MTBE: Evaluation of Management Options for Water Supply and Ecosystem Impacts

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MTBE: Evaluation of Management Options for Water Supply and Ecosystem Impacts

EXECUTIVE SUMMARY

In response to concerns of MTBE contamination of water supplies, several policies to reduce MTBE in water sources have been enacted and proposed throughout the state including treatment, boating restrictions, use of other oxygenates and reformulated gasoline, and alternative sources of water supply. Water agencies in California are facing the possible adoption of a Public Health Goal of 14 micrograms per liter (ppb), and a drinking water secondary standard (based upon taste and odor) that may be set as low as 5 ppb by the California Environmental Protection Agency (CEPA, 1998). The effectiveness of these policies in reducing MTBE concentration, limiting exposure to protect ecological and human health are evaluated as well as their cost effectiveness.

MTBE concentrations have been reported at varying levels in the air, surface water, and groundwater. Though several sources may contribute to an increase in MTBE concentrations, boating and leaky under storage fuel system are by far the most likely sources to affect water quality. For the purpose of policy evaluation, the MTBE concentration in water sources, both groundwater and surface water, are estimated from groundwater storage fuel system leaks and their operations and boating contamination, respectively.

Policies are evaluated for five scenarios developed to account for water uses, type of water source, and users. The five scenarios are: (1) lake recreation and ecosystem exposure, (2) lake supplied public drinking water, (3) groundwater supplied public drinking water, (4) diversified public drinking water (combined groundwater and surface water supplies), and (5) groundwater supplied rural household drinking water.

MTBE control policies are compared for both human health and ecological risk objectives. MTBE control policies to reduce human health exposure based on (1) reduction in MTBE concentration, (2) reduction of expected exposure, and (3) economic cost effectiveness. MTBE concentration of surface and groundwater (in ppb) with and

without proposed policies are compared to the EPA proposed secondary standard of 5 ppb and rated based on likelihood of exceeding this proposed standard.

Based on the information gathered for this evaluation groundwater contamination is found to be orders of magnitude higher than surface water contamination. Therefore, human health is more likely to be affected by groundwater than by surface water. On the other hand, Ecological health, contingent on surface water, does not appear to be affected by MTBE at the levels produced by boating activities at two lakes studied. Of all alternative policies reviewed, treatment appears to be the most cost effective for groundwater. For surface water, reduction in 2-cycle engines boating reduces MTBE levels to acceptable concentrations and is more cost effective than other alternatives. In the short term, water related costs of MTBE oxygenated costs and other reformulated gasoline are comparable and are largely due to groundwater treatment. In the long term, water related costs of replacing MTBE oxygenated fuel with either Ethanol oxygenated fuel or non-oxygenated fuel may be lower than MTBE related costs.

INTRODUCTION

This report presents an evaluation component of a multi-disciplinary effort to study the impacts and management of MTBE in aquatic systems. The research project investigates a wide variety of topics related to surface water and groundwater supplies statewide, including current levels of MTBE in water supplies, environmental toxicity and risk assessment, and treatment. This report evaluates policies proposed to protect groundwater and surface water used for recreation, habitat, and supply from MTBE contamination. Each policy is evaluated in terms of its costs and effectiveness for reducing MTBE concentrations and exposures to protect ecological and human health. A variety of source control, management, treatment, and MTBE replacement options are evaluated.

History of MTBE

The 1990 federal Clean Air Act Amendments (CAAA), mandated use of reformulated gasoline (RFG), including the addition of oxygen-containing organic molecules ("oxygenates"). In winter months oxygenates have been added to increase completeness of combustion of gasoline in all areas of the USA that exceed the national ambient air quality standards for carbon monoxide (CO). The 1990 CAAA requires that gasoline sold in nonattainment areas for CO contain at least 2.7% (w/w) of oxygen, with the choice of fuel oxygenate left to the discretion of refiners. Methyl tert-butyl ether, MTBE, a by-product of the refining process, has been the most common choice of oxygenates. In addition, reformulated gasoline with fuel oxygenates has been approved by the USEPA to help lower volatile organic hydrocarbon (VOC) emissions which are precursors for ozone in photochemical smog in summer months. As a result, gasoline-containing MTBE is now used in California throughout the year; approximately 100,000 barrels of MTBE are used per day, every day of the year in California.

Reformulated gasoline provides economic and air quality benefits and complies with federal and state mandated air quality standards, helping to avoid costs of tens of billions of dollars in the South Coast Air Basin alone for ozone abatement strategies. Attainment areas provide increased opportunities for industrial development and USEPA sanctions for noncompliance can be avoided. The refineries gain large economically from using MTBE as an oxygenate, since MTBE can be produced from refinery process byproduct (Chang and Last, in press 1998).

California's air is cleaner since the adoption of reformulated gasoline. The entire state essentially meets the CO standard as of last year (only two monitoring stations showed exceedances). Last summer was the lowest photochemical smog season in recent memory in the South Coast Air Basin. While weather patterns and newer cars with better automobile emission devices also contributed to these air quality improvements, it is likely that fuel oxygenates probably played some role in reduction of CO emissions and possibly a role in reduction of ozone formation as well (Kirchstetter et al., 1997; Zielinska et al., 1997). In addition, reformulated gasoline (RFG) with MTBE reduces aromatic content, having less benzene and other known carcinogens than conventional gasoline.

Current concerns

Though there are air quality and economic benefits to reformulated gasoline with MTBE, there are concerns regarding potential effects of MTBE on water supplies.

MTBE's rapid and widespread introduction into the fuel system has resulted in its correspondingly widespread occurrence in surface water and groundwater. The United States Geological Survey National Water Quality Assessment Program reported that by 1993-94, MTBE was the second most frequently detected VOC in shallow urban ground waters (Squillace et al., 1996). This has led to action by the USEPA, which in December 1997 published a drinking water advisory about MTBE (EPA-822-F-97-009) and listed MTBE on the SDWA Contaminant Candidate List.

Since MTBE has high solubility in water and partitions relatively less to the organic phase than other gasoline constituents, it migrates rapidly from the point of spill through soil with the groundwater. Furthermore, MTBE in the environment is not readily degraded *in situ* by most soil microorganisms. Recent reports indicate that the compound is more biodegradable than at first believed, but validated field demonstrations are still lacking (Chang and Last, in press 1998). Those properties, along with its low taste and odor threshold, recent concerns about carcinogenicity and apparent low degradation rate, give MTBE great potential to contaminate water, particularly groundwater. In California, MTBE contamination of private and municipal drinking water wells has been prominent in the cities of Santa Monica, South Lake Tahoe, and San Francisco (Wiley, 1998).

In response to concerns of MTBE contamination of water supplies, several policies to reduce MTBE in water sources have been enacted throughout the state including treatment, boating restrictions, use of other oxygenates, and alternative sources of water supply. Water agencies in California are facing the possible adoption of a Public Health Goal of 14 micrograms per liter (ppb), and a drinking water secondary standard (based on taste and odor) that may be set as low as 5 ppb by the California Environmental Protection Agency (CEPA, 19998). Hence, there are regulatory, economic, and possibly exposure risk consequences to continuous use of MTBE that should be explored.

Overview of report

Following a brief review of MTBE impacts, major MTBE sources contributing to contamination of surface water and groundwater are summarized. Policies to reduce, eliminate, and treat MTBE are described and then evaluated. The effects of policies in reducing MTBE concentration and exposure are estimated for five scenarios of water uses including drinking, recreation, and habitat preservation. Policies that comply with the proposed secondary drinking water standard of 5 ppb are evaluated further for cost effectiveness.

MTBE IMPACTS

Human Health impacts

Human health impacts concerning MTBE exposure are primarily related to carcinogenicity. MTBE has caused cancer in two strains of laboratory rats and one strain of mice raising concerns that MTBE is a potential human carcinogen since existing epidemiology database is insufficient to evaluate carcinogenicity of MTBE in humans directly. Based on these research results, in 1997, the US EPA developed a drinking water advisory for MTBE, inferring that MTBE being an animal carcinogen could potentially be carcinogenic to humans as well (USEPA, 1997). In addition, the California Environmental Protection Agency has recently proposed that MTBE in drinking water be limited to 14 ppb to prevent excess cancer risk (CAEPA, 1998).

Other human health concerns including acute effects such as noticeable odor, headaches, dizziness, nausea, eye and respiratory tract irritation, a sensation of disorientation, rashes, and a burning sensation in the nose and throat; asthma; and reproductive development are plausible but have not been substantiated in studies.

Taste and odor has been a major issue in MTBE contaminated drinking water. The taste has been characterized as nasty, bitter, nauseating, and solvent-like. Sensitivity to taste and odor of MTBE has a wide range due to varying individual detection thresholds. The California Department of Health Services proposed a secondary maximum contaminant level (SMCL) for MTBE of 5 ppb based on available data of the observable detection thresholds.

Ecological impacts

In California, potential ecological impacts considered are particular to surface water. Due to its chemical properties, MTBE does not appear to bioaccumulate to a substantial degree in biota. Both modeling and experimental studies indicate that when MTBE is brought into the body of fish, it is rapidly excreted across the surface of the gills and through urine. The chronic No Adverse Effects Level concentration (for reproduction) for fathead minnows is 288 ppm (288,000 ppb), and the LC_{50} (concentration at which half of the test organisms die) for rainbow trout is between 880-1240 ppm (Johnson, 1998).

Toxicity of MTBE to other aquatic organisms is very low. Acute toxicity tests indicate that green algae have the lowest tolerance to MTBE with an LC_{50} of 184 ppm. LC_{50}s for zooplankton range from 340-680 ppm, and the chronic NOAEL for zooplankton is 200 ppm. For the purpose of this report, 66,000 ppb will be used as the toxicity reference value. This reference value represents the lowest toxicity value to an aquatic organism (fathead minnows) multiplied by safety factors to account for uncertainty (Mancini and Stubblefield, 1997).

MTBE SOURCES, TRANSPORT, AND EXPOSURE PATHWAYS

MTBE concentrations have been reported at varying levels in the air, surface water, and groundwater. Its movements are illustrated in Figure 1. Although all sources may contribute to an increase in MTBE concentrations, boating and gasoline storage systems (USTs) have been identified as the most critical sources and are identified in Figure 1 by heavy lines. The following subsections review the source and major flows of MTBE in aquatic environment.

