# Impacts of MTBE on California Groundwater

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# 1.0 INTRODUCTION

Senate Bill 521 was introduced February 24, 1997 in response to a growing awareness of the possible environmental and health effects associated with the use of Methyl Tertiary Butyl Ether (MTBE) as an oxygenate blending agent in gasoline fuels throughout California (Appendix A). Since 1979, MTBE had been used in the State as a replacement for tetraethyl lead and as an octane booster. Although used in California since 1979 in volumes ranging from 0.5 to 3.5 percent, the volumes of MTBE in gasoline have increased to 11 percent since 1996. SB 521, which became effective January 1, 1998, called for the University of California to perform an assessment of the benefits and risks associated with the uses of MTBE in California.

This assessment report addresses: 1) the current impacts of MTBE to the state's groundwater used for drinking; 2) risks to the state's groundwater resources associated with MTBE leaking from storage tanks and other petroleum storage and conveyance facilities; and 3) potential future risks to the state's groundwater should MTBE continued to be used.

The general approach was to compile statewide data on the occurrence of MTBE groundwater contamination. The data consisted of MTBE detections and concentrations at leaking underground storage tank sites from Regional Water Quality Control Boards and MTBE detections and concentrations in water supply wells based on information from the Department of Health Services, Local Primacy Agencies, and Regional Water Quality Control Boards. We used various modeling approaches to then assess potential future impacts of MTBE on groundwater resources, focusing primarily on plume behavior in aquifer systems consisting of alluvial materials (i.e., sand, gravel, silt and clay). This report also includes specific information on MTBE impacts on groundwater in the Tahoe Basin.

A recent investigation into the impacts of MTBE on California groundwater by Happel et al. (1998) provided an important foundation for this study. The analysis of groundwater impacts contained herein complements the work of Happel et al. (1998) by accumulating more recent statewide information with broader geographic coverage. Moreover, we use plume length statistics compiled by Happel et al. (1998) as a basis for calibrating models that simulate future MTBE plume growth.

## 1.1 SOURCES OF MTBE IN GROUNDWATER

MTBE sources of groundwater contamination include leaking underground fuel tanks (LUFT's), above ground storage tanks, farm tanks, leaking petroleum fuel pipelines, underground storage tanks containing fuels other than gasoline, surface spills due to automobile or tanker truck accidents, surface spills due to abandoned or parked vehicles, MTBE contaminated surface water, and precipitation. The LUFT sites are numerous, widely dispersed, proportional to the state's population, and involve enormous volumes of fuel products. As of June 30, 1998 there were 32,779 known sites where chemical compounds, including gasoline and non-gasoline products, were discharged to the environment from underground storage tanks. Ninety percent of these discharges involve petroleum products.

Although specific information about the operation of above ground storage tanks and pipelines were not available, information contained in the Regional Water Quality Control Board (RWQCB) water purveyor reports indicate that leaking underground storage tanks are the most numerous sources of MTBE contamination. Furthermore, most of the gasoline stored in above ground storage tanks or transmitted through petroleum pipelines ultimately is stored in underground storage tanks prior to final distribution to motor vehicles.

Only a small portion of the MTBE consumed, 0.33 percent (OEHHA, 1998), is released to the atmosphere. Depending on local conditions, a fraction of the 0.33 percent is available to leach into groundwater. MTBE released into the atmosphere has been implicated as a non-point source of MTBE contaminating shallow urban groundwater at very low levels. In the U.S. Geological Survey's National Water Quality Assessment (NAWQA), 97 percent of the samples from shallow urban wells detected MTBE at concentrations of less than 20 $\mu g \cdot L^{-1}$ (Pankow et al., 1997). MTBE is detected at leaking underground storage tanks at concentrations many orders of magnitude higher. Based on information available early in our assessment, approximately 75 percent of those groundwater sites that were tested had concentrations in excess of 20 $\mu g \cdot L^{-1}$, further emphasizing the importance of leaking underground storage tanks as the primary source of acute MTBE groundwater contamination. Accordingly, most of our efforts in this 8 month study focused on MTBE contamination from LUFT sites. Future studies should continue to evaluate long-term impacts of point- as well as non-point sources of MTBE.

## 1.2 General Characteristics of MTBE Transport In Groundwater

Transport of MTBE in groundwater is controlled by the rate of groundwater movement, concentration and longevity of the source, and dispersion (i.e., the process whereby concentration of a dissolved chemical is reduced by dilution and the contaminant front spreads faster than the average rate of groundwater movement). Unlike petroleum hydrocarbons such as benzene, transport of MTBE does not appear to be limited appreciably by sorption (i.e., temporary retention of the contaminant on soil and sediment particles) or biodegradation by native microorganisms. Consequently, MTBE will potentially move with the groundwater in a manner similar to subsurface transport of, for example, chlorinated organic compounds such as TCE (trichloroethene). Extensive TCE groundwater plumes are often observed – on the order of 1,000's of feet in length. Owing to MTBE's high solubility and rather large volumetric fraction in reformulated gasoline (~11 percent), concentrations in groundwater can be very high – on the order of 6,000,000 $\mu g \cdot L^{-1}$ (Zogorski et al., 1996; Happel et al., 1998).

# 2.0 REGIONAL DATA SOURCES

Numerous data sources were used, primarily from the State Water Resources Control Board (SWRCB), the nine Regional Water Quality Control Boards (RWQCB), the Department of Health Services (DHS), the 34 DHS Local Primacy Agencies (LPA's).

## 2.1 STATE WATER RESOURCES CONTROL BOARD

Efforts were made as early as 1995 to characterize the extent of MTBE contamination statewide. The State Water Resources Control Board has not established any requirement for the testing or reporting of MTBE, except prior to closing LUFT sites (i.e., prior to ceasing site investigation and active remediation). However, guidance documents have been distributed to the nine Regional Boards and to the twenty Local Oversight Program Agencies (LOP's). On July 31, 1996, the SWRCB distributed the memo "Groundwater Monitoring Information on Methyl Tert Butyl Ether (MTBE) From Open UST Cases" which requested that MTBE be added to the list of gasoline components in contaminated groundwater that are monitored at open (i.e., still being investigated or actively remediated) LUFT sites. The memo indicated that EPA Method 8020 should be used, followed by EPA Method 8260 for detection of false positives. On June 8, 1998, a Local Guidance Letter was forwarded to Local Implementing Agencies notifying them of the requirement to test for MTBE and submit the results to the Regional Boards prior to issuance of a closure letter requiring no further action at sites where petroleum releases have occurred. Beginning January 1, 1998, closure letters could not be issued unless MTBE analysis was performed, when applicable. The requirement for MTBE testing is only at sites where applicable, which is understood to mean, sites where gasoline releases have occurred.

Information requests to the SWRCB were made verbally and in correspondence. The information requested from the Underground Storage Tank Section consisted of copies of the SWRCB LUSTIS (Leaking Underground Storage Tank Information System) databases and quarterly reports for first and second quarter 1998, the number of active and upgraded underground storage tanks, and policies and procedures which have been developed related to MTBE contamination. The information requested from the Above Ground Storage Tank Section consisted of an inventory of the above ground tanks in each county and confirmed releases of petroleum products. Information was not made available regarding releases from above ground storage tanks. The information requested in correspondence with the Underground Storage Tank Cleanup Fund Unit consisted of a database including the status of cleanup claims, the LUSTIS site code and Cleanup Fund claim number. Time did not permit checking cleanup fund status for sites where MTBE contamination exists, primarily for two reasons. First, only a portion of the Cleanup Fund database contained the LUSTIS site code used by the SWRCB and RWQCB's, and second, the MTBE site data from many of the RWQCB's

originated from MTBE reports submitted to water purveyors which were not made available electronically.

## 2.2 Regional Water Quality Control Boards

The Regional Water Quality Control Boards have the authority within the California Water Code to require monitoring for MTBE independent of any directive from the State Water Resources Control Board. The Regional Water Quality Control Boards began requiring MTBE monitoring at different times ranging from 1995 (San Francisco, RB 2) to 1998 (San Diego, RB 9), with most Regional Boards requesting monitoring in 1996 and 1997. Some Regional Boards notified all responsible parties in blanket directives while others notified on a site specific basis. The requirement for MTBE analysis has been restricted primarily to gasoline contaminated sites.

In addition to verbal requests to RWQCB staff, two letters were sent to each RWQCB Executive Office; the first in February 1998 and the second in June 1998. On February 23, 1998, correspondence was sent to each of the nine RWQCB Executive Officers requesting information regarding MTBE releases from above ground storage tanks and underground storage tanks including site number, MTBE concentration in groundwater, depth to water, possible release date, and supply well impacts. Information from this request was submitted by all RWQCB's in July 1998. Information regarding the depth to water was available only from the San Francisco Bay (2), Los Angeles (4) and Santa Ana (8) RWQCB's. No information was submitted at that time regarding impacts to supply wells.

On June 30, 1998, correspondence was again sent to each of the nine RWQCB Executive Officers which included summary statistics from the concentration and site data obtained thus far and a list of the sites where supply wells have been impacted by contaminants leaking from underground storage tanks. Survey questions were developed to better understand the context of the information obtained. Information was also requested to determine which of the supply well impacted sites also had supply wells that were contaminated by MTBE. No MTBE supply well impact information was made available, except from the Central Coast (3), Lahontan (6) and Central Valley (5) RWQCB's. Generally, this type of information is only available when sites are specifically reviewed. All of the nine RWQCB's responded by September 1998 to information requests made in the June 1998 correspondence to the RWQCB's (Appendix C).

## 2.3 Department of Health Services

In March and again in October 1998, individual requests for information were made to the DHS District Engineers in whose districts public water system wells were reported on the DHS Water Quality Information (WQI) database as having MTBE detections. The information requested included identification of possible sources of contamination and well construction details. With the exception of wells where the detections of MTBE contamination clearly related to leaking

underground storage tank sites, information regarding possible sources of contamination were scarce.

## 2.4 OTHER STATE AGENCIES

In March 1998, information was requested from the State Office of Emergency Services regarding releases of MTBE which may have been reported to the Office of Emergency Services. We were informed that releases are not summarized in databases for tracking.

In June and August 1998, information was requested from the State Fire Marshall's Office regarding the number of petroleum pipeline miles in each county and petroleum pipeline releases. We were informed that the State Fire Marshall's Office only regulates a portion of the pipelines running through California and that the information was not readily available.

In July 1998, information was requested from the California Air Resources Board regarding the extent of use of MTBE in California and air monitoring data. A meeting was held to discuss MTBE's historic use in California. Air Resources Board staff provided background information and available MTBE air monitoring data.

## 2.5 LOCAL PRIMACY AGENCIES

In March 1998, the DHS was contacted to obtain information regarding small water systems which are regulated by the 34 Local Primacy Agencies. We were provided with a list of primacy agency contacts. Initial contacts were made in March and early April by telephone. Most of the agency contacts were unaware of the requirement to test for MTBE. Efforts were made to inform each agency contact of the requirements for the RWQCB's to begin submitting quarterly water purveyor reports that list the sites with documented MTBE contamination and of the DHS September 11, 1997 Implementation Policy for monitoring MTBE as an unregulated compound. On April 29, 1998, correspondence was sent to each of the 34 Directors of Local Primacy Agencies, after these agencies should have received their first quarterly report from the RWQCB's to perform vulnerability assessment. We requested information such as, the address of each groundwater system, the state designation of each water system, the number of wells in each groundwater system, the date that each well was tested, the MTBE analytical results and detection limit of the analysis, and well logs and construction details of the impacted wells. Follow-up correspondence requesting clarification in June and July 1998 was sent to five of the 13 agencies that responded. None of the agencies responded to the follow-up correspondence.

Much of the data arrived on paper rather than in electronic format, and were sorted and, when possible, entered into the computer. Databases were managed using Microsoft® Excel or Claris® Filemaker, depending on the size. Filemaker was used for all the DHS databases and facilitated the linking of three databases to characterize the sources sampled. Whenever possible, data were checked for completeness. When information was missing or questionable, efforts were made to

complete or clarify the information. The quality of the data will be explained when cited.

Results were organized by county. In several counties there exist more than one Regional Water Quality Control Board (RWQCB) or Department of Health Services (DHS) District that has jurisdiction within the same county.

# 3.0 LOCAL IMPACTS OF UNDERGROUND TANKS

In this section we characterize impacts of MTBE on groundwater in the immediate vicinity of LUFT sites. After describing characteristics of gasoline containing MTBE and underground fuel tanks, information on MTBE in groundwater at LUFT sites is presented.

The MTBE data from already-discovered LUFT sites is presented with a description of the State Water Resources Control Board Leaking Underground Storage Tank Information System (SWRCB LUSTIS) and information available from the Regional Water Quality Control Boards (RWQCB's). This section includes information on relationships between MTBE sites and LUSTIS groundwater sites as well as MTBE concentrations detected and information on sites that are no longer being monitored that have detectable concentrations of MTBE. Furthermore, we summarize what is known about groundwater contamination from the other oxygenates used in California, including ethyl tertiary butyl ether (ETBE), tertiary amyl methyl ether (TAME), and ethanol, and we describe current site characterization methods.

## 3.1 MTBE IN GASOLINE

The use of MTBE in gasoline has increased steadily since it was first approved for use in gasoline by the United States Environmental Protection Agency (USEPA) in 1979. MTBE is produced from isobutene, a waste product of the petroleum refining process. In 1994, MTBE was ranked as the eighteenth most produced chemical in the United States. By 1995 it was ranked twelfth, and by 1997 it was ranked second (OEHHA, 1998). MTBE was used in California's lead phase out program in 1979 at volumes up to 2 percent as a lead substitute and octane booster. The US EPA approved use of MTBE in 1981 up to 10 percent and in 1988 approved its use up to 15 percent by volume (CAEPA, 1998).

As early as 1988, MTBE use in southern California had begun to increase. In 1988, a refiner introduced an environmentally clean fuel in California that included 6 to 8 percent MTBE by volume. This refiner reportedly supplied 30 percent of the fuel in California of which approximately 20 percent of this refiner's sales was the environmentally clean fuel. This fuel was sold principally in southern California (D. Simeroth, personal communication, 1998).

The complete phase out of lead in fuel occurred in 1992, at which time the Winter Time Oxygenate Program began in California. There was an increased use of MTBE in the southern part of the state, with longer wintertime intervals and an

earlier commencement of the year-round oxygenate program starting in 1995 rather than 1996. After March 1, 1996, all gasoline sold in California was Phase 2 reformulated gas containing 11 percent by volume MTBE. Approximately, 92 billion gallons of MTBE was produced in 1997 (Zogorski et al., 1998). California is reportedly the third largest worldwide consumer of MTBE, second only to the rest of the United States and the former Soviet Union (OEHHA, 1998).

The California Energy Commission (1998) has compiled estimates of the number of gasoline gallons that were consumed in each California county for 1996 based on information from the California Board of Equalization (Table 1). The gasoline gallons consumed in Alpine and El Dorado and in Mono and Inyo counties were combined. Estimates of the gasoline consumed in these counties were based on relative population. Figure 1 shows a good correlation between the number of gallons of gasoline consumed and population using the California Department of Finance 1997 population estimates.

