the present time. To address this issue, information is needed at all three of the scales discussed above. To improve our understanding of the temporal scale of the MTBE problem, a better data set of in situ MTBE biodegradation rates is needed. At the local scale, water providers need to better understand the stress that pumping is putting on their groundwater supplies. Finally, at the national scale, examination of this issue will require two new national databases, one for LUFTs and other sources, and one for CWS wells. As has been suggested by EPA's Blue Ribbon Panel on Oxygenates in Gasoline (*1*), the LUST database should focus on sites that actually represent threats to CWS wells. In addition to basic site location data, it should include information on the magnitude of each release and the available data on groundwater concentrations (i.e., source strength). The CWS database should contain hydrogeologic and pumping rate data for all CWS wells of interest to the nation. These databases will allow improved estimates of the numbers of CWS wells that may be affected by significant concentrations of MTBE over the next 10 years. And, quite independent of the MTBE issue, the databases will help identify aquifer and CWS systems that are being pumped at rates that carry unacceptable risks of contamination by persistent chemicals in general.

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