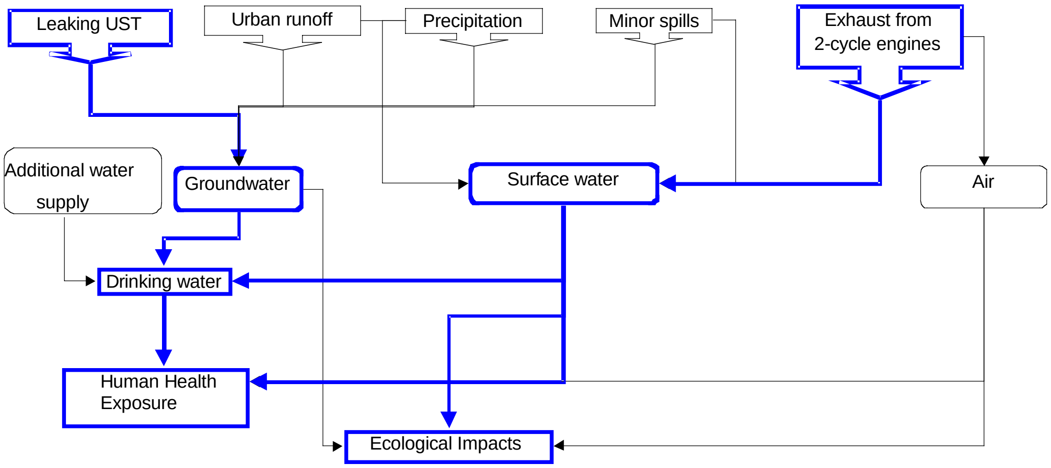


Figure 1: MTBE movements in the Environment

MTBE in Air

MTBE can enter the air atmosphere through engine exhaust, evaporative emissions from incomplete combustion, and fumes released at refueling stations (Squillance, P.J. et al, 1997). Reports of health related complaints from gasoline station attendants working near oxygenated fuel are supported by a survey that found MTBE concentration around refueling stations at averages ranging from 3 to 14 ppb and a maximum of 140 ppb. In urban areas, along roadsides, MTBE was detected at average concentration ranging between 0.025 and 8.4 ppb (Squillace, 1995).

MTBE in surface water

MTBE enters surface water (rivers, lakes, and reservoirs) through precipitation, stormwater runoff, boating activities on lakes and reservoirs, and accidental spills. Precipitation and stormwater in urban areas, where cars use gasoline with MTBE, does not appear to be a significant source of MTBE in surface water or groundwater. A monitoring study by the U.S.G.S. of 592 locations in 16 cities and metropolitan areas around the United States found MTBE concentration levels ranging from 0.2 to 8.7 ppb with a median of 1.5 ppb in 6.9% of sampled stormwater (Delzer, G.C. et al, 1996).

Motorized boating activities appear to be the most significant source of MTBE in surface waters. High MTBE concentrations are found in lakes where motorized boats are allowed, particularly near marinas and during boating seasons. In Donner Lake, a boating recreation lake in the Sierra Mountains, MTBE concentrations were found to be directly correlated to motorized watercraft activities. A survey of 120 reservoirs and lakes in California (see Table 1) found that 68% of the reservoirs with boating activities tested positive for MTBE concentration. Only 16% of the water bodies without boating activities had detectable levels of MTBE. For reservoirs without boating, detection of MTBE typically are attributed to sampling methods and generally not to other sources of MTBE. Sampling of water bodies were sporadic and MTBE concentrations were low with maximum MTBE concentration of 44 ppb (TRG survey data, not published).

Table 1: Detection of MTBE in surface water		Boating Activities		
		No Boating	Boating Allowed	Totals
MTBE Detection	Positive	8 Median Conc=1 ppb	48 Median Conc=6.4 ppb	56
	Negative	41	23	64
Totals		49	71	120

Other sources of high MTBE concentration in surface water are accidental spills from trucks transporting fuel, marina gasoline storage tanks, and refineries located along the coast (Cal/EPA, 1997). Accidental spills are reported to National Response Center of the US Coast Guard who maintains the Marine Spill Information System (MSIS). Overall spills of gasoline are very small volumes, compared with other releases. Since information on MTBE concentrations is sporadic and lacking and due to the random nature of spills, it is difficult to incorporate the impacts of accidental spills into an analysis.

MTBE in Groundwater

Sources of MTBE groundwater contamination include leaking underground fuel tanks and their inlet and outlet piping and operations, above ground storage tanks, farm tanks, leaking petroleum fuel pipelines, surface spills due to automobile or tanker truck accidents, surface spills due to abandoned or parked vehicles, and precipitation (Fogg, 1998). In comparison to stormwater runoff and boating activities, underground gasoline storage systems were found to contaminate groundwater at much higher concentrations of MTBE due to leaks and mishandling. Contaminated plumes travel easily with water through the soil, hindering the containment of MTBE in groundwater. In South Lake Tahoe, MTBE contamination has been attributed to poor operation of storage tanks where a broken gage resulted in frequent gasoline spills (Ivo Bergsohn, personal communication). A report by Lawrence Livermore National Laboratory (LLNL) reports that at 235 leaking underground fuel tanks (LUFT) sites located in 24 counties in California, 78% of 1,858 monitoring wells detected MTBE ranging in concentration from several to 100,000 ppb. 70% of wells with MTBE detection had concentrations above 20 ppb MTBE (Happel et al, 1998). Data from five major oil companies reported MTBE at levels greater than 10,000 ppb at 10% of 245 underground storage tank sites monitored (Cal/EPA, 1997). MTBE leaks are attributed both to the storage tanks and conveyance pipes.

Though all sources may contribute to an increase in MTBE concentrations, boating and leaky storage systems are by far the most likely sources to affect water quality. MTBE concentration in the air does not appear to be as significant a problem as MTBE in water. For the purpose of this report, the MTBE concentration in water sources, both groundwater and surface water, are estimated from gasoline storage system leaks and their operations and boating contamination, respectively.

EXPOSURE SCENARIOS FOR EVALUATION

Several problematic exposure scenarios are considered in this report. For each scenario, several policies are evaluated based on their potential to reduce health and ecological effects based on a risk and cost. Figure 2 is a schematic representation of the scenarios developed for policy evaluation. The following scenarios were developed to represent potentially problematic combinations of water uses, type of water source, and users:

1. Lake recreation and ecosystem exposure.
2. Lake supplied public drinking water.
3. Groundwater supplied public drinking water.

4. Diversified public drinking water (combined groundwater and surface water supplies).
5. Groundwater supplied rural household drinking water.

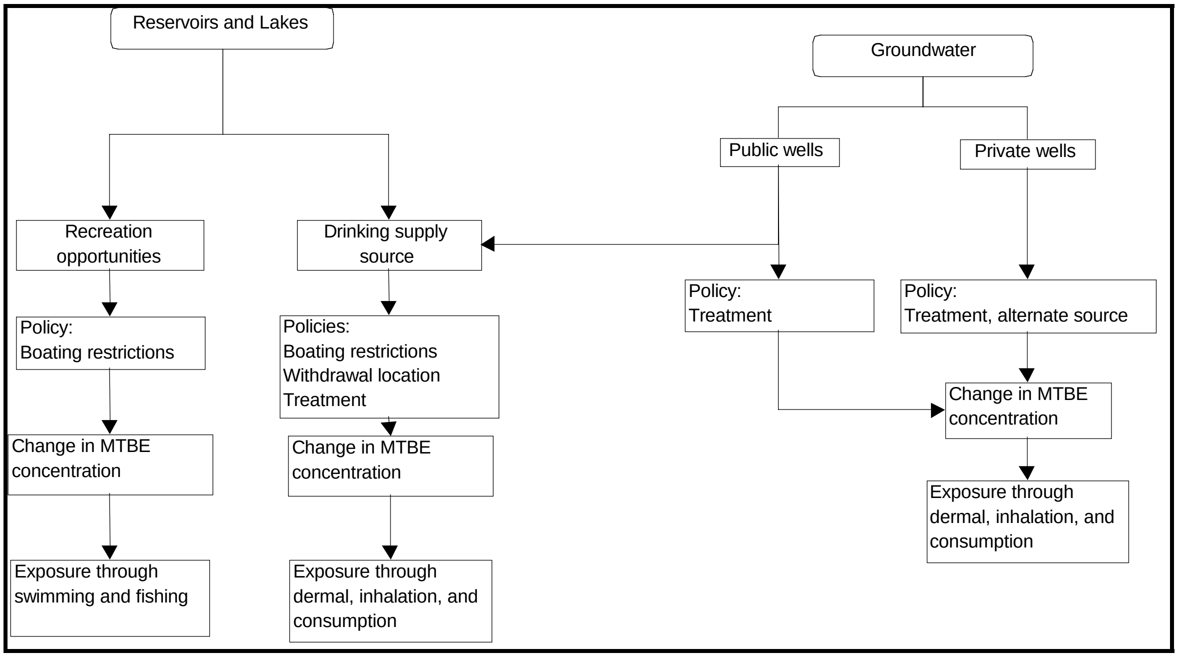


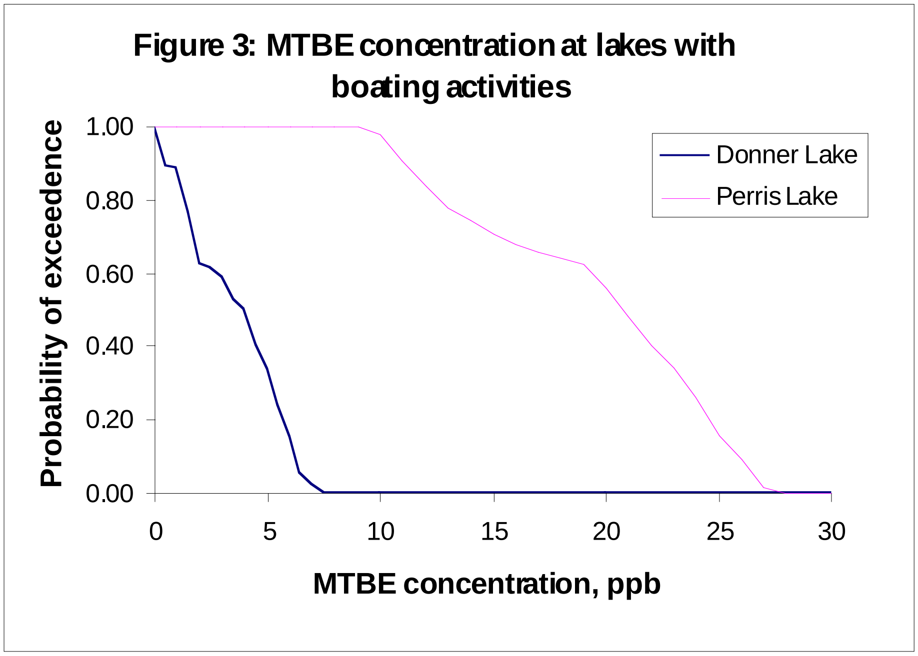
Figure 2: Policy Evaluation Scenarios

For the risk analysis, health effects are assumed to be related to water supply, through dermal, inhalation, and ingestion, and direct water contact such as swimming, and consumption of fish affected by MTBE. For evaluation of health effects, both groundwater and surface water sources are considered. Ecological impacts are based on MTBE concentration in surface water. Two lakes, Donner and Perris, are used to estimate possible ecological impacts of aquatic systems affected by MTBE.