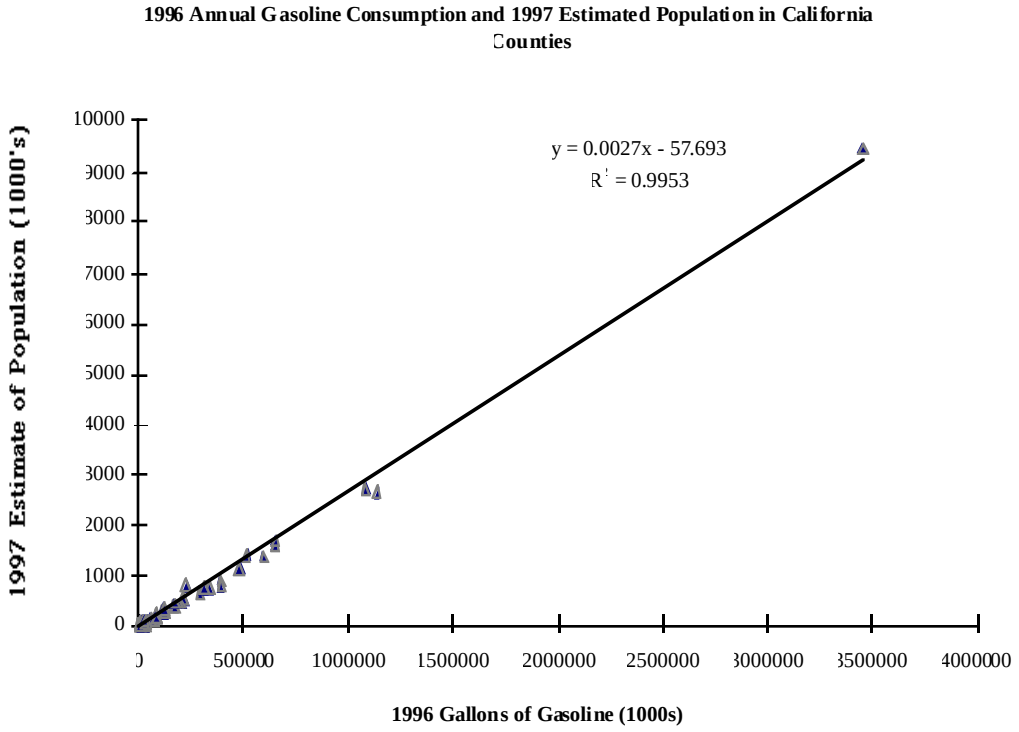


**Figure 1. Estimated 1997 population (California Department of Finance) versus 1996 estimated gallons of gasoline consumed in California counties (California Board of Equalization).**

**Table 1. Estimated number of gallons of MTBE consumed in each county and the total number of Leaking Underground Storage Tank sites reported to the State Water Resources Control Board (SWRCB, 1998b July).**

| County | 1997 Population Estimate | 1996 Board of Equalization Gallons of Gasoline Consumed | Estimated MTBE Consumed (11%) | Rank by MTBE Consumption | Total LUSTIS Sites | Rank by Total LUSTIS Sites |
|---|---|---|---|---|---|---|
| Alameda | 1,375,900 | 593,458,000 | 65,280,380 | 6 | 2,167 | 5 |
| Alpine | 1,180 | 684,627 | 75,309 | 58 | 10 | 57 |
| Amador | 33,750 | 14,541,000 | 1,599,510 | 49 | 48 | 52 |
| Butte | 199,100 | 74,846,000 | 8,233,060 | 30 | 195 | 31 |
| Calaveras | 36,500 | 14,954,000 | 1,644,940 | 47 | 73 | 47 |
| Colusa | 18,300 | 12,027,000 | 1,322,970 | 51 | 40 | 53 |
| Contra Costa | 879,200 | 389,768,000 | 42,874,480 | 9 | 761 | 15 |
| Del Norte | 28,250 | 9,856,000 | 1,084,160 | 54 | 93 | 42 |
| El Dorado | 142,200 | 82,503,373 | 9,075,371 | 28 | 133 | 39 |
| Fresno | 776,200 | 226,953,000 | 24,964,830 | 14 | 658 | 17 |
| Glenn | 26,800 | 14,195,000 | 1,561,450 | 50 | 36 | 54 |
| Humboldt | 126,600 | 73,477,000 | 8,082,470 | 31 | 453 | 18 |
| Imperial | 140,500 | 58,063,000 | 6,386,930 | 33 | 178 | 35 |
| Inyo | 18,350 | 30,561,845 | 3,361,803 | 41 | 87 | 43 |
| Kern | 628,200 | 292,339,000 | 32,157,290 | 13 | 931 | 12 |
| Kings | 118,200 | 43,442,000 | 4,778,620 | 37 | 160 | 36 |
| Lake | 54,800 | 25,897,000 | 2,848,670 | 44 | 73 | 46 |
| Lassen | 34,450 | 14,940,000 | 1,643,400 | 48 | 23 | 55 |
| Los Angeles | 9,488,200 | 3,456,569,000 | 380,222,590 | 1 | 5,261 | 1 |
| Madera | 111,600 | 51,903,000 | 5,709,330 | 34 | 182 | 34 |
| Marin | 242,200 | 115,115,000 | 12,662,650 | 24 | 312 | 26 |
| Mariposa | 16,000 | 9,055,000 | 996,050 | 55 | 76 | 45 |
| Mendocino | 85,900 | 43,691,000 | 4,806,010 | 35 | 314 | 25 |
| Merced | 201,000 | 85,860,000 | 9,444,600 | 26 | 344 | 24 |
| Modoc | 10,150 | 11,766,000 | 1,294,260 | 52 | 11 | 56 |
| Mono | 10,400 | 31,925,000 | 3,511,750 | 40 | 53 | 49 |
| Monterey | 371,500 | 161,361,000 | 17,749,710 | 20 | 365 | 22 |
| Napa | 120,800 | 61,788,000 | 6,796,680 | 32 | 277 | 28 |
| Nevada | 86,600 | 43,663,000 | 4,802,930 | 36 | 157 | 37 |
| Orange | 2,659,300 | 1,137,781,000 | 125,155,910 | 2 | 2,415 | 3 |
| Placer | 209,700 | 127,390,000 | 14,012,900 | 21 | 344 | 23 |
| Plumas | 20,350 | 10,747,000 | 1,182,170 | 53 | 49 | 51 |
| Riverside | 1,380,000 | 512,425,000 | 56,366,750 | 7 | 966 | 10 |
| Sacramento | 1,140,600 | 485,714,000 | 53,428,540 | 8 | 1,012 | 8 |
| San Benito | 44,350 | 15,388,000 | 1,692,680 | 46 | 52 | 50 |
| San Bernardino | 1,587,400 | 651,563,000 | 71,671,930 | 5 | 802 | 14 |
| San Diego | 2,724,400 | 1,080,089,000 | 118,809,790 | 3 | 2,965 | 2 |
| San Francisco | 778,100 | 387,286,000 | 42,601,460 | 10 | 979 | 9 |
| San Joaquin | 535,400 | 215,040,000 | 23,654,400 | 15 | 834 | 13 |
| San Luis Obispo | 234,100 | 119,583,000 | 13,154,130 | 23 | 193 | 32 |
| San Mateo | 701,100 | 336,611,000 | 37,027,210 | 11 | 1,065 | 6 |
| Santa Barbara | 398,000 | 210,187,000 | 23,120,570 | 16 | 754 | 16 |
| Santa Clara | 1,653,100 | 652,029,900 | 71,723,289 | 4 | 2,182 | 4 |
| Santa Cruz | 245,600 | 113,589,000 | 12,494,790 | 25 | 282 | 27 |
| Shasta | 162,700 | 82,545,000 | 9,079,950 | 27 | 244 | 29 |
| Sierra | 3,360 | 2,953,000 | 324,830 | 57 | 4 | 58 |
| Siskiyou | 44,400 | 32,169,000 | 3,538,590 | 39 | 151 | 38 |
| Solano | 375,400 | 172,160,000 | 18,937,600 | 18 | 433 | 19 |
| Sonoma | 426,900 | 188,719,000 | 20,759,090 | 17 | 960 | 11 |
| Stanislaus | 419,500 | 165,542,000 | 18,209,620 | 19 | 366 | 21 |
| Sutter | 74,700 | 30,202,000 | 3,322,220 | 42 | 77 | 44 |
| Tehama | 54,800 | 39,310,000 | 4,324,100 | 38 | 124 | 40 |
| Trinity | 13,400 | 6,260,000 | 688,600 | 56 | 56 | 48 |
| Tulare | 355,500 | 119,667,000 | 13,163,370 | 22 | 401 | 20 |
| Tuolumne | 52,100 | 24,708,000 | 2,717,880 | 45 | 113 | 41 |
| Ventura | 716,800 | 309,852,000 | 34,083,720 | 12 | 1,060 | 7 |
| Yolo | 154,500 | 81,478,000 | 8,962,580 | 29 | 238 | 30 |
| Yuba | 60,500 | 27,065,000 | 2,977,150 | 43 | 187 | 33 |
| **Totals** | **29,860,390** | **12,186,122,745** | **1,340,473,502** | Rank | **32,779** | Rank |

The estimated total gallons of MTBE consumed during 1996 in California, 1,340,473,502 (Table 1), is consistent with the 1997 DeWitt and Company estimate (Senate Office of Research, May 1998) of 1,499,086,752 gallons. Counties with the highest 1996 consumption of MTBE in Table 1 include: Los Angeles, Orange, San Diego, San Bernardino, and Santa Clara. Approximately, 26 percent of the MTBE consumed in California occurs in Los Angeles County.

## 3.2 UNDERGROUND STORAGE TANK SITES

### 3.2.1 UNDERGROUND STORAGE TANKS

In California there are 54,570 operating underground storage tanks (SWRCB, 1998c). An estimated 6 percent (58,676/969,652) of all of the operating underground storage tanks in the United States are located in California (USEPA, 1997). Generally, leaks from underground storage tanks are discovered during tank removals or upgrade activities. As of June 30, 1998, there were 32,779 known sites where discharges of chemical compounds from underground storage tanks to the environment occurred (SWRCB, 1998b). Ninety percent of these sites involve petroleum products.

Because of the vast number and widespread distribution of operating petroleum underground storage tank and sites where underground storage tanks have leaked, and the substantial amounts of gasoline used in California, gasoline that contains MTBE leaking from underground storage tanks is a significant source of groundwater MTBE contamination.

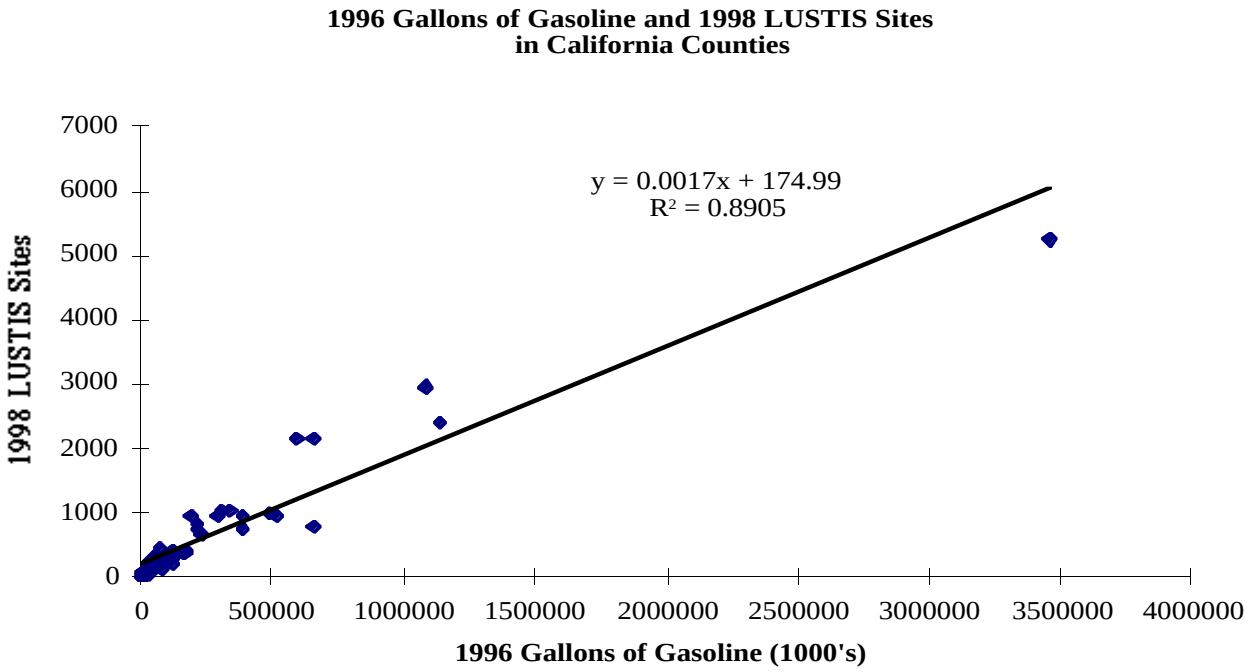


**Figure 2. Number of LUSTIS sites in 1998 (SWRCB, 1998b) versus estimated gallons of gasoline consumed in California counties during 1996 (California Board of Equalization).**

Figure 2, which uses the Board of Equalization estimate of gasoline consumption in California counties and data from the July 1998 State Water Resources Control Board LUSTIS database of the total sites discovered with leaking underground storage tanks, indicates a correlation between the amount of gasoline used and the number of leaking underground storage tanks in each county.

In August 1998, the SWRCB reported that 52 percent of the active underground storage tanks have been upgraded to meet the December 22, 1998 upgrade requirements. The percentage of active tanks that were reported upgraded in August 1998 included: underground storage tanks that hold petroleum products as well as underground storage tanks that hold other hazardous substances (10 percent). Underground storage tanks are regulated by Local Implementing Agencies of which there are 103 (SWRCB, 1998c, August). Applying the percentages of upgraded underground storage tanks to the number of active petroleum underground storage tanks in each California county leads to an estimate of the number of tanks upgraded and that still require upgrading before December 22, 1998.

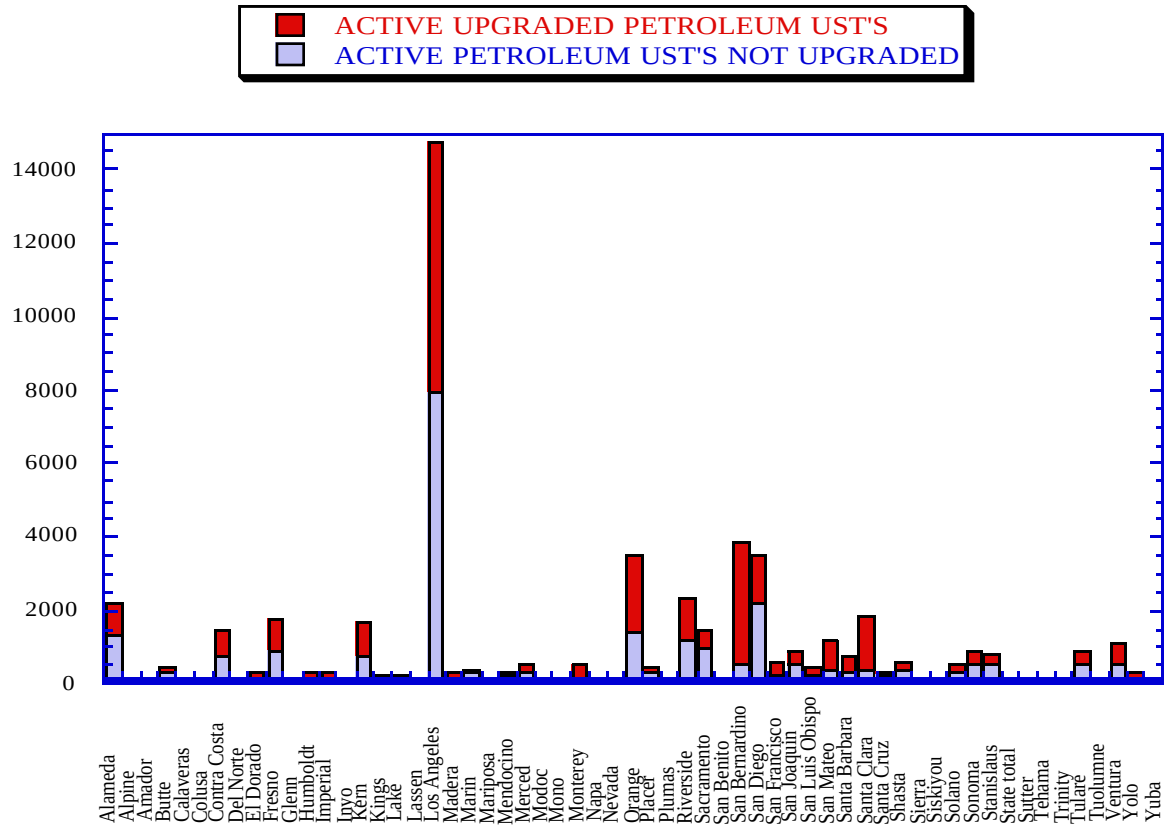


**Figure 3. Estimated numbers of California petroleum underground storage tanks upgraded and not upgraded to meet the 1998 requirements in California (SWRCB, 1998c, August).**