1. Lake recreation and ecosystem exposure (Lake Perris and Donner Lake)

Model simulation results of two lakes, Donner and Perris, are used to evaluate the effect of MTBE contamination due to boating activities on lake recreation and ecosystem habitat. Donner Lake is located in the Sierra Nevada Mountains just east of Donner Pass and south of I-80. It is a natural lake with a concrete weir structure downstream adding approximately 3 m of controlled water storage. Due to the cold climate and remoteness of the lake, most boating activities occur during the summer months. The simulation period for Donner Lake is from May through September 1997 reflecting recreational activity in the summer months. Lake Perris is located in southern California, 14 miles south east of Riverside, California. It is owned and managed by the California Department of Water Resources (DWR) as a drinking water reservoir. Lake Perris provides recreational opportunities year round including boating, camping, fishing, swimming, and hiking. Boating activities are limited to 450 boats on the lake at any one time, a limit frequently reached. Due to limited data, simulation period for Lake Perris is limited to April through December 1997 (McCord, 1998). MTBE concentrations at Donner Lake and Perris Lake are shown in Figure 3.

In this analysis, the effect of MTBE from boating activities on other uses of the lake such as fishing and swimming as well as the impacts on the lake's ecology are estimated in terms of MTBE concentration and expected exposure.

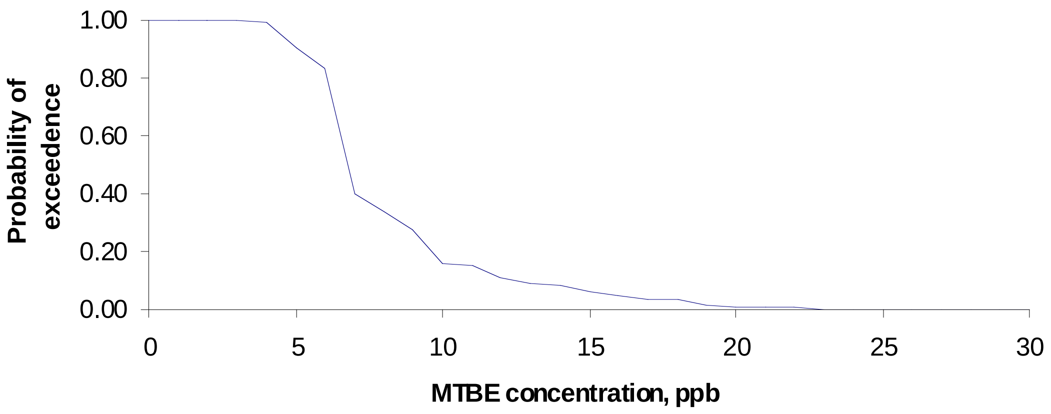


2. Lake supplied public drinking water (Lake Perris)

Lake Perris is used as an example of a public water supply source that relies on surface waters. Lake Perris provides an average of 271 thousand-acre feet (TAF) of public water supply annually. Boating activities at the lake have introduced MTBE levels as shown in Figure 4. MTBE concentration at Lake Perris, based on one-dimensional hydrodynamic model results, range from 9.9 to 27.4 ppb with an average of 19.4 ppb

(McCord, 1998). MTBE levels in Lake Perris exceed the 5 ppb proposed drinking standard 90.6 percent of the days modeled. Mitigation actions must be considered to meet a potential future standard of 5 ppb.

Figure 4: MTBE concentration at Lake Perris water supply
(existing operation and boating)



3. Groundwater supplied public drinking water

Groundwater makes up approximately 53% by volume of public water supply, serving 13.6 million people in California (USGS, 1990). Based on stochastic model studies accounting for advection, dispersion, sorption, and decay, and estimating that water supply wells within 2,000 ft horizontally and 200 ft vertically of the edge of an MTBE plume will potentially capture MTBE, estimated volume of groundwater impacted by MTBE is on the order of 100,000 acre-ft (Fogg, 1998).

Data obtained through September 17, 1998 from the Department of Health Services web site and submitted by Local Primacy Agencies were used to identify the public water systems that have been contaminated with detectable concentration of MTBE. Based on this data it is estimated that the total public wells that may be contaminated currently with MTBE ranges between 64-163 (Fogg, 1998). Groundwater MTBE levels are based on data collected by UC Davis in their efforts as part of this project. In their review of public well testing, they found that 3,493 MTBE contaminated sites have been found thus far. The number of contaminated site represents 43.6% of the open groundwater sites.

Concentrations detected at the sites reported by the nine Regional Water Quality Control Boards are based on current site maximums or the maximum at the sites when MTBE was first detected. Based on this data, 36% of the sits reporting MTBE groundwater contamination had concentrations less than 100 ppb and 48% of the sits had concentrations less than 500 ppb. 4.5% of the sites reported MTBE levels exceeding 100,000 ppb (Fogg, 1998). High MTBE concentration in public wells resulted in the closure of wells in Santa Monica, Marysville, and South Lake Tahoe. It is expected that with time MTBE concentrations will increase due to the mobile nature of MTBE and increased testing of wells throughout California.

MTBE levels in groundwater are based on MTBE levels found in aquifers affected by underground storage tanks as shown by the cumulative distribution in Figure 5 from the data collected by UC Davis revealing high levels of contamination with 85% chance of exceeding the 5 ppb proposed secondary drinking standard.

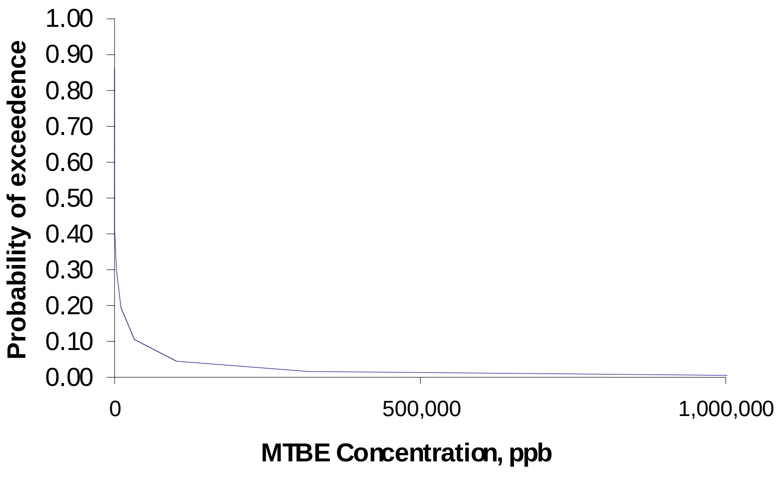


Figure 5: MTBE in groundwater (Fogg, 1998)

4. Diversified public drinking water

Public supply from groundwater and surface water serves the majority of California’s population. In California, public suppliers serve 25.5 million people. Total public supply in California by volume is almost equally divided between groundwater

(53%) and surface water (47%) (USGS, 1990). The allotment of groundwater and surface water varies by region. In the South Coast region of California, served by Metropolitan Water District, 25% of the public water supply is groundwater whereas, in the Central Coast region, 82% of public water supplies are groundwater (DWR, 1994). For this analysis, data from Lake Perris will be used to represent likely MTBE concentrations in surface water and data from the UCDavis report (Fogg, 1998) will be used to represent likely MTBE concentrations in groundwater.

5. Groundwater supplied rural household drinking water

4.28 million people in California rely on private wells, at an approximate total rate of 212 Mgal/day (USGS, 1990). Whereas in most cases, public supplies can draw from both surface and groundwater sources, private supplies depending solely on groundwater can be devastated by MTBE contamination. For example, private wells in the City of Glenville were found to be highly contaminated with MTBE resulting in their closure and dependence on imported water (Fagin, 1998). In addition, given the smaller size of rural distribution systems, treatment may be much less economical. However, most private rural wells are likely to be farther from gasoline storage systems.

Based on data from the Department of Health Services, 35 public water systems have been identified to be contaminated with detectable concentrations of MTBE. This number of impacted wells constitutes 1.17% of all the public supply wells that were tested for MTBE and 0.27% of al public supply wells in counties where at least one well was tested. The 1.17% contamination represents high bound since it is based on testing done in areas suspected of contamination. The 0.27% represents a low bound for contamination in the state’s public wells. Since there are no routine testing of private wells these bounds are used to estimate MTBE contamination in private wells. Of the 464,621 private wells reported in California during the 1990 United States Census, between 1,236 and 5,442 private wells may be contaminated with MTBE (Fogg, 1998). Since private wells are less likely than public wells to be near fuel storage tanks, the low bound of 1,236 contaminated wells is probably a more realistic estimate than the high bound of 5,442. For this exposure scenario, MTBE concentration in groundwater is assumed to have the same cumulative distribution as for public supply. Each well is assumed to provide 456 gal/day (212 MGD/464,621 wells).

CRITERIA FOR EVALUATING MTBE CONTROL POLICIES

MTBE control policies are compared for both human health and ecological risk objectives. MTBE control policies are evaluated based on potential to reduce human health exposure based on (1) reduction in MTBE concentration, (2) reduction of expected exposure, and (3) economic cost. MTBE concentration of surface and groundwater (in ppb) with and without proposed policies are compared to the EPA proposed secondary standard of 5 ppb and rated based on likelihood of exceeding this proposed standard.

Individuals can be exposed to MTBE in drinking water by several exposure pathways. Individuals ingest water by drinking and through the use of water in cooking. Tap water used for showering, bathing, and periodic washing results in dermal exposure, and inhalation exposure can occur through the volatilization of MTBE from shower water into the rest of the house. Pathway exposure factors are calculated for all pathways using parameters obtained from several sources including Brown (1998), McKone and Bogen (1992) and the U. S. EPA exposure factors handbook (USEPA 1989). Distributions used in the probabilistic assessment were obtained from McKone and Bogen (1992), the State of California (document on probabilistic risk assessments), and the Oregon Department of Environmental Quality draft guidelines on probabilistic risk assessment (Johnson, 1998).

A baseline analysis was performed using a 14 ppb concentration of MTBE in water. The 14 ppb level is the concentration calculated to increase risk of developing cancer by one in one million (1×10^{-6}) (CEPA, 1998). This concentration was estimated based on ingestion exposure only and corresponds to a daily exposure of 0.00042 mg/kg-d. In comparison to ingestion, which makes up approximately 28% of total expected exposure, inhalation accounts for 71.5% of the total expected exposure and dermal exposure is negligible. Considering all three paths of exposure, one in a million chance of having cancer due to MTBE contamination may potentially corresponds to lower MTBE concentration than 14 ppb.

The effect of MTBE on ecological and human health is evaluated in terms of expected exposure. Ecological risk is estimated as the ratio of expected exposure to toxicity reference value. Expected exposure (EE) is the probable exposure of an organism to a pollutant either through direct inhalation or through food intake, per body mass (mg/kg-day). EE is estimated using model results of surface MTBE concentration at Perris Lake and Donner Lake. EE is assumed to be 1.5 times the concentration of the water. The toxicity reference value (TRV) is the maximum pollutant concentration at which no adverse effects are observed in the organism. TRV was taken to be the fathead minnow MATC or 66,000 ppb, the lowest chronic value found in the literature (Mancini and Stubblefield, 1997). The ratio of expected exposure and toxicity reference value, the hazard quotient (HQ), is the measure used in this risk analysis. If the hazard quotient is greater than 1, the organism is assumed to be adversely affected by existing pollutant. For this analysis several assumptions were made. The analysis assumes that fish spend all their time in the epilemnion exposed to the maximum MTBE concentration in the lake; fish are exposed to MTBE through ingestion, inhalation, dermal contact, and bioaccumulation; and that the exposure is fundamentally the same as other common species likely to be found in the lake's environment. The analysis ignores variability in possible effects of variable concentration in the water and the effects of other pollutants in gasoline leaking from boats into the lake's water.

The cost analysis of MTBE policies will be based on achieving the proposed 5 ppb secondary drinking standard. Policy costs are reported as annualized quantities.

MTBE CONTROL OPTIONS

A wide variety of management options exist for MTBE contamination. Table 2 provides a summary of policies to reduce MTBE concentration in water bodies. Not all policies are applicable to all scenarios. Source control options for surface water are typically different than those for groundwater.

Table 2: MTBE Control Options	
Options	Variations
Source Control	Restrictions on 2-cycle Engine watercraft Water Withdrawal depth and intake schedule Groundwater remediation Fuel storage tank replacement
Water treatment	Air stripping Adsorption Advanced oxidation Biological treatment Membrane separation
Alternative water supply	Purchase of other water supply Bottled water
MTBE elimination	Ethanol Non-oxygenated RFG
No Action	

Surface water source control

Several source control options that are available for surface waters are described below.

Restrictions on 2-cycle Engine watercraft

For three lakes, Lake Perris, Donner Lake, and Calero Lake in California, the results of hydrodynamic models and field studies indicate that MTBE in lakes increase with motorized boating activities. This is also supported by comparison of MTBE levels statewide in lakes with and without motorized boating. In Lake Tahoe a proposal by TRPA was approved in 1997 to phase out two-cycle marine engines with restrictions on engines beginning in 1999. In Santa Clara County, boating is restricted to times when MTBE levels are below the advisory level of 20 ppb, effectively reducing water craft use by 30 percent.

The economic cost of limiting boating is assumed to be based on the willingness to pay for recreational boating. The average willingness to pay for boating based on review of several studies of lakes with boating activities is $33 per boater per trip (Wilchfort et al, 1998). Boat rental at Lake Perris is $35 per day during weekdays and $54 per day on weekends. For this analysis boats are assumed to value $162/day (assuming 3 passengers per boat).

Changing water withdrawal depth

MTBE concentrations often vary with depth in a reservoir. Different withdrawal depths from a lake or reservoir will result in varying water supply MTBE concentrations depending on the lake's stratification. The effectiveness of changing water withdrawal depth in reducing water supply MTBE concentrations is highly dependent on the lake's character and mixing patterns.

Groundwater source control

Remediation

Regional Water Quality Control Boards require remediation of contamination to protect the beneficial uses of groundwater. No cleanup goals have been established by the Regional Boards or the State Water Resources Control Board thus far for MTBE in groundwater. Though given the mobility and recalcitrance of MTBE, it is likely that investigation and remediation will be required for many MTBE groundwater contamination sites.

The costs of investigation and remediation are vary greatly with the location of the site, the depth to groundwater, the extent of the vertical and horizontal migration of the groundwater plume, contaminant characteristics and the subsurface geology. In a pump-and-treat strategy, one can anticipate pumping a volume of groundwater that is 10 to 100 times larger than the volume of groundwater than is contained in the contaminated plume. Remediation costs range from $30,000 -$500,000 for a single aquifer impacted with a 250 foot plume and groundwater table depths ranging from 20 to 100 feet. For a contaminated site where a second underlying aquifer may be contaminated with a 250 foot plume, the costs range from $75,000 to $750,000 depending on the depth of the groundwater table and where a third aquifer may be contaminated with a 1000 foot plume, the costs range from $150,000 to $2.5 million (Fogg, 1998). Because during the investigative process, sites often are prepared for remediation, the costs for remediation may not be as high. Given current technology and the characteristics of MTBE, groundwater extraction and treatment is the preferred remediation alternative. Treatment costs associated with extraction, treatment, and disposal or re-injection, range from $250,000 to $1 million. Treatment costs vary ranging from $0.5 - $0.6/1000 gallons using air stripping to $1.2 - $1.4/1000 gallons for a GAC/solid resin based treatment. The detection of tertiary butanol (TBA), another oxygenate, increases the cost and difficulty to remediate. TBA can be detected in MTBE groundwater contamination plume either because it was added deliberately as an oxygenate, was introduced into the fuel as a industrial by-product, or was produced as a degradation by-product. When TBA is present air stripping is not effective and the preferred treatment option is advanced oxidation with costs ranging from $0.80 - $0.90/1000 gallons (Fogg, 1998).

Underground fuel storage tank replacement

EPA regulation 40 CFR 280 requires upgrading of old fuel storage tanks and monthly testing for leaks in tanks and piping. The federal standard requires that all tanks and piping be replaced with a non-corroding variety (cathodically protected steel, fiberglass or fiberglass clad steel (tanks only)). California also has required that all storage tanks be double-walled to prevent releases. Replacement deadline of tanks and piping is Dec. 23, 1998 with the goal of reducing gasoline spills that contaminate groundwater supplies. The estimated cost of complete replacement of underground storage tank system is between $60,000 and $80,000 (Dr. Tom Young, UC Davis personal communication).

Inspection of tanks and piping for leaks were found to be infrequent and unreliable. Out of a data set of 1705 records of reported leaks inspection results were available for only 29% tanks and 23% piping. Of the leaky tanks that were inspected, 95% passed their last test. Similar observations were made for piping testing. This high percent of test failure suggests that required tests, if performed, are not a reliable method of identifying under storage system leaks (Couch and Young, 1998).

To estimate the effect of new tanks on the probability of leaks, Couch and Young (1998) obtained two databases from USEPA and CaSWRCB with national and statewide UST information, respectively. The EPA database (the Corrective Action Database or

CAD) with information on numbers of active tanks, cumulative number of tanks closed, and cumulative number of confirmed releases, per state on a quarterly or semiannual basis was used to identify leakage incidence trends. Data from 1991 to 1997 were used in analysis of the EPA CAD. From these data, an average baseline leakage probability of 2.6% per year was estimated, representing an estimate of the incidence of leakage in the active tank population over a one-year period if UST population demographics remain relatively static (Couch and Young, 1998). Since no clear trend was observed representing reduction in leaks with new storage systems and given the consistent occurrence of leaks from storage systems (2.6%) as documented by the EPA database for years 1992 through 1997, it unlikely that replacing under storage tanks would have substantial impact on reducing leak events and MTBE concentration in groundwater.

Water treatment

MTBE can be removed from water using a variety of well-established treatment technologies. The selection of treatment method will depend on treatment's removal efficiency and reliability, desired capacity, feasibility, operational requirements, flexibility in handling variability in pollutant concentration, and cost. Treatment technologies proposed for MTBE removal are described briefly below. Though a combination of treatment technologies sometimes can improve MTBE removal, for the purpose of this report, treatment technologies are considered independently.

Air stripping

Air stripping treatment removes volatile compounds from drinking water supplies. Air stripping technologies include packed towers, low profile air strippers, bubble diffusion trippers, spray towers, and aspiration air strippers. Of all available stripping technologies, packed towers were found to be the most cost effective technology for MTBE (Pirnie, 1998draft). Packed tower stripping generally consists of high-surface-area packing material supported and contained in a cylindrical shell. Water flow is normally downward through the packing material with either forced draft or induced draft upward airflow. Packed towers are generally more efficient than other air stripping method in removing highly volatile VOCs (Hamann, et al., 1990).

The removal efficiency of air stripping depends on the contaminant's mass transfer rate and Henry's law constant. In general, increased temperature and increasing mass transfer rate can improve removal efficiency. For highly soluble compounds, such as MTBE, high air/water ratio and low loading rate is needed to ensure high removal rate. Air stripping produces contaminated effluent air and effluent water with reduced contaminant concentrations. Where daily MTBE emission from the air stripping system exceeds 1 pound, off-gas treatment may be required. Off-gas treatment technologies include carbon adsorption, thermal and catalytic oxidation, biological treatment, and advanced oxidation. The most cost efficient off-gas treatments appear to be thermal oxidation for high concentrations and carbon adsorption and biological treatment for concentrations below 100 ppb (Pirnie, 1998).

Adsorption

Adsorption is the process of a substance accumulation at the interface between two phases, liquid and a solid. The pollutant accumulates, or adsorbs, at the interface, the adsorbent. Adsorbents used in water treatment include activated carbon, various synthetic resins, and clays. Granulated activated carbon (GAC) is widely used, in columns or beds, for the removal of dissolved organic, color, and taste-and color-causing compound in water. Contact time and application rate, with a given feed-water quality and desired finished water quality, determine the size of the GAC contactor and the activated carbon usage rate, which in turn control the capital and operating cost for the GAC process (Hamman et al., 1990).

GAC has been very effective at treating many organic chemicals such as benzene. However, MTBE is more soluble in water and has relatively low affinity to activated carbon, and so requires large amounts of carbon, making the process uneconomical for large-scale treatment. High grade coconut shell has been proposed for removing MTBE from water since coconut shell carbon has significantly higher adsorptive capacity for MTBE in comparison to the commonly used coal-based carbon (ACWA, 1998). Synthetic resins are an alternative adsorption media for MTBE removal from water and can be used for liquid phase adsorption of MTBE. Synthetic resins are water insoluble and have a high specific surface area. Synthetic resins have shown good TDS removal in groundwater and are cheaper than Carbon adsorption because of resin's larger adsorption capacity.

Advanced oxidation technologies (AOT)

Advanced oxidation is the chemical process that involves the removal of electrons. Advanced oxidation generates highly reactive hydroxyl radicals (OH) that are useful for the transformation of a wide range of pollutants found in water. Hydroxyl radicals are especially useful for treatment of low concentrations of organic pollutants in contaminated groundwater. Advanced oxidation technologies include ozone (O_3), hydrogen peroxide (H_2O_2), ultraviolet (UV) light, ultrasonic cavitation, titanium dioxide (TiO_2), and high-energy electron beam. Advanced oxidation is widely used for both drinking water treatment and groundwater remediation for oxidation of a variety of organic chemicals.

The critical factors influencing advanced oxidation efficiency are contact time, concentration of the reactive intermediate, and reaction rate. MTBE is not a very reactive compound, and only strong oxidizing agents have the potential for being successful in a full-scale system. In a full-scale MTBE system, there must be high efficiency of reagent consumption, and it must operate at a high flow rate (greater than 1,000 gpm). In some cases, the use of such a strong oxidizing agent may cause oxidizing of other species. Treatment of these oxidation by-products may be problematic and difficult (ACWA, 1998).

Biological treatment

Biological degradation of organic contaminants is common in wastewater treatment. Biological MTBE removal converts MTBE to cell mass, carbon dioxide, and water by microbial cultures. MTBE in the liquid or air phase is brought into contact with microbial cultures that are either attached to a support media or suspended in liquid and use MTBE as a carbon and energy source. MTBE from the contaminated liquid or air diffuses into the thin film and is degraded.