**Table 2. Underground storage tank upgrade percentages (SWRCB, 1998c, August) and estimated number of new groundwater sites from tank closures.**

| California County | Active Petroleum USTs | Percent USTs Meeting 1998 Upgrade Deadline | Estimate of Active Petroleum USTs NOT meeting the 1998 Deadline Requirements | Estimate of Tanks NOT Upgraded that will have leaked (2.6% annual leaks) | Estimate of New Groundwater sites (51% GW sites) |
|---|---|---|---|---|---|
| ALAMEDA | 2156 | 39% | 1,317 | 34 | 17 |
| ALPINE | 24 | 13% | 21 | 1 | 0 |
| AMADOR | 110 | 64% | 39 | 1 | 1 |
| BUTTE | 459 | 36% | 293 | 8 | 4 |
| CALAVERAS | 114 | 73% | 31 | 1 | 0 |
| COLUSA | 81 | 40% | 49 | 1 | 1 |
| CONTRA COSTA | 1498 | 52% | 716 | 19 | 9 |
| DEL NORTE | 120 | 37% | 76 | 2 | 1 |
| EL DORADO | 324 | 62% | 124 | 3 | 2 |
| FRESNO | 1764 | 50% | 882 | 23 | 12 |
| GLENN | 65 | 69% | 20 | 1 | 0 |
| HUMBOLDT | 319 | 48% | 167 | 4 | 2 |
| IMPERIAL | 298 | 87% | 38 | 1 | 0 |
| INYO | 155 | 29% | 110 | 3 | 1 |
| KERN | 1647 | 57% | 711 | 18 | 9 |
| KINGS | 239 | 61% | 94 | 2 | 1 |
| LAKE | 195 | 32% | 133 | 3 | 2 |
| LASSEN | 110 | 32% | 75 | 2 | 1 |
| LOS ANGELES | 14743 | 46% | 7,900 | 205 | 104 |
| MADERA | 276 | 54% | 127 | 3 | 2 |
| MARIN | 363 | 30% | 254 | 7 | 3 |
| MARIPOSA | 122 | 16% | 102 | 3 | 1 |
| MENDICINO | 308 | 32% | 210 | 5 | 3 |
| MERCED | 483 | 36% | 309 | 8 | 4 |
| MODOC | 42 | 52% | 20 | 1 | 0 |
| MONO | 110 | 44% | 62 | 2 | 1 |
| MONTEREY | 557 | 84% | 87 | 2 | 1 |
| NAPA | 157 | 50% | 79 | 2 | 1 |
| NEVADA | 178 | 35% | 116 | 3 | 2 |
| ORANGE | 3502 | 60% | 1,387 | 36 | 18 |
| PLACER | 456 | 37% | 288 | 7 | 4 |
| PLUMAS | 128 | 30% | 89 | 2 | 1 |
| RIVERSIDE | 2310 | 48% | 1,211 | 31 | 16 |
| SACRAMENTO | 1484 | 36% | 952 | 25 | 13 |
| SAN BENITO | 11 | 36% | 7 | 0 | 0 |
| SAN BERNARDINO | 3858 | 87% | 506 | 13 | 7 |
| SAN DIEGO | 3493 | 38% | 2,166 | 56 | 29 |
| SAN FRANCISCO | 631 | 71% | 184 | 5 | 2 |
| SAN JOAQUIN | 903 | 47% | 482 | 13 | 6 |
| SAN LUIS OBISPO | 449 | 50% | 226 | 6 | 3 |
| SAN MATEO | 1213 | 66% | 408 | 11 | 5 |
| SANTA BARBARA | 734 | 58% | 310 | 8 | 4 |
| SANTA CLARA | 1845 | 79% | 384 | 10 | 5 |
| SANTA CRUZ | 325 | 42% | 189 | 5 | 2 |
| SHASTA | 596 | 39% | 363 | 9 | 5 |
| SIERRA | 25 | 8% | 23 | 1 | 0 |
| SISKIYOU | 162 | 68% | 51 | 1 | 1 |
| SOLANO | 555 | 53% | 261 | 7 | 3 |
| SONOMA | 892 | 36% | 571 | 15 | 8 |
| STANISLAUS | 861 | 40% | 514 | 13 | 7 |
| SUTTER | 156 | 71% | 45 | 1 | 1 |
| TEHAMA | 169 | 53% | 80 | 2 | 1 |
| TRINITY | 71 | 28% | 51 | 1 | 1 |
| TULARE | 927 | 43% | 530 | 14 | 7 |
| TUOLUMNE | 167 | 32% | 114 | 3 | 1 |
| VENTURA | 1106 | 48% | 577 | 15 | 8 |
| YOLO | 348 | 70% | 103 | 3 | 1 |
| YUBA | 176 | 44% | 99 | 3 | 1 |
| **Totals** | **54,570** | **52%** | **26,333** | **685** | **347** |

Based on a 2.6 percent annual leak rate for underground storage tanks (Couch and Young, 1998), the number of active petroleum tanks, and the percentage of tanks yet to be upgraded, we estimate that at least 690 of the tanks that have not been upgraded, will have leaked, and be discovered as part of the remaining 1998 upgrade efforts. Given results of recent upgrade efforts, this is believed to be a minimum. For example, between October 1996 and October 1997, 8 percent of the underground storage tanks that were upgraded or discovered to have released product into the subsurface environment. The 1,440 confirmed leaks from underground storage tanks out of 17,590 tank closures (removals and closures in place), represents approximately 360 new LUSTIS sites per quarter. When a leak from an petroleum underground storage tanks is confirmed a new leaking underground storage tank (LUFT) site is opened. This discovery rate of new contaminated LUFT sites continues today. The SWRCB reported 399 confirmed leaks for first quarter 1998 (SWRCB, 1998a, April) and 380 for second quarter 1998 (SWRCB, 1998b, July). As of August 1998, 48 percent of California's underground storage tanks have not been upgraded to comply with December 22, 1998 requirements.

It is further estimated based on the 51 percent of "open" LUSTIS "groundwater sites" statewide out of the total LUSTIS sites, (SWRCB, 1998b, July) that 350 new "groundwater sites" may result from currently operating underground storage tanks following investigation and tank upgrade efforts (Table 2). "Open sites" are sites that are currently being investigated, remediated, or monitored for contaminants released from underground storage tanks. "Groundwater sites" are sites that include LUFT's where the released contaminants have reached groundwater and are categorized in the LUSTIS database as impacting a supply well, an aquifer used for drinking water, or other groundwater.

### 3.2.2 LUSTIS DATABASE

The California State Water Resources Control Board Leaking Underground Storage Tank Information System (LUSTIS) database is updated quarterly with information provided by the nine Regional Water Quality Control Boards (Figure 4). Additionally, there are twenty LOP (local oversite program) Agencies which regulate LUFT sites and report to the SWRCB (Appendix E).

The LUSTIS database is updated when new leaks from underground storage tanks have been reported or there has been a change of information related to an already existing site. Additionally, the LUSTIS database is used by most Regional Water Quality Control Boards as a framework that has been expanded to track information not specified in LUSTIS.

The SWRCB LUSTIS Database identifies the contaminated sites by case types: W, supply well impacted; A, aquifer impacted; O, other groundwater impacted; F, surface water impacted; S, soil only; and U, unknown. The individual sites throughout the state total 32,779, and each is assigned a unique case number. Another field, the "status code," describes site status in terms of the process leading

to closure. “Closure” occurs when the site is deemed to require no further action based on available information.

**Figure 4. Boundaries of the Regional Water Quality Control Boards.**

**Table 3. SWRCB LUSTIS Database summaries by county (SWRCB, 1998b, July).**

| County | Total Closed Sites | Total Closed Sites | Total Close Groundwater Sites | Total Ope Sites | Total Open S Sites | Total Oper Groundwater Sites | Total Site |
|---|---|---|---|---|---|---|---|
| Alameda | 932 | 442 | 473 | 1,235 | 383 | 760 | 2,167 |
| Alpine | 5 | 4 | 1 | 5 | 2 | 1 | 10 |
| Amador | 11 | 9 | 1 | 37 | 13 | 21 | 48 |
| Butte | 131 | 73 | 56 | 64 | 11 | 33 | 195 |
| Calaveras | 32 | 27 | 5 | 41 | 21 | 15 | 73 |
| Colusa | 14 | 13 | 1 | 26 | 3 | 17 | 40 |
| Contra Costa | 364 | 203 | 157 | 397 | 111 | 274 | 761 |
| Del Norte | 36 | 24 | 11 | 57 | 12 | 40 | 93 |
| El Dorado | 62 | 43 | 16 | 71 | 2 | 47 | 133 |
| Fresno | 292 | 244 | 42 | 366 | 21 | 74 | 658 |
| Glenn | 21 | 15 | 6 | 15 | 2 | 11 | 36 |
| Humboldt | 162 | 111 | 51 | 291 | 65 | 172 | 453 |
| Imperial | 145 | 104 | 34 | 33 | 3 | 20 | 178 |
| Inyo | 45 | 30 | 13 | 42 | 7 | 30 | 87 |
| Kern | 700 | 642 | 48 | 231 | 106 | 46 | 931 |
| Kings | 86 | 51 | 35 | 74 | 7 | 61 | 160 |
| Lake | 32 | 24 | 7 | 41 | 7 | 23 | 73 |
| Lassen | 6 | 2 | 2 | 17 | 2 | 12 | 23 |
| Los Angeles | 2,694 | 1,407 | 1,002 | 2,567 | 916 | 1,003 | 5,261 |
| Madera | 104 | 99 | 5 | 78 | 9 | 10 | 182 |
| Marin | 149 | 42 | 105 | 163 | 32 | 117 | 312 |
| Mariposa | 43 | 35 | 8 | 33 | 11 | 19 | 76 |
| Mendocino | 160 | 114 | 43 | 154 | 11 | 95 | 314 |
| Merced | 176 | 105 | 71 | 168 | 87 | 64 | 344 |
| Modoc | 6 | 5 | 0 | 5 | 0 | 5 | 11 |
| Mono | 24 | 20 | 2 | 29 | 6 | 19 | 53 |
| Monterey | 160 | 91 | 31 | 205 | 17 | 112 | 365 |
| Napa | 131 | 73 | 56 | 146 | 54 | 86 | 277 |
| Nevada | 57 | 33 | 19 | 100 | 27 | 59 | 157 |
| Orange | 1,318 | 952 | 366 | 1,097 | 461 | 636 | 2,415 |
| Placer | 99 | 67 | 29 | 245 | 74 | 121 | 344 |
| Plumas | 34 | 18 | 16 | 15 | 8 | 6 | 49 |
| Riverside | 612 | 502 | 86 | 354 | 146 | 181 | 966 |
| Sacramento | 483 | 442 | 41 | 529 | 231 | 206 | 1,012 |
| San Benito | 31 | 14 | 2 | 21 | 10 | 4 | 52 |
| San Bernardino | 425 | 354 | 61 | 377 | 240 | 95 | 802 |
| San Diego | 1,549 | 915 | 631 | 1,416 | 690 | 721 | 2,965 |
| San Francisco | 739 | 521 | 209 | 240 | 85 | 133 | 979 |
| San Joaquin | 310 | 219 | 91 | 524 | 267 | 188 | 834 |
| San Luis Obispo | 124 | 53 | 43 | 69 | 7 | 53 | 193 |
| San Mateo | 364 | 168 | 189 | 701 | 165 | 485 | 1,065 |
| Santa Barbara | 322 | 223 | 29 | 432 | 181 | 115 | 754 |
| Santa Clara | 1,269 | 828 | 424 | 913 | 358 | 481 | 2,182 |
| Santa Cruz | 130 | 70 | 46 | 152 | 25 | 103 | 282 |
| Shasta | 190 | 100 | 88 | 54 | 11 | 22 | 244 |
| Sierra | 3 | 2 | 1 | 1 | 0 | 1 | 4 |
| Siskiyou | 83 | 63 | 20 | 68 | 12 | 49 | 151 |
| Solano | 193 | 118 | 68 | 240 | 53 | 162 | 433 |
| Sonoma | 444 | 222 | 219 | 516 | 49 | 423 | 960 |
| Stanislaus | 200 | 141 | 59 | 166 | 50 | 86 | 366 |
| Sutter | 38 | 30 | 8 | 39 | 5 | 21 | 77 |
| Tehama | 87 | 59 | 28 | 37 | 8 | 20 | 124 |
| Trinity | 26 | 21 | 5 | 30 | 6 | 15 | 56 |
| Tulare | 210 | 162 | 48 | 191 | 30 | 90 | 401 |
| Tuolumne | 32 | 30 | 2 | 81 | 29 | 43 | 113 |
| Ventura | 696 | 476 | 185 | 364 | 114 | 205 | 1,060 |
| Yolo | 132 | 99 | 33 | 106 | 10 | 74 | 238 |
| Yuba | 50 | 45 | 5 | 137 | 84 | 34 | 187 |
| TOTAL | 16,973 | 10,999 | 5,333 | 15,806 | 5,357 | 8,019 | 32,779 |