The liquid film in biofilters is maintained by adding water to keep the bed moist. For the aerobic process dissolved oxygen is added in the influent or diffused through the thin film. Nutrients are added if the contaminated flow does not contain adequate amounts to support biological activity. The removal rate of MTBE depends strongly on the composition of the water to be treated. In addition, there is concern over the reliability and microbial quality of treated water.

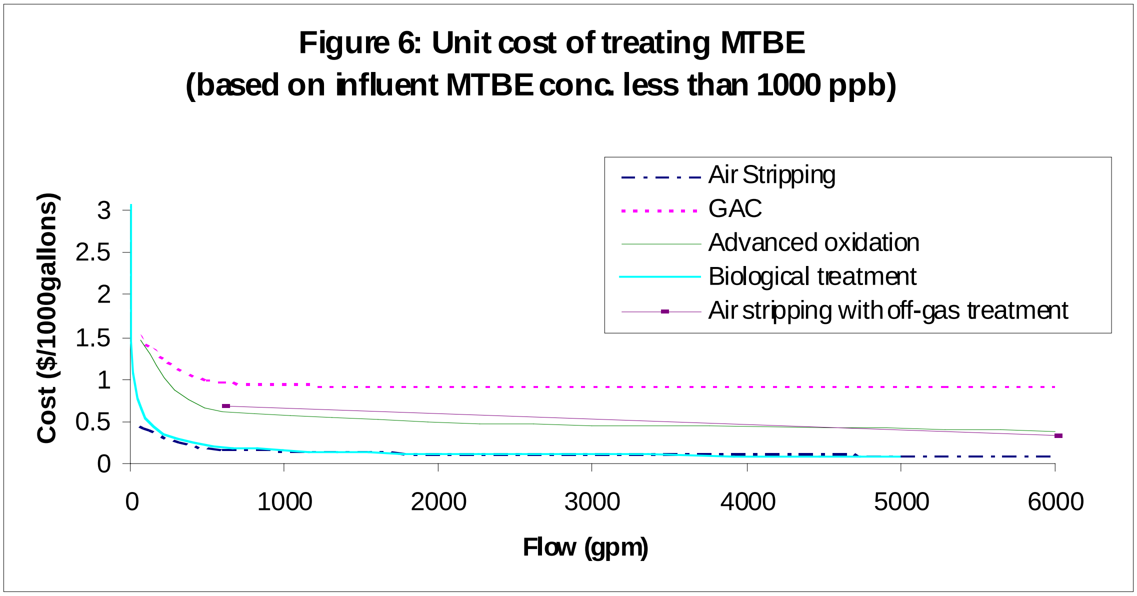
Membrane Separation Processes

Membrane processes require a membrane is able to reject or select passage of certain dissolved species based on compound size, shape, and/or charge. Membrane processes include reverse osmosis, electrodialysis, and ultrafiltration. Membrane processes are generally considered in cases such as desalination, brackish water conversion, and removal of specific ions that are difficult to remove with other processes. Removal efficiency of membrane process depends on the quality of the feed water and desired product water quality; the more contaminated the feed water and the higher the desired product water quality, the greater the likelihood of membrane fouling (Hamman et al., 1990).

Though reverse osmosis and nanofiltration are possible processes to selectively remove MTBE from water, reverse osmosis has the greatest potential for MTBE removal because it is designed to remove small solutes such as sodium and chloride ions. Since no information is available on MTBE removal efficiency with membrane separation, it will not be considered further in the analysis.

Treatment costs

Costs for the treatment alternatives, shown graphically in Figure 7, are based on a system with 99.5% removal efficiency and incoming MTBE concentrations below 1000 ppb. Costs are based on 20-year period at 4% discount rate and include both capital and operation and maintenance costs.



Cost of treatment is very sensitive to site specific parameters such as water temperature, MTBE concentration, presence of other organic compounds, general water chemistry, cost of property, and the number of treatment systems required. Therefore, accuracy of estimates can vary between –30 to +50 percent of the actual cost (Pirnie, 1997). The least expensive alternatives are air stripping and biological treatment. Air stripping cost will increase with a need for off-gas treatment and flow. Of all treatment alternatives, GAC appears to be the least attractive alternative.

Elimination of MTBE as a fuel component

MTBE is used in California in response to the federal 1990 Clean Air Amendment requiring that reformulated gasoline sold in non attainment areas be formulated to contain at least 2 percent oxygen by weight. Though MTBE is the most commonly used oxygenate because of its low cost and ease of production and transfer, other alternatives are available including other oxygenates and reformulated gasoline that meet the 2 percent oxygen by weight requirement.

Ethanol

Ethanol is an alternative oxygenate widely used as a gasoline additive nationwide. In California, Ethanol is being used experimentally in limited region of Northern

California. Though Ethanol can be used to meet the regulatory standard it is difficult to use. Ethanol has high affinity to water making its distribution and storage difficult; great care must be taken to isolate Ethanol from water before and after it is blended with gasoline. The Ethanol/gasoline mixture has high vapor pressure requiring refinement of the base gasoline used. Also, some health concerns related to air quality and water supply contamination have been raised with potential wide use of Ethanol (Keller et al., 1998). Ethanol has very high solubility and therefore readily dissolves in groundwater, potentially at high concentrations. Like MTBE, Ethanol behaves as a conservative solute, moving with water but unlike MTBE, ethanol is very biodegradable. Treatment options for Ethanol are limited to bioremediation and soil vapor extraction. Air stripping and adsorption are not practical treatment alternatives since Ethanol has low volatility and low affinity for carbon (Western States Petroleum Association, WSPA). Replacing MTBE with Ethanol may not change the need to treat water supplies contaminated with oxygenates and therefore would not alleviate all the perceived problems of MTBE.

Non-Oxygenated Reformulated Gasoline (RFG)

Two primary requirements control RFGs composition: the Federal RFG and the California Phase 2 RFG. The California Phase 2 RFG has more stringent regulations than the Federal RFG. Statistically, there is no significant difference in the emissions reduction of benzene and peak ozone concentrations between the use of oxygenated and non-oxygenated RFGs that meet all CaRFG2 standards. Since fuel oxygenates are required by the Federal RFG, non-oxygenated RFGs may not be a viable option at this time. In addition, most refiners in California are not prepared to immediately produce only non-oxygenated RFG (Keller, 1998). Although, in the short term non-oxygenated RFG may not be a feasible alternative, non-oxygenated RFG are considered in this evaluation since its use may in the future result in MTBE exposure reduction in California's water supply while meeting CaRFG2 requirements.

Use an alternative water supply source

Cities dependent on either surface waters or groundwaters contaminated with MTBE can look for an alternative supply such as bottled water for drinking or other groundwater or surface water sources. The City of Santa Monica, dependent on groundwater supply, found two of its three aquifers to be contaminated with MTBE levels high enough to require the closure of several wells. Water was imported from MWD to augment water supply. In this analysis imported water will be assumed to be $500 per acre foot based on MWD's cost of imported water (MWD, 1996). This type of wholesale alternative water is available for most urban areas, particularly those located in major metropolitan areas, though at an increasing expense.

For more rural households, with isolated drinking water sources, alternative drinking water supplies would likely be bottled water eliminating ingested exposure, but retaining most dermal and inhalation exposures. In these rural contamination cases, household treatment of water used indoors may be desirable.

No response

If existing MTBE levels in groundwater or surface water are not affecting the ecology or human health, it may not be necessary to change existing use of MTBE as a gasoline additive. Policies to reduce MTBE concentration in water sources or water supply will be compared to existing conditions based on existing use of MTBE.

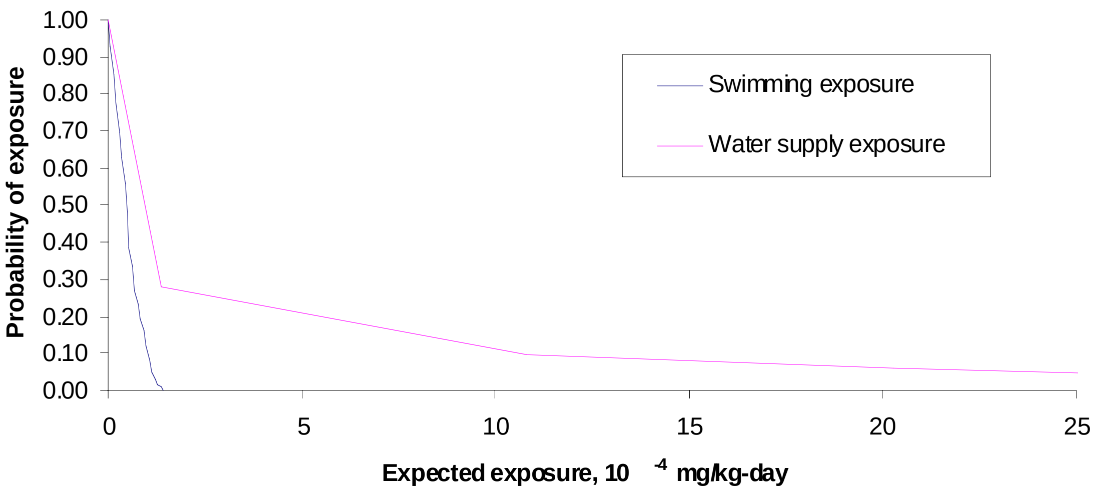
COMPARISON OF ALTERNATIVES FOR THE SCENARIOS

Policies to reduce MTBE concentration and exposure are compared for the five scenarios described above. Policies are evaluated based on the likelihood of exceeding the proposed secondary standard of 5 ppb and expected exposure for ecological and human health. Policies that meet the 5 ppb proposed standard are compared for cost effectiveness.

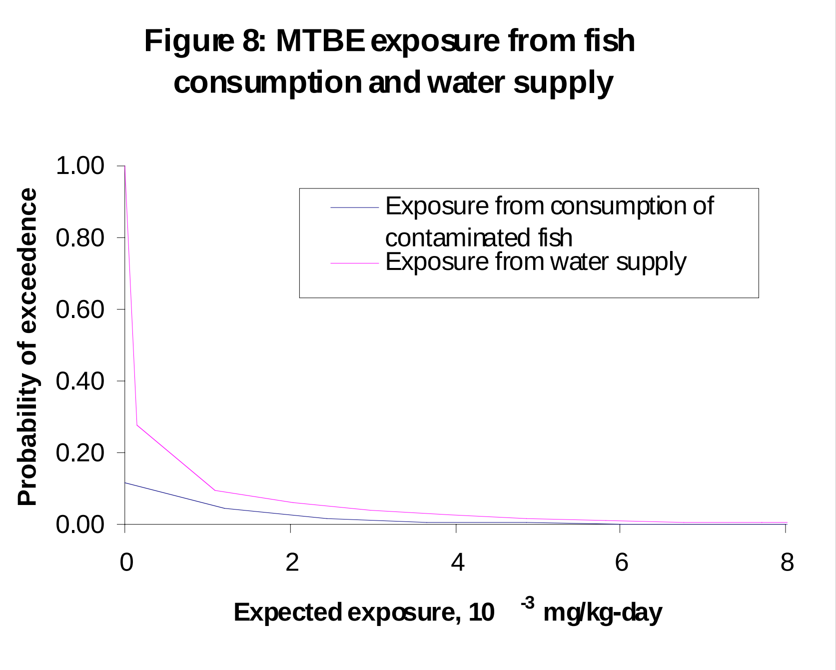
1. Lake recreation and ecosystem exposure

Swimming and consumption of contaminated fish are considered as MTBE exposure pathways. Exposure during swimming is due to dermal contact and incidental ingestion of water while swimming. Time spent in contact with the water during swimming is approximated as 30 minutes to 2 hours per day, every day. Ingestion rate of water while swimming is estimated as the U.S. EPA default value of 7 x 10-4 liters per kilogram of body weight per day. It was assumed that during the entire time spent swimming, 65% of the body would be exposed to MTBE in the water. With these assumptions, the exposure during swimming is an order of magnitude lower than that for exposure to indoor water as shown in Figure 7 and is therefore not considered an exposure threat (1998).

Figure 7: MTBE exposure through swimming and water supply



Exposure due to consumption of contaminated fish is based on the Oregon Department of Environmental Quality guidelines and estimated with the following assumptions: 1) all fish consumed originated in a lake contaminated with MTBE; 2) the fish spent all of their time in the upper portions of the lake where the concentrations of MTBE are the highest; 3) the fish bioaccumulate MTBE at a rate of 1.5 times the concentration of MTBE in the water; 4) fish are consumed daily; 5) between 20 and 60% of the fish is edible; and 6) all MTBE from the fish is absorbed in the gastrointestinal tract. Even with the restrictive assumption of daily consumption of fish, average daily exposures are between 50% and 75% of the exposure generated by the 14 ppb PHG level. Using a less restrictive assumption of consumption of fish three times per week, the exposure drops to an order of magnitude lower than the 14 ppb exposure level (Johnson, 1998). Exposure levels from contaminated fish consumption are lower than proposed standards for water supply and water supply exposures as demonstrated by Figure 8, and therefore contaminated fish consumption is not considered an exposure risk.



For ecological risk, the hazard quotient was calculated based on expected exposure of 1.5 times MTBE concentration in Lake Perris and Donner Lake and a toxicity reference value of 66,000 ppb (Mancini and Stubblefield, 1997). The hazard quotient distributions, representing the likely adverse effects of MTBE concentration on aquatic specie in Donner Lake and Lake Perris, are well below one, as shown in Figure 9. It is therefore assumed that MTBE at present levels in Donner Lake, Perris Lake, and most other lakes are unlikely to adversely affect aquatic life and do not require any mitigation.

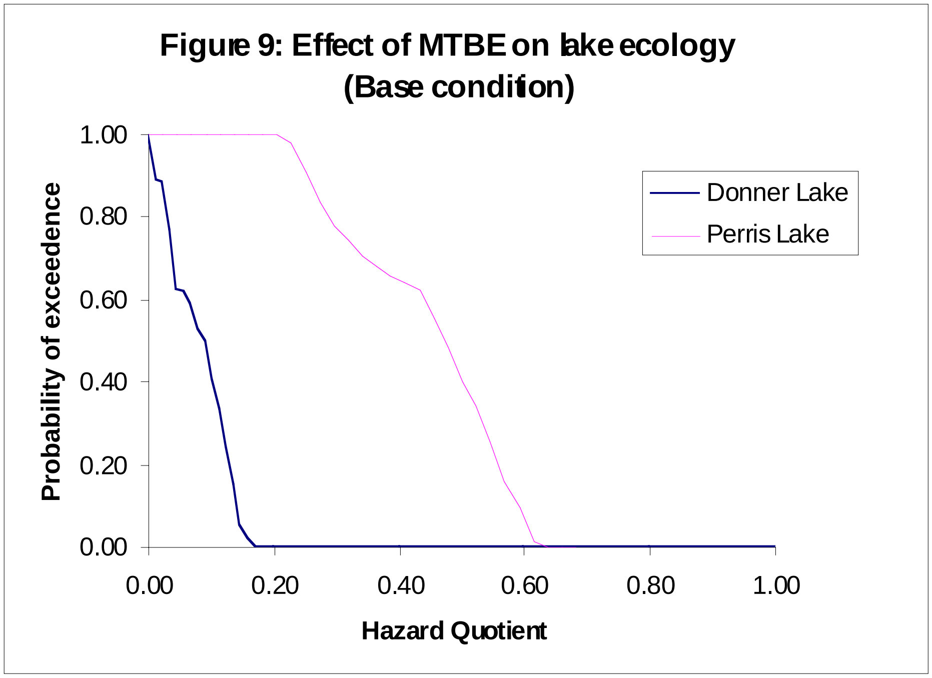


Figure 9: Effect of MTBE on lake ecology (Base condition)

2. Lake supplied public drinking water

Of available policies, reduction in motorized boating activities, change in intake depth, treatment, MTBE ban, and imported water supply may potentially improve lake-supplied public drinking water. Table 3 provides a comparison of policies relevant to lake-supplied public drinking water at Lake Perris.

Table 3: Lake supplied public drinking water (Lake Perris)[1]

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[1] Data in the table is based on modeling MTBE in Lake Perris during a period between April and December, 1997.

	Policy	Proposed secondary drinking standard		Proposed Public Health Goal		Cost ($M/yr)
		Ave. Conc. (ppb)	Exceed. 5 ppb (% days)	Ave. EE[2] (10^{-3} mg/kg-d)	Exceeding EPA EE[2] (%)	
	Existing condition	8.76	90.6	0.922	75.2	
Source Control Options	Reduce 2-cycle engines					
	10%	8.32	89.8	0.875	72.1	N.F.[3]
	25%	7.52	86.5	0.791	68.2	N.F.
	50%	6.26	66.4	0.659	60.7	N.F.
	100%	0	0	0	0	6
	Withdrawal depth (m)					
	11.9	7.67	92.2	0.807	72	N.F.
	16.8	8.94	98.0	0.940	81.4	N.F.
	21.6	13.2	98.0	1.38	91.5	N.F.
Treatment Options	Air stripping	5	0	0.53	0	2
	Air stripping w/gas	5	0	0.53	0	8
	Carbon Adsorption	5	0	0.53	0	11
	Advanced oxidation	5	0	0.53	0	9
	Biological treatment	5	0	0.53	0	3
					0	
	Alternative Supply	0			0	36

For Lake Perris, the results of hydrodynamic modeling (McCord, 1998) show that boating restrictions reduce MTBE concentration in water supply, but not nearly enough to meet the proposed 5 ppb standard unless 2-cycle engine boating activities are banned as shown in Figure 10. Compared to an average MTBE concentration of 8.76 ppb in the outflow, boating reduction of 50% has an average MTBE concentration of 6.26 ppb which is higher than the desired 5 ppb standard.

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[2] EE- Expected Exposure

[3] N.F.- Not feasible in meeting 5 ppb proposed secondary drinking standard alone.

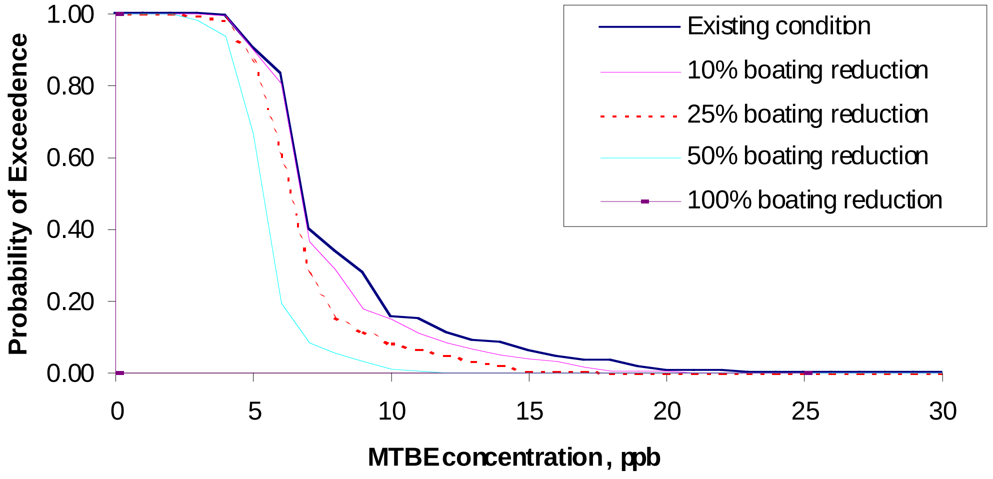


Figure 10: Effect of boating reduction on MTBE concentration at Lake Perris water supply

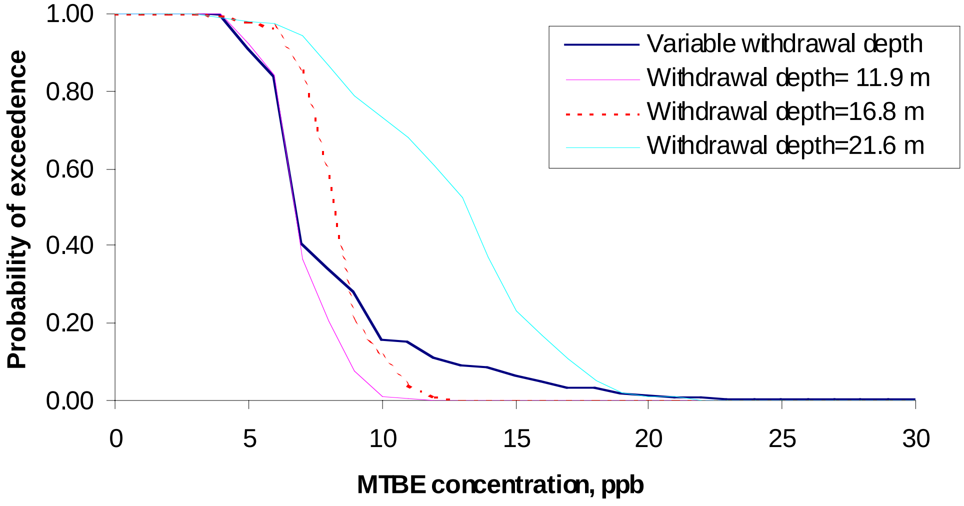
In comparison to Lake Perris, based on available monitoring data, Donner Lake appears to be less impacted by 2-cycle engine boating activities and therefore reducing boating by 25% may be sufficient to lower MTBE levels in the lake to acceptable levels for a drinking water supply. Table 4 provides a comparison of the hydrodynamic model results for various boating scenarios at Lake Perris and Donner Lake.