## Table 3 Cont'd. SWRCB LUSTIS Database summaries by county.

| County | Total Sites (Closed and Open) | Total Open Sites | Total Open Soil Sites | Total Open Groundwater Sites | Open W Sites | Open A Sites | Open O Sites | Open S Sites | Open F Sites | Open U Sites |
|---|---|---|---|---|---|---|---|---|---|---|
| Alameda | 2,167 | 1,235 | 383 | 760 | 14 | 1 | 745 | 383 | 0 | 92 |
| Alpine | 10 | 5 | 2 | 1 | 0 | 1 | 0 | 2 | 1 | 1 |
| Amador | 48 | 37 | 13 | 21 | 2 | 17 | 2 | 13 | 2 | 1 |
| Butte | 195 | 64 | 11 | 33 | 2 | 30 | 1 | 11 | 1 | 19 |
| Calaveras | 73 | 41 | 21 | 15 | 1 | 10 | 4 | 21 | 1 | 4 |
| Colusa | 40 | 26 | 3 | 17 | 0 | 16 | 1 | 3 | 0 | 6 |
| Contra Costa | 761 | 397 | 111 | 274 | 1 | 75 | 198 | 111 | 0 | 12 |
| Del Norte | 93 | 57 | 12 | 40 | 0 | 40 | 0 | 12 | 0 | 5 |
| El Dorado | 133 | 71 | 2 | 47 | 6 | 41 | 0 | 2 | 3 | 19 |
| Fresno | 658 | 366 | 21 | 74 | 2 | 72 | 0 | 21 | 0 | 271 |
| Glenn | 36 | 15 | 2 | 11 | 0 | 11 | 0 | 2 | 0 | 2 |
| Humboldt | 453 | 291 | 65 | 172 | 7 | 165 | 0 | 65 | 1 | 53 |
| Imperial | 178 | 33 | 3 | 20 | 0 | 20 | 0 | 3 | 0 | 10 |
| Inyo | 87 | 42 | 7 | 30 | 1 | 28 | 1 | 7 | 1 | 4 |
| Kern | 931 | 231 | 106 | 46 | 1 | 44 | 1 | 106 | 1 | 78 |
| Kings | 160 | 74 | 7 | 61 | 0 | 61 | 0 | 7 | 0 | 6 |
| Lake | 73 | 41 | 7 | 23 | 1 | 22 | 0 | 7 | 2 | 9 |
| Lassen | 23 | 17 | 2 | 12 | 2 | 10 | 0 | 2 | 0 | 3 |
| Los Angeles | 5,261 | 2,567 | 916 | 1,003 | 7 | 17 | 979 | 916 | 1 | 647 |
| Madera | 182 | 78 | 9 | 10 | 1 | 9 | 0 | 9 | 0 | 59 |
| Marin | 312 | 163 | 32 | 117 | 3 | 1 | 113 | 32 | 0 | 14 |
| Mariposa | 76 | 33 | 11 | 19 | 1 | 18 | 0 | 11 | 0 | 3 |
| Mendocino | 314 | 154 | 11 | 95 | 7 | 88 | 0 | 11 | 1 | 47 |
| Merced | 344 | 168 | 87 | 64 | 2 | 62 | 0 | 87 | 0 | 17 |
| Modoc | 11 | 5 | 0 | 5 | 0 | 5 | 0 | 0 | 0 | 0 |
| Mono | 53 | 29 | 6 | 19 | 0 | 19 | 0 | 6 | 0 | 4 |
| Monterey | 365 | 205 | 17 | 112 | 1 | 8 | 103 | 17 | 0 | 76 |
| Napa | 277 | 146 | 54 | 86 | 2 | 1 | 83 | 54 | 0 | 6 |
| Nevada | 157 | 100 | 27 | 59 | 1 | 58 | 0 | 27 | 0 | 14 |
| Orange | 2,415 | 1,097 | 461 | 636 | 0 | 494 | 142 | 461 | 0 | 0 |
| Placer | 344 | 245 | 74 | 121 | 1 | 119 | 1 | 74 | 12 | 38 |
| Plumas | 49 | 15 | 8 | 6 | 0 | 6 | 0 | 8 | 1 | 0 |
| Riverside | 966 | 354 | 146 | 181 | 0 | 180 | 1 | 146 | 1 | 26 |
| Sacramento | 1,012 | 529 | 231 | 206 | 8 | 191 | 7 | 231 | 0 | 92 |
| San Benito | 52 | 21 | 10 | 4 | 0 | 1 | 3 | 10 | 0 | 7 |
| San Bernardino | 802 | 377 | 240 | 95 | 1 | 78 | 16 | 240 | 2 | 40 |
| San Diego | 2,965 | 1,416 | 690 | 721 | 4 | 413 | 304 | 690 | 3 | 2 |
| San Francisco | 979 | 240 | 85 | 133 | 0 | 1 | 132 | 85 | 0 | 22 |
| San Joaquin | 834 | 524 | 267 | 188 | 3 | 184 | 1 | 267 | 0 | 69 |
| San Luis Obispo | 193 | 69 | 7 | 53 | 0 | 1 | 52 | 7 | 1 | 8 |
| San Mateo | 1,065 | 701 | 165 | 485 | 0 | 1 | 484 | 165 | 0 | 51 |
| Santa Barbara | 754 | 432 | 181 | 115 | 0 | 17 | 98 | 181 | 0 | 136 |
| Santa Clara | 2,182 | 913 | 358 | 481 | 3 | 4 | 474 | 358 | 0 | 74 |
| Santa Cruz | 282 | 152 | 25 | 103 | 0 | 4 | 99 | 25 | 1 | 23 |
| Shasta | 244 | 54 | 11 | 22 | 0 | 22 | 0 | 11 | 0 | 21 |
| Sierra | 4 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 |
| Siskiyou | 151 | 68 | 12 | 49 | 2 | 47 | 0 | 12 | 0 | 7 |
| Solano | 433 | 240 | 53 | 162 | 3 | 42 | 117 | 53 | 0 | 25 |
| Sonoma | 960 | 516 | 49 | 423 | 23 | 369 | 31 | 49 | 1 | 43 |
| Stanislaus | 366 | 166 | 50 | 86 | 0 | 86 | 0 | 50 | 0 | 30 |
| Sutter | 77 | 39 | 5 | 21 | 2 | 19 | 0 | 5 | 0 | 13 |
| Tehama | 124 | 37 | 8 | 20 | 1 | 19 | 0 | 8 | 0 | 9 |
| Trinity | 56 | 30 | 6 | 15 | 0 | 15 | 0 | 6 | 0 | 9 |
| Tulare | 401 | 191 | 30 | 90 | 5 | 85 | 0 | 30 | 0 | 71 |
| Tuolumne | 113 | 81 | 29 | 43 | 2 | 41 | 0 | 29 | 0 | 9 |
| Ventura | 1,060 | 364 | 114 | 205 | 0 | 0 | 205 | 114 | 0 | 45 |
| Yolo | 238 | 106 | 10 | 74 | 2 | 72 | 0 | 10 | 0 | 22 |
| Yuba | 187 | 137 | 84 | 34 | 3 | 31 | 0 | 84 | 0 | 19 |
| TOTAL | 32,779 | 15,806 | 5,357 | 8,019 | 128 | 3,493 | 4,398 | 5,357 | 37 | 2,393 |

### 3.2.3 Leaking Underground Fuel Tanks Sites with MTBE Detections

A total of 3,486 MTBE groundwater contaminated sites, 133 of which are not LUFT sites, have been discovered thus far. This total is controlled partly by whether the site has been tested for MTBE and whether the petroleum product that leaked into groundwater contained MTBE. Sites where the possibility of groundwater contamination has not been investigated and are still classified as a soil only sites, have not been monitored for MTBE in the groundwater. Table 5 is a summary of the current and new MTBE groundwater sites resulting from upgrade investigations.

Statewide, 55 percent (3,180/5,738) of the open (i.e., currently investigated) groundwater gasoline sites have detectable concentrations of MTBE in groundwater. Minimum detectable concentrations range from 0.5 $\mu g \cdot L^{-1}$ to greater than 10.0 $\mu g \cdot L^{-1}$, depending on analytical method and interference levels. Including MTBE groundwater sites that have been closed, an estimated 43 percent of all gasoline LUFT sites (closed and open) contaminating groundwater have detectable concentrations of MTBE. Using the 350 groundwater LUFT sites that are anticipated from the 1998 tank upgrade efforts, and the percentage of LUFT sites that include gasoline and impact groundwater (5,738/8,019), we estimate there may be at least an additional 250 MTBE groundwater sites after all tank upgrade efforts are complete. This assumes that all of the newly discovered gasoline LUFT's will have stored gasoline that contains MTBE. In summary, an estimated 3,736 groundwater LUFT sites have detectable levels of MTBE, including sites currently reported and sites anticipated with the 1998 upgrade efforts.

Data used to compile the MTBE site totals are summarized in Tables 4 and 5. The data from the Los Angeles Regional Water Quality Control Board (4) came from two sources, because the most recent data from the Water Purveyor's Report did not distinguish between open and closed sites.

**Table 4. Regional Board MTBE data summary.**

| REGIONAL BOARD | TOTAL MTBE SITES | TOTAL UST MTBE SOIL | TOTAL UST MTBE GW | OTHER MTBE SITES | TESTED NONE DETECTED | TOTAL OPEN MTBE SITES | TOTAL SUPPLY WELL MTBE SITES | TOTAL CLOSED MTBE SITES | DATA DATE |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 317 | 35 | 247 | 35 | UNKNOWN | 271 | 17 | 11 | JULY 15, 199 |
| 2 | 879 | UNKNOWN | 879 | UNKNOWN | UNKNOWN | 809 | UNKNOWN | 70 | AUGUST 1998 |
| 3 | 232 | 1 | 224 | 7 | UNKNOWN | UNKNOWN | UNKNOWN | UNKNOWN | JULY 21, 199 |
| 4 | 880 | 49 | 822 | 9 | 212 | 606 | 1 | 167 | APRIL/JULY 199 |
| 5 | 742 | 96 | 572 | 74 | 451 | 677 | 21 | 65 | AUGUST 1998 |
| 6 | 99 | 5 | 88 | 6 | UNKNOWN | UNKNOWN | 3 | UNKNOWN | JULY 6, 1998 |
| 7 | 56 | 7 | 47 | 2 | 2 | UNKNOWN | UNKNOWN | UNKNOWN | JULY 27, 199 |
| 8 | 395 | UNKNOWN | 395 | UNKNOWN | UNKNOWN | UNKNOWN | UNKNOWN | UNKNOWN | FEBRUARY 1998 |
| 9 | 241 | 29 | 212 | UNKNOWN | UNKNOWN | UNKNOWN | UNKNOWN | UNKNOWN | AUGUST 1, 199 |
| TOTALS | 3841 | 222 | 3486 | 133 | | | | | |

Although some Regional Boards reported in their databases the sites where MTBE was not detected in groundwater, most did not because the reports to the

water purveyors. The Regional Boards include only sites where there has been a detection.

**Table 5. Total MTBE sites, estimated new MTBE groundwater sites discovered during tank upgrades, estimated MTBE groundwater sites open, and total MTBE sites.**

| COUNTY | MTBE UST SOIL SITES | MTBE UST GROUNDWATER SITES | OTHER MTBE SITES | ESTIMATED NEW MTBE GROUNDWATER FROM 1998 TANK UPGRADES | ESTIMATED OPEN MTBE LUSTIS GROUNDWATER SITES | CURRENT TOTAL MTBE SITES |
|---|---|---|---|---|---|---|
| Alameda | 1 | 173 | 0 | 12 | 174 | 174 |
| Alpine | 0 | 1 | 0 | 0 | 2 | 1 |
| Amador | 0 | 5 | 2 | 0 | 5 | 7 |
| Butte | 6 | 24 | 3 | 3 | 20 | 33 |
| Calaveras | 1 | 4 | 0 | 0 | 4 | 5 |
| Colusa | 0 | 6 | 2 | 0 | 6 | 8 |
| Contra Costa | 0 | 102 | 0 | 7 | 102 | 102 |
| Del Norte | 0 | 12 | 0 | 1 | 12 | 12 |
| El Dorado | 0 | 27 | 5 | 1 | 27 | 32 |
| Fresno | 0 | 10 | 4 | 8 | 9 | 14 |
| Glenn | 0 | 7 | 0 | 0 | 6 | 7 |
| Humboldt | 21 | 53 | 6 | 2 | 53 | 80 |
| Imperial | 2 | 3 | 1 | 0 | 3 | 6 |
| Inyo | 0 | 5 | 0 | 1 | 5 | 5 |
| Kern | 3 | 11 | 0 | 7 | 11 | 14 |
| Kings | 0 | 8 | 0 | 1 | 6 | 8 |
| Lake | 0 | 7 | 0 | 1 | 7 | 7 |
| Lassen | 0 | 6 | 1 | 1 | 6 | 7 |
| Los Angeles | 45 | 719 | 8 | 75 | 538 | 772 |
| Madera | 0 | 4 | 2 | 1 | 4 | 6 |
| Marin | 0 | 44 | 0 | 2 | 36 | 44 |
| Mariposa | 1 | 5 | 0 | 1 | 5 | 6 |
| Mendocino | 7 | 41 | 2 | 2 | 41 | 50 |
| Merced | 5 | 26 | 6 | 3 | 19 | 37 |
| Modoc | 0 | 3 | 0 | 0 | 3 | 3 |
| Mono | 0 | 5 | 0 | 1 | 5 | 5 |
| Monterey | 1 | 36 | 4 | 1 | 36 | 41 |
| Napa | 0 | 27 | 1 | 1 | 23 | 28 |
| Nevada | 0 | 20 | 0 | 1 | 20 | 20 |
| Orange | 17 | 427 | 0 | 13 | 427 | 444 |
| Placer | 8 | 58 | 10 | 3 | 44 | 76 |
| Plumas | 0 | 3 | 0 | 1 | 3 | 3 |
| Riverside | 4 | 79 | 1 | 11 | 79 | 84 |
| Sacramento | 26 | 90 | 8 | 9 | 86 | 124 |
| San Benito | 0 | 2 | 0 | 0 | 2 | 2 |
| San Bernardino | 5 | 55 | 1 | 5 | 55 | 61 |
| San Diego | 11 | 118 | 0 | 20 | 118 | 129 |
| San Francisco | 0 | 49 | 0 | 2 | 39 | 49 |
| San Joaquin | 25 | 95 | 7 | 5 | 93 | 127 |
| San Luis Obispo | 0 | 33 | 0 | 2 | 33 | 33 |
| San Mateo | 0 | 158 | 0 | 4 | 155 | 158 |
| Santa Barbara | 0 | 78 | 1 | 3 | 78 | 79 |
| Santa Clara | 0 | 250 | 0 | 4 | 219 | 250 |
| Santa Cruz | 0 | 62 | 2 | 2 | 62 | 64 |
| Shasta | 5 | 19 | 6 | 3 | 12 | 30 |
| Sierra | 0 | 0 | 0 | 0 | 0 | 0 |
| Siskiyou | 0 | 13 | 0 | 0 | 13 | 13 |
| Solano | 2 | 81 | 1 | 2 | 74 | 84 |
| Sonoma | 5 | 157 | 21 | 5 | 157 | 183 |
| Stanislaus | 7 | 46 | 4 | 5 | 37 | 57 |
| Sutter | 1 | 11 | 0 | 0 | 11 | 12 |
| Tehama | 2 | 13 | 4 | 1 | 10 | 19 |
| Trinity | 2 | 8 | 6 | 0 | 8 | 16 |
| Tulare | 1 | 23 | 10 | 5 | 23 | 34 |
| Tuolumne | 0 | 10 | 1 | 1 | 10 | 11 |
| Ventura | 6 | 107 | 1 | 5 | 97 | 114 |
| Yolo | 0 | 36 | 2 | 1 | 36 | 38 |
| Yuba | 2 | 11 | 0 | 1 | 11 | 13 |
| TOTAL | 222 | 3486 | 133 | 249 | 3,180 | 3841 |

Approximately 13 percent of the sites tested did not detect MTBE contamination in the samples collected (Figure 6).

Currently, 72 percent (5,738/8,019) of open groundwater LUFT sites are contaminated with gasoline (SWRCB, 1998b, July). However, not all of the sites contaminated with gasoline have been tested for MTBE. MTBE groundwater sites are assumed to be all gasoline sites since those are the groundwater sites primarily sampled thus far. Approximately 55 percent (3,180/5,738) of the open gasoline groundwater contaminated sites are also contaminated with MTBE. The MTBE analytical results that have been reported thus far range from non-detect to greater than 1,000,000 $\mu g \cdot L^{-1}$.

Figure 5 shows numbers of groundwater contaminated sites and MTBE contaminated sites in relation to the total number of releases reported in California counties.

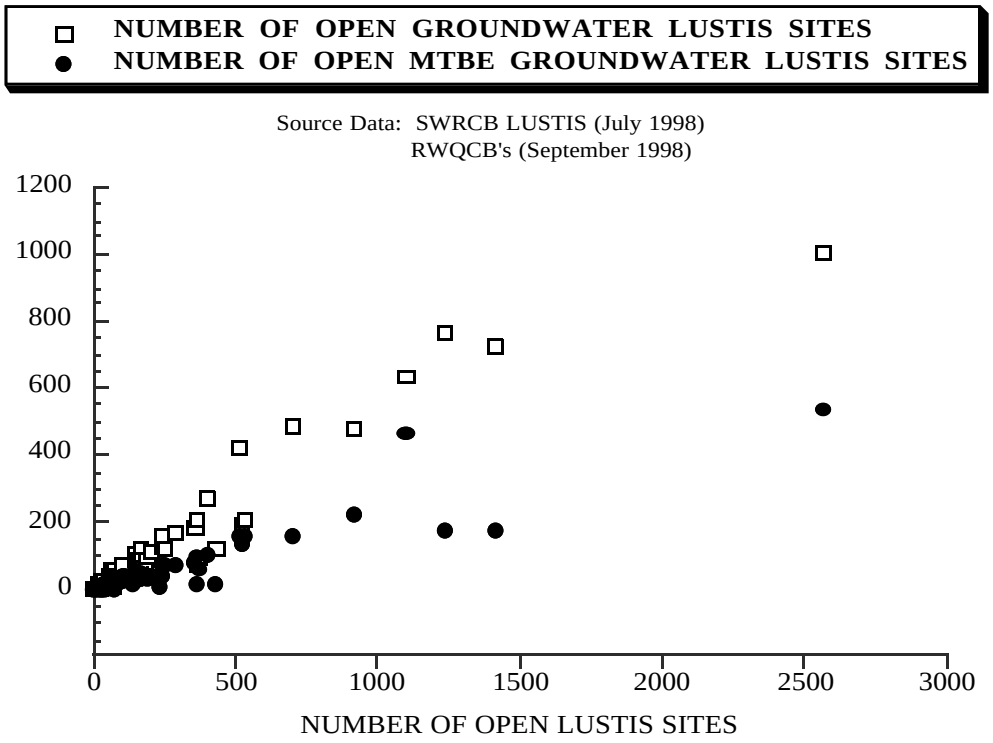


**Figure 5. Open groundwater LUSTIS sites and MTBE groundwater LUSTIS sites versus total open LUSTIS sites.**

The Santa Clara Valley Water District, which implemented in 1996 an aggressive MTBE groundwater protection strategy, reports that 78 percent of their gasoline contaminated groundwater sites have been monitored for MTBE, and MTBE has been detected at 73 percent of the sites tested (Santa Clara Valley Water District, 1997, November; 1998b, August).