Table 4: Comparison of Donner Lake and Perris Lake

Policy	Location	Exceeding Secondary drinking standard (%)	Primary Health Goal Average EE (mg/kd-day)	Cost ($1,000/yr)
Existing condition	Donner Lake (2,400 boats/yr)	33.6	86	
	Perris Lake (113,698 boats/yr)	90.6	922	
10% reduction in 2-cycle engines	Donner Lake	25.3	80	13
	Perris Lake	89.8	875	614
25% reduction in 2-cycle engines	Donner Lake	5.5	69	32
	Perris Lake	86.5	791	1,535
50% reduction in 2-cycle engines	Donner Lake	0	52	65
	Perris Lake	66.4	659	3,070
100% reduction in 2-cycle engines	Donner Lake	0	0	130
	Perris Lake	0	0	6,140

Currently Lake Perris water intake is operated to draw water from three different depths throughout the year to meet water temperature requirements (McCord, 1998). Modeling results shows that drawing from lower depths in the lake results in higher MTBE concentration in the water supply as shown in Figure 11. Higher MTBE levels in the lower depths of the lake may be explained by the mixing process of Lake Perris. As the lake mixes, MTBE is drawn down and is trapped in the hypolimnion. Whereas MTBE at the surface tends to volatilize, MTBE in greater depth cannot escape through volatilization resulting in higher MTBE concentrations.

Figure 11: Effect of withdrawal depth on MTBE concentration at Lake Perris water supply

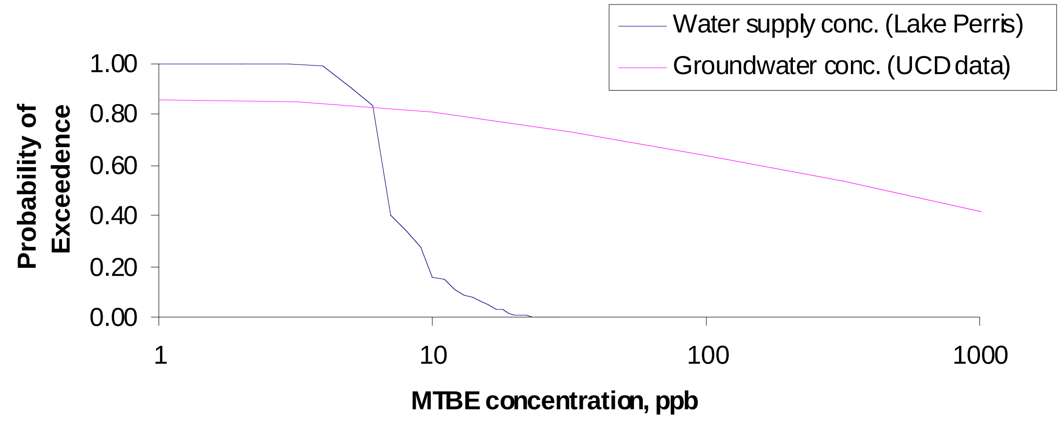


The only policies that can ensure that water supply from Lake Perris will satisfy the 5 ppb proposed secondary drinking standard are banning motorized boating on the lake, treatment (air stripping or biological treatment), imported water, and MTBE ban. For Lake Perris, the most cost-effective policy to meet MTBE concentration of 5 ppb is treatment, either air stripping or biological treatment depending on the need for off-gas treatment. In Comparison to treatment, a ban on boating at an annual cost of about $6 million is more expensive then air stripping (about $2 million) but cheaper than some of the other treatment methods. For this scenario, water demand would have to triple, before a ban on motorized boating would become more cost effective than air striping treatment. The trade off between banning motorized boating activities and treatment depends on the feasibility of treatment and the need for off-air treatment, which would increase air stripping cost to $8 million, and the value of boating at the lake. Lake Perris is a well-utilized lake. Due to its close proximity to a metropolitan area and mild climate, it is used year round. Importing water to replace contaminated water would cost about $36 million based on an average demand of 195 acre-ft per day, for exceeding the cost of all treatment options. For lakes such as Lake Perris, which are intensely used for both urban water supply and recreation, treatment seems to be the best option.

3. Groundwater supplied public drinking water

Contaminated groundwater has MTBE concentrations much higher than those found in surface water and therefore is more likely to harm human health. The difference in likely exposure between contaminated surface and groundwater is apparent from Figure 12. Policies that can affect groundwater supply are limited to remediation of spills, imported water, and water treatment. The tank replacement program does not appear to have significant impact in lowering probability of leaks to the groundwater (Couch and Young, 1998). Eliminating MTBE from gasoline will not have an immediate effect on groundwater. Since MTBE is not easily biodegradable, contaminated aquifers need to be remediated or treated when used.

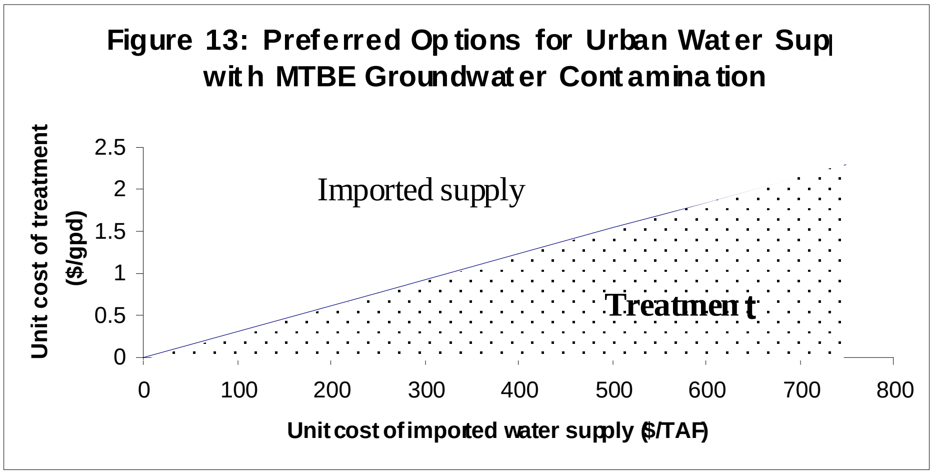
Figure 12: MTBE concentration in water supply (base condition)



Water treatment will reduce MTBE concentration in water supply to 5 ppb whereas remediation would reduce MTBE concentration in groundwater to 500 ppb requiring additional treatment or blending to reduce the concentration further to 5 ppb. The choice between importing additional water supply and treatment depends greatly on the cost of treatment. The cost of treatment is a function of both water demand and MTBE concentration in the contaminated aquifer. Higher water demands will decrease the unit treatment cost. For small areas with low water demand, it may be more cost efficient to import water. In areas with high levels of contamination, treatment cost will be high and importing water to either replace contaminated source or blend it to acceptable levels may be preferable.

4. Diversified public drinking water (combined groundwater and surface water supplies)

Since MTBE concentrations in groundwater are orders of magnitude higher than in surface water, water supplies consisting of a combination of groundwater and surface water will be mostly affected by its groundwater source. Blending of contaminated groundwater and surface water reduces MTBE concentrations but concentrations are likely to still be high enough that either treatment or replacement source of water would be required. Blending contaminated groundwater with 25% imported water reduces the likelihood of exceeding a 5 ppb standard from 86% to 83%. Cities that rely on both groundwater and surface water may have to either treat or find new water supplies. This determination will depend on the cost of both options. Figure 13 shows the trade off between treatment and new source of water supply. Treatment will be preferable for costs below the trade off line and imported water supply for costs above the trade off line.



5. Groundwater supplied rural household drinking water

In rural areas where groundwater is contaminated with MTBE, remediation, treatment, or imported water supply can help reduce exposure to MTBE. In California, over 4 million people rely on private wells and draw at approximate rate of 212 Mgal/day. Table 5 provides a summary and comparison of policies that can be implemented to mitigate contamination of a well in rural setting. Data in Table x is based on MTBE concentration distribution in aquifers sampled and recorded by the Department of Health and analyzed by Fogg (1998).

Table 5: Groundwater supplied rural household drinking water (one contaminated well)[4]

	Policy	Secondary std.	Pubic Health goal	Cost per household ($/yr)
		Exceedence of 5 ppb (%)	Average Expected Exposure (mg/kg-day)	
	Existing condition	86	2.9	
Source Control Options	Remediation	MTBE conc.= 500 ppb	0.0526	100,000-500,000
	Tank replacement	83.4		60,000-80,000
Treatment Options	Air stripping	0	0.00053	70
	Air stripping w/gas treatment	0	0.00053	300
	Carbon Adsorption	0	0.00053	300
	Advanced oxidation	0	0.00053	300
	Biological treatment	0	0.00053	100
Alternative water supply	Imported water supply	0	0	300
	Bottled water[5]	0	2.05	N.F.

There are 464,621 recorded private wells in California. Assuming each well supplies approximately 456 gallons/day (212 MGD/464,621 private wells) importing water would cost $300 annually for each well assuming infrastructure is available for distribution. In

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[4] Assume a rural water supply well provides 456 gallons/day (166,400 gallons/yr).

comparison, the cost of treatment of the water ranges between $100 and $300 per year depending on the treatment method used. If more than four wells are afected by a leak, remediation and tank replacement may become cost efficient.

In rural areas, the infrastructure required to import water from water suppliers may not exist, limiting imported water to bottled supplies for drinking water. The cost of bottle water is about $1 per gallon. Assuming 2 % of water supply used for ingestion and cooking (9 gallons/day), purchasing bottled water would cost $3,300/year. Replacing drinking water supply with bottled water is much more expensive than treatment. Moreover since MTBE exposure is related mostly to inhalation (70% of exposure) rather than ingestion (30%), bottled water would not sufficiently reduce exposure risk of MTBE.

Summary

MTBE does not appear to be in high enough concentrations to affect habitat and aquatic life in surface water. On the other hand, limited data and testing of MTBE both in surface and groundwater suggest that concentrations are sufficiently high to pose human health risk thereby merit some mitigation.

Removing MTBE from water supply whether it is public or private, or from a surface water or groundwater source, appears to be most economical with available treatment methods, most notably by air stripping or biological treatment. In rural areas where water demands are low, it may be more beneficial to provide imported water supply if infrastructure is available. For public supplies, where water demands are high, economies of scale point to treatment as the preferred alternative. Public supplies that rely on groundwater will be most affected by contamination, since groundwater contamination tends to be much higher in concentration and likelihood than surface water contamination.

Source control policies such as reduction in motorized boating activities are location specific. In Lake Perris reducing motorized boating activities was not sufficient to reduce MTBE concentration. However, these results are specific to this lake.

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[5] Assume water ingested comprise of 5% of total water supply, bottled water cost $1/gallon.

STATEWIDE IMPLICATIONS AND OPTIONS

This section attempts to extend the results and impacts developed for the previous scenarios to a statewide scale.