Counties with the highest number of open groundwater LUFT sites are Los Angeles (1,003), Alameda (760), San Diego (721), Orange (636), San Mateo (485), Santa Clara (481) and Sonoma (423). Approximately 13 percent of all the open groundwater sites are in Los Angeles and 16 percent of all the releases from underground storage tanks have occurred in Los Angeles (5,261/32,779). These same seven counties have the highest number of sites with reported MTBE groundwater contamination: Los Angeles (772), Orange (444), Santa Clara (250), Alameda (174), Sonoma (183), San Mateo (158), and San Diego (129).

Approximately 21 percent of all the MTBE groundwater sites have been reported in Los Angeles. It must be stressed that in Los Angeles awareness of the impacts that MTBE may have on public drinking water supply wells is high, with 37 percent of all recorded, MTBE-contaminated public supply wells in California occurring in Los Angeles (MWD, 1997). According to Los Angeles RWQCB staff (Bacharowski, 1998) 83 percent of all the gasoline contaminated groundwater sites have been tested for MTBE.

### 3.2.4 CONCENTRATIONS OF MTBE IN GROUNDWATER AT LUFT SITES

The concentrations detected at sites, reported by the nine Regional Water Quality Control Boards (RWQCB's), are based on current site maximums or the maximum at the site when MTBE was first detected (Appendix C). Using information from four RWQCB's, maximum concentrations of MTBE detected in groundwater monitoring wells at LUFT sites are compiled in a cumulative probability plot in Figure 6. The data on maximum concentration represent different dates. The database from Santa Ana Region (8) was dated February 1998 and the databases for North Coast (1), San Francisco Bay (2), and Los Angeles (4) Regions were dated April 1998.

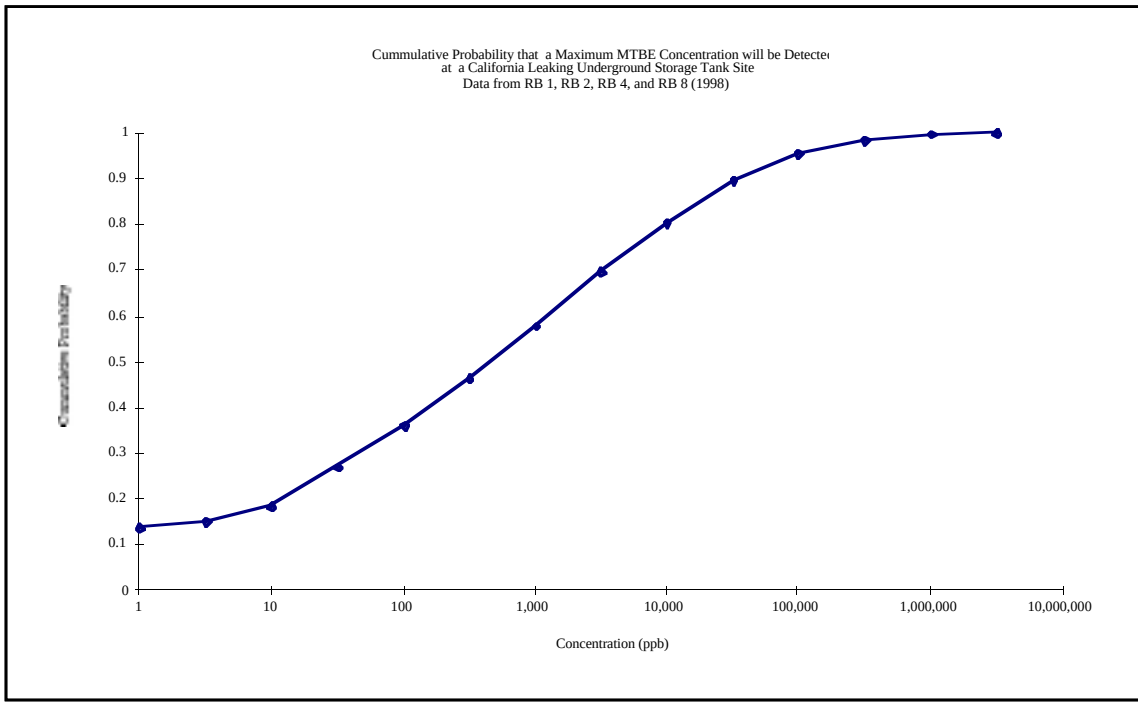


**Figure 6. Cumulative probability plot of MTBE maximum concentrations at LUFT sites.**

Figure 6 shows, for example, that 36 percent of the sites reporting MTBE groundwater contamination had concentrations less than 100 $\mu g \cdot L^{-1}$, 48 percent had concentrations less than 500 $\mu g \cdot L^{-1}$, 80 percent had concentrations less than 10,000 $\mu g \cdot L^{-1}$, and 4.5 percent had maximum concentrations greater than 100,000 $\mu g \cdot L^{-1}$. The high concentrations found at many sites are not surprising, given the high solubility of MTBE in water (50,000 $mgL^{-1}$ Zogorski et al., 1996), the low sorption potential of MTBE, and its recalcitrance with respect to biodegradation.

### 3.2.5 Closed LUFT Sites

There are 3,432 gasoline contaminated groundwater sites that have been closed, requiring no further actions (SWRCB, 1998b, July). Insufficient data are available to assess the numbers of closed sites that have been contaminated with MTBE, because it was only recently that the Health and Safety Code was amended (SB 521) to require MTBE analysis prior to issuance of a closure letter. Once a closure letter is issued, no further action at the site is required, unless there is an indication that changing site conditions or additional information warrants the re-opening of the site.

The exact number of MTBE contaminated closed sites reported by region cannot be estimated at this time because Regional Boards do not all report in the water purveyor's reports whether a site is open or closed, and many Regional Board's did not provide data electronically to perform matching with the LUSTIS database. The available data suggested that a significant proportion of the closed gasoline contaminated sites with reported test results had detectable concentrations of MTBE (169/286 Los Angeles (4) and 38/65 Central Valley (5)). It is not likely that

the majority of closed gasoline contaminated groundwater sites have MTBE groundwater contamination, because many of these sites were closed prior to the widespread use of MTBE in gasoline. However, sites that were rapidly closed as low risk groundwater sites or soil only sites, based the December 8, 1995 SWRCB letter reporting the findings of the report "Recommendations to Improve the Cleanup Process for California's Leaking Underground Fuel Tanks" (Rice et al., 1995a), may not have yet been analyzed for MTBE. That letter to Regional Boards and Local Oversight Program Agencies defined "low risk groundwater sites" as having shallow groundwater with maximum depths to water of less than 50 ft and no drinking water wells screened in the shallow groundwater zone within 250 ft of the leak.

## 3.3 RESULTS OF HAPPEL ET AL. (1998)

The analysis of groundwater impacts contained herein complements and extends the recent work of Happel et al. (1998). Benefiting from greater availability of data at the time of our investigation, we were able to compile more statewide information and document impacts that are more recent.

Happel et al. (1998) estimated from a sample of 236 leaking underground storage tanks in 24 urban counties that 78 percent of the groundwater impacted sites are contaminated by MTBE. This value is consistent with the 73 percent frequency of MTBE contamination observed at Santa Clara LUFT sites (Santa Clara Valley Water District, 1998b, August). Happel et al. (1998) used the 78 percent to estimate the existence of at least 10,000 MTBE impacted sites. The 10,000 sites represent 78 percent of the all sites with groundwater contamination (13,278; SWRCB, 1998a, April) from all products stored in underground storage tanks, including gasoline, diesel, waste oil, aviation fuel, and solvent tanks. In contrast, we identified 3,180 sites with detectable MTBE concentrations out of 5,738 open gasoline LUFT sites which have impacted groundwater. The corresponding estimate by Happel et al. (1998), 10,000, is substantially higher than ours because it was calculated by computing a percentage of all leaking underground fuel tanks, not just the gasoline tanks. Nevertheless, the actual number of MTBE-impacted sites is no doubt greater than the 3,180 estimated open LUFT sites with MTBE contamination or the 3841 total sites reported thus far.

Additionally, Happel et al. (1998) studied time series data from 29 LUFT sites located in San Diego County where MTBE samples had been collected beginning in 1992. They observed a gradual disassociation of MTBE plumes from plumes containing other gasoline constituents including benzene, toluene, ethylbenzene, and xylene (BTEX). They concluded from this data and the assumption that most BTEX plumes were stable that MTBE plumes were mobile. This conclusion is consistent with results obtained by the USGS (Landmeyer et al., 1998) reflecting a chromatographic-like separation of MTBE from benzene plumes in the direction of groundwater flow.

Happel et al. (1998) observed that MTBE concentrations in the San Diego County downgradient wells were often equivalent or significantly higher than concentrations of BTEX compounds, suggesting to them that at many of the sites

MTBE was leaving established monitoring networks at significantly higher concentrations than individual BTEX compounds. Thirty percent of the sites studied had downgradient wells with MTBE concentrations more than 20 $\mu g \cdot L^{-1}$. MTBE's higher mobility and recalcitrance results in larger plumes that require more extensive monitoring networks to characterize these plumes. Part of the increased cost associated with MTBE plumes directly relates to the increased costs of investigation and monitoring.

Finally, Happel et al. (1998) evaluated the effects of high precipitation events on MTBE concentrations in monitoring wells. They observed spikes in the MTBE concentrations after the particularly wet winters of 1992/1993 and 1994/1995. These spikes are related to increased leaching of MTBE from contaminated soil into groundwater. Happel, et al. (1998) expressed concern regarding the intermittent surges in concentrations and suggested that periodic monitoring (i.e., quarterly monitoring at fixed intervals) may fail to detect significant concentrations of MTBE that move outside of monitoring networks. The Santa Ana RWQCB has been collecting time series data for over 250 LUFT sites since 1996 (Santa Ana RWQCB, 1998). Analysis of this data together with site specific mass balances and precipitation levels may provide further information regarding effects of precipitation on leaching and atmospheric deposition

## 3.4 Regional Board Testing for ETBE, TAME, and Ethanol

Two Regional Boards, North Coast (1) and Central Valley (5), have included alternative oxygenate testing results in their database. While data are scarce, detections of other oxygenates besides MTBE have been reported. These detections include impacts from the following oxygenates: methanol; ethanol; tertiary butyl alcohol (TBA); di-isopropyl ether (DIPE); ethyl tertiary butyl ether (ETBE); and tertiary amyl methyl ether (TAME). The LUSTIS database does not accommodate substance codes for oxygenates, with the exceptions of ethanol and methanol. Ethanol and methanol are substances that are currently reportable in LUSTIS because there are ethanol and methanol tanks in operation. Since there is only one substance code reported in LUSTIS, which is the framework for Regional Board databases, if ethanol or methanol were detected at a gasoline fuel site, it is most likely that the substance reported on LUSTIS would be gasoline, instead of ethanol or methanol.

The requirement to test for the alternative oxygenates varies within regions (Appendix C). There is analysis that must be performed, in addition to the standard petroleum analysis, to measure concentrations of the alternative oxygenates. Generally, analysis for petroleum contamination including MTBE, is accomplished using EPA Method 8020; however, the more expensive analysis using EPA Method 8260 must be used to confirm MTBE results and to detect the alternative oxygenates. Regional Board 1, Regional Board 2 and Regional Board 5 have reported that EPA Method 8260 for analysis of the alternative oxygenates is required. Regional Board 4 requires alternative oxygenate analysis, if a water supply well has been contaminated. The other Regional Boards do not require analysis for other oxygenates at this time.

# 4.0 OTHER SOURCES OF MTBE GROUNDWATER CONTAMINATION

There have been reported instances where sources of MTBE, other than from gasoline leaking underground storage tanks, have resulted in detection of MTBE in groundwater resources. These sources will be briefly described, but there are insufficient data to perform thorough analysis. The other sources of MTBE groundwater contamination include: above ground storage tanks, farm tanks, leaking petroleum fuel pipelines, underground storage tanks containing fuels other than gasoline, surface spills due to automobile or tanker truck accidents, surface spills due to abandoned or parked vehicles, MTBE contaminated surface water, precipitation and storm water runoff.

Fuels other than gasoline including diesel, jet fuel, heating oil, aviation fuel and waste oil leaking from underground storage tanks have also been implicated as sources of MTBE contamination. The amount and concentration of MTBE in fuels other than gasoline, however, should be relatively small. Petroleum industry representatives have suggested that the MTBE found in these fuels may have been inadvertently added when the fuels were transported in distribution systems that previously transported MTBE laden fuel (Hitzig et al.,1998).

Information was requested from the State Fire Marshall's office describing releases and the number of pipelines in California counties. Unfortunately, information was not available that could be included in this report. The most frequently cited example where a petroleum pipeline leaked affecting groundwater quality is the Elmira leak in Solano County.

In September 1996, a fracture was discovered in a fuel line owned by Santa Fe Pacific Pipeline Partners L. P. in Elmira California, which is estimated to have leaked between 20,000 to 60,000 gallons of gasoline (Martineau, 1997a, May). The pipeline reportedly carries petroleum products from the Bay Area to Nevada (Martineau 1997b, June). Residents of Elmira were told of the leak on December 1996, when fuel was found in the town's drinking water. Santa Fe is reported to have paid for the installation of new water lines in Elmira and was ordered to continue investigations when a new fuel contaminated site was identified 1,000 ft from where the fracture was first found (Schelbe, 1998). The pipeline reportedly has leaked three times in Solano County since 1993. This pipeline is the same that leaked in March 1997 near Donner Lake in Placer County.

Information was obtained from the SWRCB about the number of above ground storage tanks in each county (Table 6); however, information regarding leak or spill histories were not available (SWRCB, 1998d, September).

**Table 6. Above ground tanks in each county.**

| County | Active Petroleum USTs (August 1998) | Active Above Ground Storage Tanks (September 1998) | County | Active Petroleum USTs (August 1998) | Active Above Ground Storage Tanks (September 1998) |
|---|---|---|---|---|---|
| Alameda | 2,156 | 109 | Orange | 3,502 | 63 |
| Alpine | 24 | 3 | Placer | 456 | 33 |
| Amador | 110 | 21 | Plumas | 128 | 24 |
| Butte | 459 | 60 | Riverside | 2,310 | 74 |
| Calaveras | 114 | 14 | Sacramento | 1,484 | 104 |
| Colusa | 81 | 13 | San Benito | 11 | 14 |
| Contra Costa | 1,498 | 72 | San Bernardino | 3,858 | 120 |
| Del Norte | 120 | 12 | San Diego | 3,493 | 101 |
| El Dorado | 324 | 25 | San Francisco | 631 | 23 |
| Fresno | 1,764 | 135 | San Joaquin | 903 | 110 |
| Glenn | 65 | 32 | San Luis Obispo | 449 | 27 |
| Humboldt | 319 | 85 | San Mateo | 1,213 | 27 |
| Imperial | 298 | 40 | Santa Barbara | 734 | 37 |
| Inyo | 155 | 15 | Santa Clara | 1,845 | 68 |
| Kern | 1,647 | 199 | Santa Cruz | 325 | 19 |
| Kings | 239 | 35 | Shasta | 596 | 79 |
| Lake | 195 | 18 | Sierra | 25 | 9 |
| Lassen | 110 | 21 | Siskiyou | 162 | 61 |
| Los Angeles | 14,743 | 312 | Solano | 555 | 46 |
| Madera | 276 | 30 | Sonoma | 892 | 41 |
| Marin | 363 | 18 | Stanislaus | 861 | 107 |
| Mariposa | 122 | 5 | Sutter | 156 | 14 |
| Mendocino | 308 | 33 | Tehama | 169 | 47 |
| Merced | 483 | 66 | Trinity | 71 | 18 |
| Modoc | 42 | 8 | Tulare | 927 | 51 |
| Mono | 110 | 8 | Tuolumne | 167 | 19 |
| Monterey | 557 | 49 | Ventura | 1,106 | 57 |
| Napa | 157 | 15 | Yolo | 348 | 30 |
| Nevada | 178 | 14 | Yuba | 176 | 22 |
| | | | State total | 54,570 | 2,912 |

The number of petroleum underground storage tanks are included in Table 6 above for comparison. Requests were made of each Regional Water Quality Control Board regarding MTBE contamination from above ground storage tanks; however, the staffing levels of the above ground tank program are limited, and the information requested could not be provided.

Atmospheric deposition has been implicated as the source of low levels of MTBE identified, as part of United Stated Geological Survey (USGS) studies, in the shallow urban groundwater in Denver and New England (Pankow et al., 1997). Sources of MTBE to the atmosphere include motor vehicle exhaust and point sources – primarily refineries, evaporative emissions during spillage or vehicular fueling (Zogorski et al., 1996). Because of MTBE's high water solubility, atmospheric concentrations will partition into precipitation, transferring mass from the gaseous phase into the water phase (Squillace et al., 1997). One indirect measure of MTBE concentrations in precipitation is stormwater runoff. Zogorski et al. (1998) further evaluated the results obtained from stormwater samples analyzed during 1991 – 1995 wherein MTBE was detected in 6.9 percent of the samples. They suggested that

most detections of MTBE were from gasoline flushed from land surfaces rather than from atmospheric deposition. Regardless of whether the MTBE concentrations came from atmospheric deposition or land surface, where stormwater is collected in unlined catchments there is a potential for leaching of MTBE into the groundwater, depending on infiltration rates and temperature effects on volatility.

The USGS, as part of their National Water Quality Assessment Program, detected MTBE at concentrations in excess of 0.2 $\mu g \cdot L^{-1}$ in 27 percent of the shallow wells sampled in urban areas sampled, in 14 percent of the urban wells completed in drinking water aquifers and in 2 percent of the rural wells completed in drinking water aquifers (Zogorski et al., 1998). The NAWQA program is designed to randomly sample groundwater throughout the study areas rather than target areas of known gasoline contamination. In efforts to better understand non-point-source MTBE contamination, Pankow et al. (1997) performed a series of modeling experiments which indicated that urban atmosphere containing MTBE may be important as a source of MTBE contamination of shallow urban groundwater, albeit at substantially lower concentrations than at LUFT sites.

The California Air Resources Board has undertaken monitoring efforts to characterize the concentrations of MTBE in the atmosphere. Preliminary data are summarized below.

**Table 7. Atmospheric MTBE concentrations.**

| Testing Locations | Study Period | Average Concentration (ppb) | Max Airborn MTBE Concentration (ppb) | Sampling Date |
|---|---|---|---|---|
| Burbank-W Palm Avenue | 2-Jun-96 - 28-May-97 | 5.0 | 10 | 28-Jan-97 |
| Chico-Manzanita Avenue | 8-Jun-96 - 16-Apr-97 | 2.0 | 4.9 | 17-Dec-97 |
| El Cajon-Redwood Avenue | 2-Jun-96 - 28-May-97 | 2.2 | 6.6 | 28-Jan-97 |
| Fresno-1st Street | 8-Jun-96 - 22 May-97 | 2.3 | 8.1 | 11-Nov-96 |
| Los Angeles-North Main Street | 2-Jun-96 - 28 May-97 | 4.1 | 11.1 | 4-Dec-97 |
| North Long Beach | 2-Jun-96 - 28 May-97 | 3.4 | 8.6 | 23-Dec-97 |
| Roseville-N Sunrise Blvd | 8-Jun-96 - 22 May-97 | 1.1 | 2.8 | 31-Aug-96 |

Data Source: California Air Resources Control Board July 21, 1998

As further information becomes available, it will be possible to assess the groundwater impacts that may occur as a result of atmospheric sources of MTBE contamination. It is estimated that approximately 0.33 percent of the MTBE consumed is emitted to the atmosphere (OEHHA, 1998).

Tanker truck accidents where extensive containment and removal do not occur is another example of spills potentially affecting groundwater resources. These accidents are not uncommon in California, although statistics are not readily available. For example, a gasoline tanker truck overturned on a mountain highway (State Route 38) near Angelus Oaks California spilling 3,100 gallons of fuel. Due to erratic winds and the volatility of gasoline, all responders were restricted to a minimum distance of 1,000 ft for 5 hours until the accident scene had been treated. The released fuels drained into a drainage pipe and then into the then dry Forsee Creek. It was not anticipated that much contaminated soil could be removed due to steep terrain (CHP, 1997). Stream channel beds tend to be porous and permeable, providing migration routes to groundwater. While MTBE site specific information

was unavailable, this site provides an example of possible impacts associated with tanker spills.

The Central Coast (3) Regional Water Quality Control Board noted in their July 1998 water purveyor's report that in Watsonville at the intersection of Highway 1 and Highway 129 a truck spill resulted in a discharge of MTBE with detectable groundwater contamination at 1,500 $\mu g \cdot L^{-1}$ (CCRWQCB, 1998).

Other MTBE sources were reported in review of results from groundwater public water system. Re-injection of surface water has been implicated as the source of contamination to a well operated by Calleguas Muni Water District in Ventura County, which uses the well to store surface water when available (DHS Santa Barbara District, 1998). A wrecking yard where there was remaining motor fuel in the tanks of abandoned vehicles has been implicated as the source of contamination to three wells in San Luis Obsipo County (B. Seek, personal communication, 1998).

# 5.0 CONTAMINATION OF DRINKING WATER WELLS BY MTBE

## 5.1 DATA

The Department of Health Services (DHS) was contacted to obtain information regarding public water systems and information about the small water system regulatory agencies known as Local Primacy Agencies (LPA's). The following 34 counties are LPA's:

| | | | |
|---|---|---|---|
| Alpine | Amador | Butte | Calaveras |
| Contra Costa | El Dorado | Fresno | Imperial |
| Inyo | Kings | Los Angeles | Madera |
| Marin | Merced | Mono | Monterey |
| Napa | Nevada | Placer | Riverside |
| Sacramento | San Bernardino | San Diego | San Joaquin |
| San Luis Obispo | Santa Barbara | San Mateo | Santa Cruz |
| Shasta | Stanislaus | Tulare | Tuolumne |
| Yolo | Yuba | | |

In May 1998, the DHS Division of Environmental Management and Drinking Water Quality provided a copy of the system inventory, which included the public water system identification number and name, the water purveyor, the classification, number of connections, and population served; however, groundwater and surface water systems are not labeled in this inventory. Starting in June 1998, numerous requests were made for information that would allow a distinction between surface and groundwater systems and between systems regulated by the DHS and Local Primacy Agencies. In August 1998, a portion of this information was provided by DHS. Our compilation of impacts on drinking water supply wells was based both on the DHS information mailed to us and information from the DHS Water Quality Information (WQI) database on the DHS web site. Some discrepancies that we discovered in these data are described in Appendix F.

The 13,920 wells on the DHS Inventory are regulated by the DHS (8,957 wells) and the 34 Local Primacy Agencies (4,963). Various amounts of MTBE testing of public water wells has occurred throughout the state. In counties reporting the most frequent detections of MTBE in public water wells, there has been the highest frequency of testing for MTBE.

In February 1997, monitoring of MTBE as an unregulated compound was required by the DHS (DHS, 1997). Criteria was established by the DHS to assess vulnerability of a public water system well based on the well's location relative to a potential source of MTBE contamination. By this criteria, DHS recommended that only sites having known, fuel contamination should be considered "potential sources" (DHS correspondence, 1998). Wells located within 2,000 ft (or farther depending on local subsurface geology) of a gas tank, gas pipeline, refinery or farm tank that were in use after 1979, at which fuel contamination was known, were to be considered vulnerable. All systems that were deemed vulnerable by the regulating agency were required to test for MTBE by August 31, 1998 (September 11, 1997 Implementation Policy). LPA's which used known groundwater sites rather than tank or pipelines locations to determine vulnerability have significantly reduced the number of wells which were deemed vulnerable (Appendix G).

Local Primacy Agencies that submitted information for this assessment included:

| | | | |
|---|---|---|---|
| Amador | Contra Costa | El Dorado | Imperial |
| Kings | Los Angeles | San Bernardino | Riverside |
| San Joaquin | San Luis Obispo | Tulare | Tuolumne |
| Yolo | Yuba | | |

### 1.5.2 Detects in Public Water Supply Wells

The DHS Water Quality Information (WQI) Database (September 1998) listed 32 public water supply (PWS) wells which have reported detections in excess of 0.5 $\mu g \cdot L^{-1}$ of MTBE. In addition, information received from the 14 LPA's responding to our inquires indicated that three public water system wells in San Luis Obsipo have been impacted by MTBE. A total of 35 PWS wells have been impacted by MTBE to date, based on available information (Table 8; Fig. 7). If it is assumed that most of the impacts that have been identified resulted from contamination entering the subsurface environment prior to 1996, then it can be expected that the impacts will continue to increase, regardless of whether MTBE's use is discontinued, because the use of MTBE has increased since 1996.

PWS wells with detections of contaminants undergo an assessment to determine the source of the contamination. In many cases this is complex because it involves issues of property damage with litigious implications. Agencies require a high level of certainty before identifying a responsible party. Additionally, some DHS districts are severely understaffed and not able to respond at the speed that new PWS wells are impacted by MTBE. Full site histories and characterizations of possible sources of the MTBE contaminants detected in these wells were not obtained for all wells. Assessments in other states (Hitzig et al., 1998) indicate that

the primary source of MTBE contamination of PWS wells is from leaking underground storage tanks. A secondary source that has been identified is surface spills from stored automobiles.

**Table 8. Reported detections of MTBE in groundwater sources of drinking water (September 1998)**

| County | System and Source Name |
|---|---|
| El Dorado | South Tahoe PUD – Main, Arrowhead Well 01<br>South Tahoe PUD – Main, Arrowhead Well 02<br>South Tahoe PUD – Main, Gardner Mt. WTP -- raw<br>South Tahoe PUD – Main, Gardner Mt. WTP -- treated<br>South Tahoe PUD – Main, Tata Well 04 (Angora Well 10) |
| Kern | Union Pacific Railroad Company |
| Los Angeles | Cal State Polytechnic University-Pomona, Well 01<br>Los Angeles Water & Power, N Hollywood Well 17<br>Los Angeles Water & Power, Tujunga Well 04<br>Los Angeles Water & Power, Tujunga Well 05<br>Los Angeles Water & Power, Verdugo Well 01<br>Los Angeles Water & Power, Verdugo Well 02<br>City of Santa Monica, Arcadia Well 04 (standby)<br>City of Santa Monica, Arcadia Well 05 (inactive)<br>City of Santa Monica, Charnock Well 13<br>City of Santa Monica, Charnock Well 15 (standby)<br>City of Santa Monica, Charnock Well 16 (standby)<br>City of Santa Monica, Charnock Well 18<br>City of Santa Monica, Charnock Well 19 (inactive) |
| Riverside | Jurupa Community SD, Well 11 -- Standby<br>City of Riverside, Gage Well 92-1<br>City of Riverside, Van Buren Well 01 |
| Sacramento | Fruitridge Vista Water Company, Well 11 |
| San Bernardino | San Bernardino City, 19th Street GAC -- treated<br>Sheep Creek Water Company, Head Weir Tunnel<br>Sheep Creek Water Company, Well 01 |
| San Francisco | Presidio of San Francisco, Well 06 (abandoned)<br>Presidio of San Francisco, Well 13, (abandoned) |
| San Joaquin | City of Manteca, Well 17 |
| San Luis Obispo | United Parcel - San Luis Obispo<br>Whitson Water Supply - San Luis Obispo<br>Holdgrapher - San Luis Obispo |
| Sonoma | City of Sebastopol, Well 04 |
| Ventura | Calleguas MWD, Fairview ASR Well |
| Yuba | Cal-Water, Marysville, Well 03-01 |

Data obtained from the DHS and Local Primacy Agencies were used to summarize the PWS Wells where MTBE detections have been reported. The counties where MTBE contamination was detected include El Dorado, Kern, Los Angeles, Riverside, Sacramento, San Bernardino, San Francisco, San Joaquin, San Luis Obispo, Sonoma, Ventura, and Yuba.

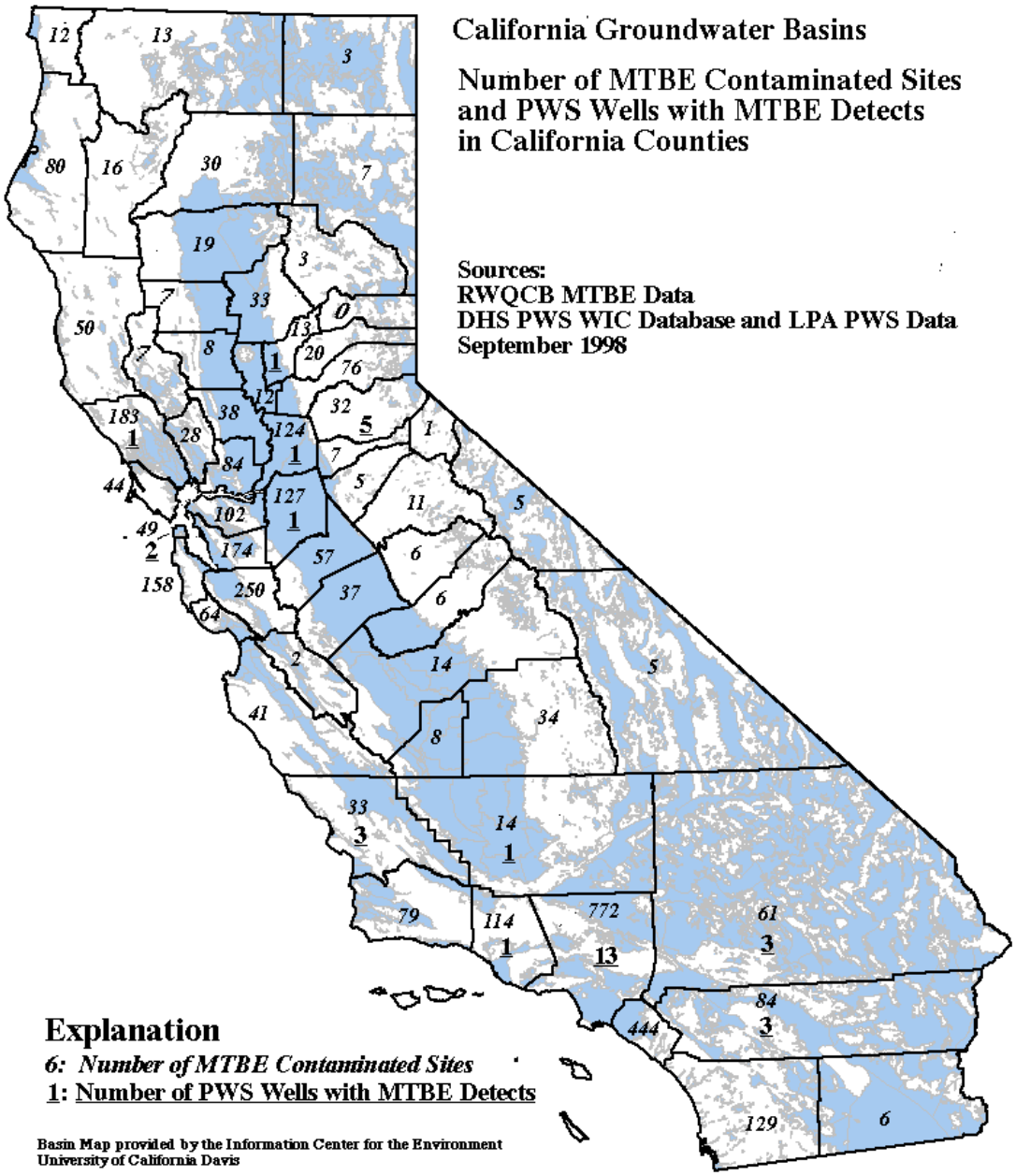


**Figure 7. Map showing numbers of PWS (public water supply) wells impacted with detectable concentrations of MTBE in each county reported by California Department of Health Services and Local Primacy Agencies.**

Counties that have tested more than 25 percent of the PWS wells and where MTBE has not been reported include Alameda, Orange, Santa Barbara, and Santa Clara. According to additional information obtained from the Santa Clara Valley Water District (Santa Clara Valley Water District, January 1998), one well in Santa Clara was shut down due to an MTBE detection by the Water Purveyor to prevent further migration of a contaminant plume. This information was not in the DHS WQI database.