Surface Waters

Water quality sampling for MTBE in California's surface water is relatively recent; monitoring data is available mostly since 1996-1997. MTBE monitoring has been done mostly voluntarily, sporadically, and without specific guidelines. Of the 245 identified waterbodies used for drinking water, only 105 (43%) had data of which 38 (16%) had no measurements for MTBE. Lake Perris and Donner Lake, used as examples in this report, have the most consistent monitoring with 528 and 363 samplings recorded, respectively. In comparison, 50% of waterbodies with data had five or fewer individual samples (Reuter, 1998). Though limited data and information are available, some conclusions may be made about MTBE contamination of California's surface water that are used as drinking supply. Table 6 lists the hydrologic regions in California and summarizes the available MTBE information for the water supply reservoirs.

Table 6: MTBE concentrations sampled by hydrologic regions of California

Hydrologic Region	Reservoirs	Reservoirs sampled	Sampled Reservoirs w/Boating	MTBE concentration with boating (ppb)
South Coast	30	17 (57%)	11	1-45
San Francisco	18	15 (83%)	4	8-10
San Joaquin	16	6 (38%)	5	1.6-12
Sacramento	43	7 (16%)	7	0.5-16
Central Coast	8	4 (50%)	4	3-(88)
North Coast	12	2 (17%)	2	2.8
North Lahontan	6	1 (17%)	1	
Tulare Lake	6	0	-	-
South Lahontan	8	0	-	-
Colorado Region	0	-	-	-

Generally, reservoirs with boating activities have some detectable levels of MTBE (above 0.5 ppb). The South Coast region, including Santa Clara, Metro Los Angeles, Santa Ana, and San Diego, has the highest number of sampled reservoirs and correspondingly, has the highest levels of MTBE ranging from 1 to 45 ppb, with an average of 11.3 ppb. As shown in Figure 14, MTBE concentrations in the South Coast region have 47% chance of exceeding the proposed 5 ppb standard and 23.5% likelihood of exceeding the 14 ppb health goal for drinking water. Lake Perris, which is located in the South Coast region, can be considered representative of the other lakes in the region with high recreational use and within the most populated metropolitan area in California. The South Coast Region has an average water supply of 4,379 TAF of which 73% is from surface water (based on 1990 data, DWR, 1994) that could potentially be contaminated and will therefore need to be either treated or replaced. In cases where MTBE levels are low, it may be sufficient to monitor for MTBE and reduce boating activities on the reservoirs to ensure acceptable levels of MTBE as was the case at Donner Lake. In lakes with high boat use it may be more cost efficient to treat the water since limiting boating activities in one lake may result in increased use of another lake within the basin. Air stripping with off-gas treatment in the South Coast basin for the water supply could potentially cost $350 million. Blending the contaminated water supply (assuming average of 11.3 ppb) with 55% imported water to meet the 5 ppb threshold would requiring a purchase of $880 million of imported water to supply basin wide.

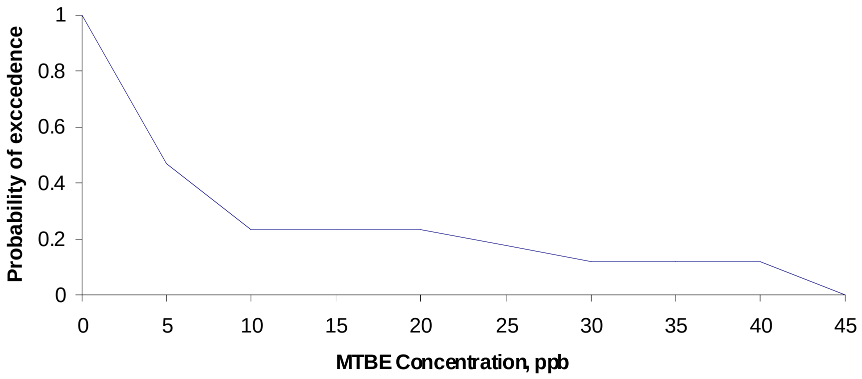
Figure 14: MTBE conc. detected at water supply reservoirs (South Coast Region)

Of the seventeen sampled reservoirs, three had MTBE concentrations levels similar to Lake Perris, four reservoirs had concentrations within the range of Donner Lake, and the rest of the reservoirs (10) had MTBE concentrations below 5 ppb. Assuming boating activities similar to Lake Perris, reducing motorized boating activities and eliminating motorized boating activities to ensure acceptable levels of MTBE at all reservoirs would cost $25 million. Table 7 summarizes the cost of policies to reduce surface water MTBE concentrations in the South Coast Region to the 5 ppb proposed secondary drinking standard.

Table 7: Estimated cost of MTBE policies or surface water (South Coast Region)

Policy	Cost ($M/year)
Boating reduction	25
Importing water for blending	880
Treatment	350

Based on the information available for MTBE in water surface supplies in California, the South Coast region is the most affected region by MTBE contamination. In other regions in California, MTBE levels in reservoirs sampled are generally within the range of the proposed standards (5 and 14 ppb). Data is unavailable for the less populated areas of North Coast, North Lahontan, Tulare Lake, and South Lahontan. Cost of mitigating MTBE contamination in other regions is therefore assumed to be much smaller than those estimated for the South Coast Region. Overall, 2-cycle engine boating reduction appears to be the most cost effective option for MTBE reduction in water supply from surface water in California.

Groundwater

Based on stochastic model studies accounting for advection, dispersion, sorption, and decay, and estimating that water supply wells within 2,000 ft horizontally and 200 ft vertically of the edge of an MTBE plume will potentially capture MTBE, estimated volume of groundwater impacted by MTBE is on the order of 100,000 acre-ft (Fogg, 1998). MTBE concentration distribution in groundwater is shown in Figure 5.

Eliminating MTBE from gasoline will not have an immediate effect on groundwater. Since MTBE is not easily biodegradable, contaminated aquifers need to be remediated or treated when used. Water treatment will reduce MTBE concentration in water supply to 5 ppb whereas remediation would reduce MTBE concentration in groundwater to 500 ppb requiring additional treatment or blending to reduce the concentration further to 5 ppb.

The cost of policies to meet the 5 ppb proposed secondary drinking standard in groundwater supplied public water statewide are summarized in Table 8. Values for exceeding 5 ppb and average expected exposures are based on Department of Health data analyzed by Fogg (1998) and represent statewide conditions. Specific conditions and contamination levels at individual aquifers will differ in costs for feasible policies and may result in different conclusions regarding the most cost-effective alternative.

Table 8: Groundwater supplied public water (statewide)

	Policy	Secondary std.	Public Health Goal	Cost
		Exceedence of 5 ppb (%)	Ave. Expected Exposure (mg/kg-day)	($millions/yr)
	Existing condition	86	2.87	
Source Control Options	Remediation[6]	MTBE conc.=500 ppb	.053	180-900
	Tank replacement[7]	No significant change	2.87	2,000-2,600
Treatment Options[8]	Air stripping	0	0.00053	100-500
	Air stripping w/gas treat.	0	0.00053	200-2,200
	Carbon Adsorption	0	0.00053	600-1,800
	Advanced oxidation	0	0.00053	400-1,800
	Biological treatment	0	0.00053	100-500
Replace MTBE	Ethanol	86	2.87	N.F.
	Non-oxygenated RFG	86	2.87	N.F.
	Alternative Water Supply[9]	0	0	1,826

Overall Policy Implication

Policy choices to reduce MTBE concentrations in water supply from surface waters seem to be location specific and dependent on level of recreation use. This was evident in the comparison of Donner Lake and Lake Perris. On a statewide scale, controlling 2-

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[6] Based on cleanup of estimated 1816 contaminated sites in California, $100,000-500,000/site.
[7] Based on 32,438 tanks, $60,000-80,000/tank.
[8] Based on treatment to 5 ppb.

cycle engine boating activities will generally be sufficient and cost effective in reducing MTBE to acceptable levels.

Statewide, addressing groundwater contamination could potentially be more problematic due to the already present high concentrations of MTBE. Statewide, it appears to be most cost effective to treat contaminated groundwater both in rural and urban areas. Table 9 summarizes statewide water related costs for retaining MTBE as a fuel oxygenate and replacing MTBE oxygenated fuel with either ethanol or non-oxygenated fuel. If MTBE is retained as a fuel oxygenates, groundwater treatment and 2-cycle boating reduction would be the most economical options to meet the proposed secondary drinking standards. If MTBE is replaced with either Ethanol oxygenated RFG or non-oxygenated RFG that meet the CaRFG2 requirements, treatment of already contaminated groundwater will be necessary to meet the secondary drinking standard.

Table 9: Total estimated statewide water related costs

Recommended approaches		Cost ($M/year)
Retain MTBE	Surface water options Boating reduction	25
	Groundwater options Treatment	100-500
	Total Cost	**125-525**
Replace MTBE	Ethanol oxygenated RFG	0
	Non-oxygenated RFG	0
	Groundwater treatment	100-500
	Total Cost	**100-500**

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[9] Based on $500/ac-ft.

CONCLUSIONS AND RECOMMENDATIONS

Evaluation of policies to remove MTBE from public and private water supplies sources lead to the following conclusions:

Water recreation and ecological habitat

Based on the evaluation of Lake Perris, recreational uses and ecological health are not adversely affected by MTBE produced from 2-cycle engine boating activities. Since Lake Perris has relatively high MTBE concentrations compared to other sampled reservoirs and lakes in California, it is probably safe to extend this conclusion to the whole state of California.

Water supply from surface water

Water supply from surface water in some regions in California may have MTBE concentrations higher than the proposed secondary drinking standard of 5 ppb due to 2-cycle boating activities. However, exposure through water supply of surface water origin is likely to be much lower than water supply of groundwater origin. Water treatment and reduction in 2-cycle engine boating activities were found to be the most economical policy choices depending on the reservoir and its recreational use. In Lake Perris in the South Coast regions, with high MTBE concentrations, treatment was found to be the most economical alternative whereas in Donner Lake, in the high Sierras, reduction in boating activities was found to be most economical.

Water supply from groundwater

Groundwater contamination is attributed mainly to under storage fuel tank systems. Groundwater contamination is orders of magnitude higher than surface water contamination and therefore could potentially be much more expensive to treat. Policies to reduce contamination levels to acceptable drinking standards are limited to treatment. Existing policy for replacement of old storage fuel tanks do not appear to have a measurable impact on groundwater contamination and remediation would reduce contamination levels only to 500 ppb requiring additional treatment. Importing water to replace groundwater will help avoid exposure to MTBE in urban areas but in rural areas without adequate conveyance system, treatment is the only policy that can eliminate exposure to MTBE.

Statewide water supply

Groundwater and surface water are contaminated with MTBE mainly from under storage tank systems and 2-cycle boating activities, respectively. Groundwater contamination appears to be a much more significant problem than surface water for drinking water supply. Of all alternative policies reviewed, treatment appears to be the most cost effective for groundwater. For surface water, reduction in 2-cycle engines boating reduces MTBE levels to acceptable concentrations and is more cost effective than other alternatives. In the short term, water related costs of MTBE oxygenated costs and other reformulated gasoline are comparable and are largely due to groundwater treatment. In the long term, water related costs of replacing MTBE oxygenated fuel with either Ethanol oxygenated fuel or non-oxygenated fuel may be lower than MTBE related costs.

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