There are three false positives which are included in the count of detects in Figure 7 and Table G-3. Two of these were reported in Riverside County. Information obtained from the DHS San Diego District indicated that there were three detections reported at one time on the DHS WQI database in Riverside County and all three were false positives (DHS San Diego, 1996). One of the detections was less than the reporting limit of 5 $\mu g \cdot L^{-1}$ (City of Riverside Gage 30-1 well) and was changed on the DHS database to report <5 $\mu g \cdot L^{-1}$. Two of the detections (City of Riverside Gage 92-1 and Van Buren 1 wells) are retained on the DHS database as false positives because the initial test results that were positive used detection limits of 1 $\mu g \cdot L^{-1}$ (1.09 and 1.34 $\mu g \cdot L^{-1}$ respectively), and follow-up test results were non-detect at the same detection limit of 1 $\mu g \cdot L^{-1}$. The DHS initially had an MTBE 1$\mu g \cdot L^{-1}$ detection limit for reporting (DLR), but in April 1996 DHS modified this limit to 5 $\mu g \cdot L^{-1}$ due to possible contamination by laboratories using MTBE for other analysis. As of July 1998, the DLR has been reduced to 3 $\mu g \cdot L^{-1}$.

One of the false positives was reported in San Joaquin County. The false positive designation was made because follow-up testing did not confirm the 2.8 $\mu g \cdot L^{-1}$ reported initially.

## 5.3 Estimated Statewide Impacts on Public Water Supply Wells

Based on the percentages of public water supply (PWS) wells in California showing MTBE detects, one can calculate order-of-magnitude estimates of how many PWS wells have been impacted to date. Although many of the detects in PWS wells represent low MTBE concentrations, leaking underground fuel tanks can be strongly implicated as the most likely sources because of their pervasiveness and substantial numbers. Many PWS wells are shut down as soon as concentrations reach detectable levels in order to avoid drawing in much higher MTBE concentrations present at known or suspected LUFT sites in the vicinity. Moreover, because more PWS wells are screened at depths significantly below the water table, contamination at detectable levels due to atmospheric deposition or other, non-LUFT sources is unlikely.

Information was obtained from DHS District Offices and a LPA describing the construction of 26 PWS wells where MTBE detections have been reported (Fig. 8). The highest percentage of PWS wells with MTBE detections all had screened intervals that started between 200 and 249 ft below ground surface. These results indicate that impacts from MTBE are not limited to shallow wells.

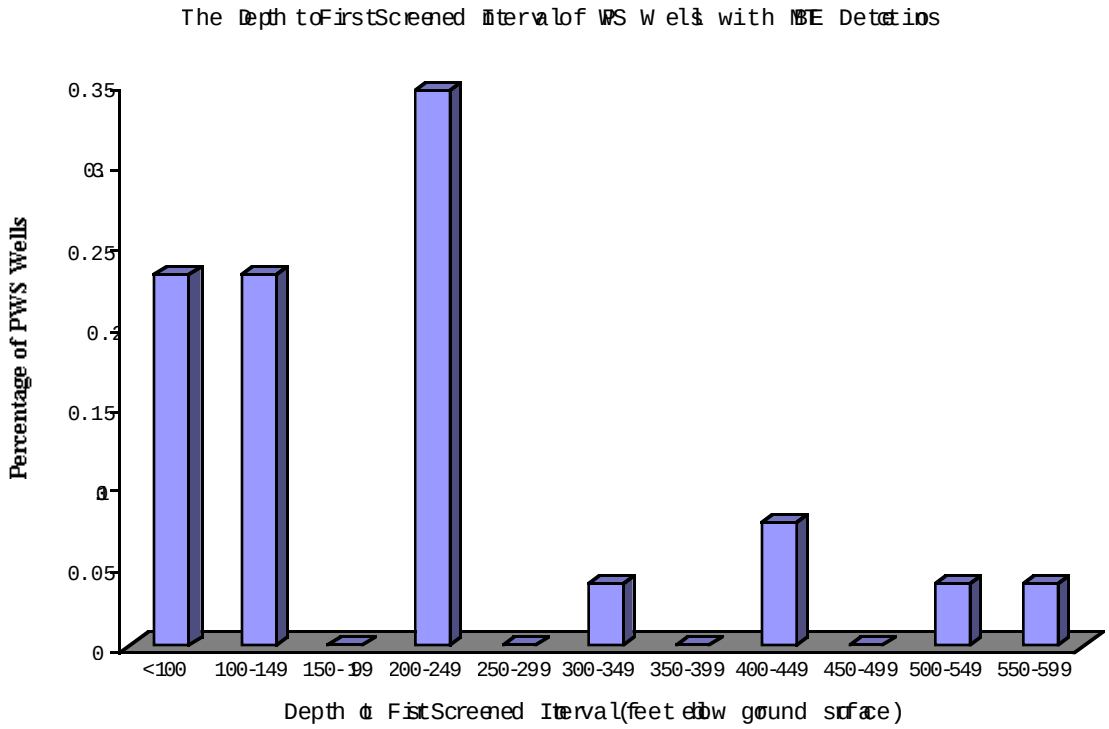


**Figure 8. Depths to top of first screened interval among 26 of the PWS wells that have MTBE detects.**

An upper bound on the probability that a PWS well has been impacted was estimated to be 1.2 percent (Table 9), using data from the number of wells with MTBE detections, 35 wells, and the total number of PWS wells tested, 2,988 (excluding abandoned, agricultural and inactive wells). Similarly, a lower bound was calculated to be 0.3 percent (Table 9) using data from the number of wells with MTBE detections, 35 wells, and the total number of PWS wells in the counties where testing has been performed, 13,161. The 1.2 percent is considered an upper bound because it is based only on those PWS wells that have been tested for MTBE. Much of that PWS testing has presumably targeted wells near suspected sources, hence it probably represents a biased sample. As of September 1998, 21 percent of California's PWS wells had been tested for MTBE (Appendix G).

Counties where there is no record of testing PWS wells include Alpine, Colusa, Del Norte, Imperial, Modoc, Mono, Shasta, Sierra, Siskiyou, and Trinity. Statistics for testing and positive detections weigh heavily on results from Los Angeles County, which has sampled 76 percent of the PWS wells in the county, representing 28 percent of the wells tested in the state. The Los Angeles County sampling was evidently not biased toward PWS wells that were near suspected sources, because no small public water systems were deemed "vulnerable" by the Los Angeles County LPA (Los Angeles County Dept. of Health, 1998).

The PWS well MTBE detect information suggests that on the order of 65 to 165 PWS wells have been impacted to date. Although the upper bound may be

substantially greater than the actual number of impacted PWS wells to date, it may be appropriate to use as a conservative estimate because the relatively rapid spreading of MTBE in groundwater may cause relatively rapid growth in future impacts. As discussed elsewhere in this report, experiences in the Tahoe Basin suggest a potential for continued increases in frequency of PWS impacts.

**Table 9. Estimated public and private wells with detections of MTBE using DHS and local primacy agency data.**

| | |
|---|---|
| Total PWS Wells | 13,919 |
| Total PWS Wells Tested | 2,988 |
| Number of PWS NOT Tested | 10,931 |
| Estimated PWS Wells Impacted based on **Upper Bound** (1.17%) | 128 |
| Estimated PWS Wells Impacted based on **Lower Bound** (0.27%) | 29 |
| Number of Private Wells (1990 US Census) | 464,621 |
| Estimated Private Wells Impacted based on **Upper Bound** (1.17%) | 5,442 |
| Estimated Private Wells Impacted based on **Lower Bound** (0.27%) | 1,236 |
| Estimated Total Wells Impacted Upper Bound | 5,570 |
| Estimated Total Wells Impacted Lower Bound | 1,265 |
| Estimated Wells Impacted **Upper Bound** (PWS Wells) and **Lower Bound** (Private Wells) | 1,364 |
| Current Wells with Detections of MTBE | 35 |
| Total Estimated Wells with MTBE Detections | 1,400 |

## 5.4 ESTIMATED STATEWIDE IMPACTS ON PRIVATE WELLS

In California, private wells are not regulated once installed. Wells serving less than 5 connections are not regulated as a public water supply and therefore have no monitoring requirements. Private wells are typically shallower than public water supply wells and completed in the first water bearing zone. Also, the grout seals that are installed around the well casings are usually at the minimum depth required by the well installation permitting agency. Pumping rates at private wells tend to be smaller than at public supply wells, thereby effectively decreasing the radius of vulnerability to contamination. On the other hand, the shallow depth of these wells and their construction characteristics can make the private more vulnerable to contamination from surface sources near the wells.

When estimating the MTBE impacts to private wells statewide, the lower bound of 0.3 percent was used (Table 9). The lower bound of 0.3 percent was obtained using PWS wells with detectable MTBE and the total number of PWS wells in tested counties (35/13,161). The number of private wells in each county was obtained from 1990 US Census Bureau data summarizing responses to the question regarding water sources for the household (US Census Bureau, 1990). Only 1 well per household was assumed present for the purpose of this assessment. It is likely that this count underestimates the number of household wells which serve as backup to existing municipal supplies.

The lower bound was used to estimate private well impacts primarily because it is anticipated that the majority of these wells are located in rural areas where there are not the density of underground storage tanks found in urban areas. Information on locations of the private wells is not available. Private wells located in urban incorporated areas have a greater likelihood of being impacted than wells in rural areas. The 0.3 percent that was used considered urban and rural influences, since the testing performed thus far has occurred primarily in urban areas, but the percentage is based on all wells in the counties, rural and urban, where testing occurred. The PWS well MTBE detect information suggests that on the order of 1,300 to 5,500 of the 464,621 private wells statewide may have been impacted with detectable concentrations of MTBE to date.

With only 21 percent of the groundwater systems reporting MTBE analyses and the increased use of MTBE since 1996, it is reasonable to expect that roughly 1,400 or more public and private water supply wells have detectable levels of MTBE.

The above approximations appear reasonable, if not excessively low, in light of a comprehensive study by the State of Maine Bureau of Health, Department of Environmental Protection and Department of Conservation (State of Maine, 1998). The study randomly selected 951 household wells out of the 275,000 (0.34 percent) household wells reported during the 1990 Census. The study also sampled 793 of the 830 (95.5 percent) regulated nontransient public water supply wells. They found that MTBE was detected above 0.1 $\mu g \cdot L^{-1}$ in 15.8 percent (150) of the private wells tested and in 16.0 percent (127) of the tested public supply wells. The frequency of higher concentration detections was much lower. 6.6 percent of wells sampled had MTBE concentrations between 1 $\mu g \cdot L^{-1}$ and 35 $\mu g \cdot L^{-1}$, and 1.1 percent of wells sampled had MTBE concentrations above 35 $\mu g \cdot L^{-1}$. No public water well samples contained concentrations above 35 $\mu \cdot gL^{-1}$; however, 6.1 percent had concentrations between 1 $\mu \cdot gL^{-1}$ and 35 $\mu \cdot gL^{-1}$. Direct comparisons between our results and those of Maine are difficult due to differences in detection limits. As indicated previously, the DHS has only recently reduced the reporting limit for MTBE from 5 $\mu \cdot gL^{-1}$ to 3 $\mu \cdot gL^{-1}$, while the detection limit used in the Maine study was 0.1$\mu \cdot gL^{-1}$. Concentrations in excess of 35 $\mu \cdot gL^{-1}$ have been detected in California water supply wells. Another difference which does not allow direct comparison relates to the private well sampling that the State of Maine performed. The State of California has not performed an assessment of drinking water that includes the sampling of private wells.

## 5.5 Estimate of Supply Well Impacts Based on Site Specific Data

As noted in Table 9, a significant number of private wells statewide are anticipated to be contaminated by MTBE. Leaking underground storage tanks have been identified as the MTBE source for many PWS well MTBE detections. Private wells are not regulated and have no monitoring requirements, except in the rare instance when a leaking underground storage tank contaminates a private well. The State Water Resources Control Board Leaking Underground Storage Tank Information System (LUSTIS) Database identifies this type of site where a supply

well has been contaminated as a "W" site. The July 1998 LUSTIS database listed 128 "W" sites statewide. The LUSTIS database does not indicate the number of supply wells which have been contaminated at each site nor does it indicate the contaminant(s) of the supply well(s).

The nine Regional Water Quality Control Boards (RWQCB's) were contacted to obtain information necessary for estimating the number of supply wells that are contaminated with MTBE from leaking underground storage tanks. The RWQCB's were first contacted by correspondence in February 1998 and asked to provide information regarding the number and location of third party wells tested and the sample results at sites where MTBE or other oxygenate was detected. We were informed that there was not staff time available to provide such site specific information. The RWQCB's were contacted by correspondence in June 1998 in which a list of LUSTIS sites with supply well impacts was enclosed. We requested identification of sites where the supply well impacting contaminant was MTBE. Three RWQCB's responded, Central Coast (3) Central Valley (5) and Lahontan (6). Within the time frame of this project, it was impossible to survey the other 6 RWQCB's. No supply well impacted sites are reported in the Santa Ana (4) region. In order to estimate the number of supply wells that may be contaminated with MTBE, a sample of 15 "W" sites from the North Coast region were reviewed and site specific information collected. These 15 constitute 37 percent of the "W" sites (40) reported in the North Coast region and 11 percent of the "W" sites (128) reported statewide. The sites were selected randomly by the administrative staff pulling the files for review. Purpose of this limited review of RWQCB site files was to both gather information regarding the frequency of supply wells contaminated with MTBE and to assess the reliability of MTBE site data reported by a Regional Board.

A total of 20 of the North Coast RWQCB (1) site files were reviewed. 15 of the sites were identified in LUSTIS as "W" sites. Five of the sites were reviewed as part of the data quality check and to collect information related to impacts from alternative oxygenates. The data quality check of the listed MTBE maximum concentrations in North Coast RWQCB (1) MTBE database indicated that the data was reliable, with only one data entry error observed.

Seven (47 percent) of the 15 "W" sites reviewed had supply wells that were sampled for MTBE, and 6 of these reported MTBE detections. Overall, 6 (40 percent) of the 15 "W" sites reviewed had supply wells contaminated with MTBE.

In order to estimate the number of wells impacted, a count was made of the MTBE supply wells with detectable MTBE concentrations at the six sites. There were a total of 22 supply wells impacted by leaking underground storage tank at the 6 sites, representing an average of 3.66 wells per site. With such a small sample set, it was not possible to perform statistical analysis of the results.

These percentages may not be representative of other regions of the state; however, incidences of significant releases of MTBE from leaking underground storage tanks that contaminate nearby supply wells have been reported in California. Examples of supply wells that have had MTBE detections are found throughout the state. The 186 Dry Creek Road Healdsburg site in Sonoma County

reported 10 supply wells with MTBE detections. MTBE contamination from the Glennville site in Kern County resulted in at least 15 wells contaminated with MTBE (J. Whitter, personal communication, 1998,). A site in Lasson County, Payless Gas, resulted in at least 5 supply wells with MTBE detections (Broadbent and Associates, 1998a).

# 6.0 IMPACTS ON GROUNDWATER IN THE TAHOE BASIN

## 6.1 NON-POINT-SOURCES OF MTBE

### 6.1.1 PRECIPITATION SAMPLING

Given detectable atmospheric levels of MTBE, the Lake Tahoe Basin could have detectable amounts of MTBE in precipitation, due to the typically cool air temperatures in the Lake Tahoe Basin (elevation 6,225 ft at lake level). Colder air temperature markedly increases partitioning of MTBE from air to the aqueous phase (Squillace et al., 1995) and could result in MTBE levels as high as a few $\mu g \cdot L^{-1}$ in rainfall (Squillace et al., 1996a and 1996b) and thus lead to MTBE contamination of shallow groundwater (Pankow et al., 1997, and Squillace et al, 1997). A rainwater sampling system was readied April 1998 for collection of rain samples for VOC analysis. Rainwater samples were obtained on June 12, 1998. Unfortunately, due to laboratory error, the sample vials were destroyed, so that VOC testing could not be performed. No additional rainwater samples have been obtained.

MTBE has been found in snowfall at very low levels (0.01 to 0.1 $\mu g \cdot L^{-1}$) in the Denver urban area (Bruce and McMahon, 1996). On June 5, 1998 we obtained snow samples near a Soil Conservation Service "snotel" data site located at 8,600 ft elevation within the Heavenly Valley ski resort. Heavenly Valley is located within several miles to the southeast and east of the urbanized areas of South Lake Tahoe and Meyers. Prevailing winds in the area are toward the southeast and northeast, so that Heavenly Valley is often downwind from major urban areas in the Tahoe Basin. Snow samples were obtained and stored in accordance with methods utilized in investigations of the Donner Lake area by the Tahoe Research Group (John Reuter, personal communication, 1998). Samples were obtained at depths of 0.1, 1, 2, 3, and 4 ft depths below the top surface of the snow. Ground surface was encountered at a depth of 4.4 ft below the snow surface. The snow texture was dense, crumbly, and glazed at all depths, suggesting prior partial melting and refreezing. There was no evident layering of the snow. Each snow sample was assayed for MTBE, and was found to contain $<0.1\ \mu g \cdot L^{-1}$ (detection limit).

The absence of MTBE in snow samples at Heavenly Valley indicates either that little MTBE was scavenged by the snow (due to, e.g., low atmospheric levels of MTBE), or that MTBE was scavenged by the snow, but subsequently lost to volatilization or to meltwater during earlier spring melt phases of the snowpack. Partitioning of volatile organics between snow and air has been examined previously (e.g., Hoff et al., 1995).

### 6.1.2 SHALLOW GROUNDWATER SAMPLING

Procedure

We sampled shallow groundwater monitoring wells in the Tahoe Basin during July and August 1998 for MTBE occurrence. A total of 10 wells in Pope Marsh were sampled, along with a sample of Lake Tahoe water adjacent to Pope Marsh. Pope Marsh borders the southern shore of Lake Tahoe, on the California side of the basin, just west of the City of South Lake Tahoe. Several of the sampled wells were USGS monitoring wells; the remainder were monitoring wells installed during our previous investigations of this site (Green, 1998; Green and Fogg, 1997). All wells sampled in Pope Marsh had screened depths less than 20 ft below ground surface.

On the Nevada side of the Tahoe Basin, six shallow wells (less than 30 ft deep) and one spring were sampled for MTBE occurrence during August 1998. The USGS site numbers and names are #23 (Edgewood 1), #24 (Edgewood 4), #25 (Folsom Spring; located near Stateline), #28 (Zephyr 4), #30 (Glenbrook 2), #31 (Glenbrook 3), and #41 (Ivgid 3; located in Incline Village). These Nevada sites are part of the USGS groundwater monitoring network for the Lake Tahoe Basin (Boughton et al., 1997) and were sampled in cooperation with Tim Rowe and Kip Allander of the Carson City office of the USGS.

All well sampling was performed by first purging more than 3 wellbore volumes of water from the well, using either a clean stainless steel or polyethylene bailer. Well samples were recovered using factory-cleaned and clean-wrapped disposable teflon or polyethylene bailers, fitted with tips designed to dispense samples for VOC analysis (VOSS technologies, San Antonio, TX). Groundwater samples were dispensed into 45 ml amber VOA vials, which were filled to the rim such that no headspace was present in the capped vial. The Lake Tahoe sample was obtained by wading out into Lake Tahoe to a depth of about 5 ft, filling and capping the VOA vial at about 2 ft below the water surface. The Folsom Spring sample was obtained by immersing the VOA vial below the stream surface at about 2 ft downstream from the source of the spring.

A drop of 1:1 HCl was added to each sample before capping. Samples were immediately placed on ice, and stored in an ice chest and transported to a 4° C refrigerator until analysis for VOC's. Each sample was analyzed for both MTBE and BTEX by Alfa Analytical (Sparks, NV) using EPA method 524.2. Assay results were reported to a lower level of 0.1 $\mu g \cdot L^{-1}$ for both MTBE and BTEX, but were qualified to only 0.5 $\mu g \cdot L^{-1}$.

Results

During July of 1998, 6 wells in Pope Marsh were sampled for MTBE and BTEX. MTBE and BTEX were below detection (0.1 $\mu g \cdot L^{-1}$) for all samples except for a sample from well #20, for which 0.13 $\mu g \cdot L^{-1}$ MTBE and 0.21 $\mu g \cdot L^{-1}$ of toluene were detected. A replicate of this sample was re-assayed 6 weeks later, and found to contain 0.14 $\mu g \cdot L^{-1}$ MTBE and toluene below detection (0.1 $\mu g \cdot L^{-1}$). Toluene can diffuse through the VOA septa (Dr. Roger Shole, Alfa Analytical, personal communication), and thus may have been lost from the sample during sample storage.

During August 1998, 7 wells in Pope Marsh, and Lake Tahoe water adjacent to Pope beach were sampled for MTBE. Three of these wells had been sampled previously during July 1998, including well #20. Of these three, only well #20 had detectable levels of MTBE. In analyses of two well #20 replicate samples, 0.16 and 0.22 $\mu g \cdot L^{-1}$ MTBE were detected. Four additional wells were sampled that had not been sampled during July. Groundwater at one of these well sites (#2) had detectable levels of MTBE (0.13 and 0.18 $\mu g \cdot L^{-1}$ MTBE in duplicate samples) and BTEX. Duplicate samples of Lake Tahoe water (from shallow water off Pope Beach) had MTBE at 1.1 and 1.4 $\mu g \cdot L^{-1}$; and benzene, toluene, and xylenes at levels between 0.1 and 0.5 $\mu g \cdot L^{-1}$. This level of MTBE and BTEX in Lake Tahoe surface waters is within the range found in Lake Tahoe during summer, 1997 (Boughton and Lico, 1998). Well #20 is located about 50 ft from the Lake Tahoe shoreline at the interface between Pope Beach and the marsh, and well #2 is located about 60 ft further inland from well #20, thus about 110 ft from the Lake Tahoe shoreline. Three wells located westward of wells #2 and #20, and at slightly further distances from the Lake Tahoe shoreline, had no detectable MTBE or BTEX. All other sampled wells in Pope Marsh were located substantially further (>300 ft) inland from Lake Tahoe, and had no detectable levels of MTBE or BTEX.

Dissolved oxygen levels were measured at wells #2 and #20, in samples collected using the same sampling procedures used for obtaining samples for MTBE analysis. Water samples from wells #2 and #20 both had measured dissolved oxygen levels of <0.8 ppm and temperatures of 12˚ C. These low dissolved oxygen levels indicate little mixing of ambient air with the water during sampling. This implies that at most a small fraction of dissolved MTBE was exchanged with ambient air as a consequence of the sampling procedure utilized.

Positive controls for sample handling and sample transport were made by pouring from standard stock solutions into VOA vials on site at Pope Marsh after the completion of well sampling. These positive controls were handled in the same manner as all other water samples, and transported with the groundwater samples to the analytical lab for analysis. Results for MTBE were within dilution error for makeup of the stock solutions (nominal concentrations 0.5 and 5.0 $\mu g \cdot L^{-1}$). Negative control was provided by those groundwater samples which did not have detectable MTBE (<0.1 $\mu g \cdot L^{-1}$). This indicates that MTBE concentrations in water samples were not altered during sample handling and transport.

On the Nevada side of the basin, replicate samples from a well (USGS site #28) near a beach at Zephyr Cove showed 0.14 and <0.10 $\mu g \cdot L^{-1}$ (detection level) MTBE, and 39 and 43 $\mu g \cdot L^{-1}$ benzene, as well as detectable levels of toluene (0.2 $\mu g \cdot L^{-1}$) and o-xylene (0.7 $\mu g \cdot L^{-1}$). These high levels of benzene, along with heavy automobile traffic and commercial activity uphill from the well site, suggest the well may be located within a hydrocarbon plume or spill site. From a well (USGS site #23) at Edgewood Golf Course, two replicate samples showed 0.44 and 0.46 $\mu g \cdot L^{-1}$ MTBE, but no detectable BTEX. None of the four remaining wells or Folsom Spring had detectable levels (<0.1 $\mu g \cdot L^{-1}$) of MTBE or BTEX, including another well (USGS site #24) at Edgewood Golf Course.

### 6.1.3 SUMMARY OF NON-LUFT SITE DATA:

Snow samples collected June 5, 1998 at 8,600 ft elevation downwind from an urbanized area of Lake Tahoe contained no detectable MTBE (<0.1 $\mu g \cdot L^{-1}$). Two shallow wells located in Pope Marsh at approximately 50 and 110 ft from the Lake Tahoe shoreline tested positive for MTBE in replicate samples, at levels between 0.1 and 0.2 $\mu g \cdot L^{-1}$. The source of MTBE in the two Pope marsh wells was most likely water from Lake Tahoe because: (1) nearby water samples from Lake Tahoe contained MTBE at 1-2 $\mu g \cdot L^{-1}$, (2) groundwater flow is from Lake Tahoe into the marsh during summer months (Green, 1998), and (3) eight other shallow wells in this marsh, all located further away from Lake Tahoe, tested negative for MTBE (<0.1 $\mu g \cdot L^{-1}$).

On the Nevada side of the basin, two shallow groundwater wells located in the southeastern portion of the Tahoe Basin (Zephyr Cove and Edgewood Golf Course) tested positive for MTBE at 0.1-0.5 $\mu g \cdot L^{-1}$; whereas 4 other shallow wells and a spring all tested negative for MTBE (<0.1 $\mu g \cdot L^{-1}$). The Zephyr Cove sample had about 40 $\mu g \cdot L^{-1}$ benzene, suggesting the well was located within a LUFT plume or near a spill. The source of MTBE at the Edgewood Golf Course well is not known.

Our data shows that the occurrence of MTBE in shallow groundwater away from LUFT sites or spills is sparse in the Tahoe Basin. Most shallow groundwater wells tested had <0.1 $\mu g \cdot L^{-1}$ (reporting limit) MTBE; those few wells that had measurable MTBE had <0.5 $\mu g \cdot L^{-1}$ MTBE that was likely attributable to sources other than precipitation. The MTBE detected at two Pope Marsh groundwater wells was probably transported from Lake Tahoe in the direction of groundwater flow, through sandy sediments near the lakeshore and into the marsh groundwater. Additional sampling of precipitation events would be needed to clarify the role (if any) played by precipitation in transporting atmospheric MTBE to surface and ground waters in the Lake Tahoe Basin. However, our data, together with that of the Tahoe Research Group (John Reuter, personal communication, September 1998) and others (Boughton and Lico, 1998; Bruce and McMahon, 1996), strongly suggests that the contribution of precipitation (rain and snow) to MTBE in regional groundwater is small (<1 $\mu g \cdot L^{-1}$ at most) in the Lake Tahoe Basin.

## 6.2 LUFT SITES: POINT SOURCES OF MTBE

### 6.2.1 NEVADA SIDE OF TAHOE BASIN

As of July 1998, analysis of drinking water for MTBE has not been required in the State of Nevada (Dana Penington; Nevada Bureau of Health Protection Services, personal communication). As of September 1998, MTBE has not been a required analyte for any LUFT site (Bill Storey; Nevada Department of Environmental Protection (NDEP)). Starting in Spring 1998 NDEP has recommended (but not required) testing for MTBE at LUFT sites involving gasoline contamination of soil and/or groundwater.

As of September 1998, there were 5 LUFT sites registered at the NDEP on the Nevada side of the Tahoe Basin that were listed as active gasoline sites impacting

groundwater. Bob Kelso of NDEP found two LUFT sites (designated sites 1 and 2 in this report) in the Nevada side of the Tahoe Basin at which groundwater samples were tested for the presence of MTBE. At each of sites 1 and 2, contractor reports for the LUFT site owners (Site 1: Broadbent and Associates, Inc., 1998b; Site 2: Cambria Environmental Technology, Inc., 1998) include MTBE analysis of some groundwater samples. Site geology and aquifer characterization were not included in contractor reports for either site. At both sites, MTBE was detected in some groundwater samples at over 1,000 $\mu g \cdot L^{-1}$.

At site 1, groundwater samples collected from 7 monitoring wells in April and June 1996 were analyzed for BTEX and MTBE. Although BTEX analysis was performed on samples through 1998, MTBE analysis was discontinued in 1996. At 4 of these 7 monitoring wells, MTBE was detected in the absence of detectable BTEX compounds; whereas only 1 monitoring well had detectable BTEX in the absence of MTBE. This demonstrates that monitoring wells testing negative for BTEX may test positive for MTBE, and thus BTEX testing alone is not adequate in defining hydrocarbon plume extent from a gasoline LUFT site.

At site 2, MTBE was first monitored for and detected during July 1996. During April 1998, MTBE was present as far as 400 ft downgradient from the nearest underground storage tank UST, whereas benzene was detected at 120 ft downgradient but not at 400 ft downgradient. Several monitoring wells had detectable levels of MTBE but not of benzene, demonstrating that for this site the MTBE plume was larger than the benzene plume. Generally, remediation efforts (soil vapor extraction and groundwater extraction) initiated during 1997 have been more successful in reducing BTEX levels than MTBE levels.

### 6.2.2 California side of Tahoe Basin

The Lahontan RWQCB has requested MTBE monitoring in groundwater wells at petroleum release sites since June 1996. As of July 1998, the Lahontan RWQCB has identified in the California portion of the Tahoe Basin 29 LUFT sites with confirmed MTBE discharges and groundwater detections, out of a total of 43 active LUFT sites involving gasoline leaks. These 29 sites are scattered throughout communities within the Tahoe Basin. According to Lisa Dernboch of Lahontan RWQCB, the rate of MTBE detections reported has increased in 1998, with 7 of 29 sites first reporting MTBE in the second quarter of 1998. Approximately 67 percent of all active LUFT sites in the Tahoe Basin are classified by the Lahontan RWQCB as impacting or threatening surface water or ground water.

Two California counties include portions of the Lake Tahoe Basin – Placer County (north and west Tahoe Basin) and El Dorado County (south and west Tahoe Basin). In 1997, Placer County added MTBE to its list of required analytes in drinking water, for community and non-transient non-community water systems. As of September 1998, only 3 of 35 community and non-transient non-community water systems in the Tahoe Basin portion of Placer County have reported monitoring data for MTBE, according to Ralph Echols of the Placer Division of Environmental Health. These 3 water systems reported no detectable levels of MTBE. Small private

water systems are not required to test for MTBE, and none have reported MTBE monitoring results as of September 1998.

In the summer of 1998, El Dorado county added MTBE to its list of required analytes in drinking water, for community and non-transient non-community water systems. As of September 1998, no community or non-transient non-community systems in the Tahoe Basin portion of El Dorado County have reported monitoring data for MTBE, according to Ginger Huber of the El Dorado County Environmental Management Agency. Small private water systems are not required to be tested for MTBE, but are recommended to test for MTBE if they are near LUFT sites. As of September 1998, four small water systems near LUFT sites have been tested for the presence of MTBE, and all four systems have had MTBE levels below detection, according to Ginger Huber. These water systems continue to be monitored for the presence of MTBE due to the proximity of plumes containing MTBE from nearby LUFT sites.

As of July 1998, the California Department of Health Services has listed 41 large public water systems within the Tahoe Basin that have been monitored for MTBE, 34 of which are operated by South Tahoe Public Utility District (STPUD). Five of these 41 systems have reported MTBE detections. Three of these five systems are STPUD drinking water wells. The other two systems listed are the influent and effluent streams from a STPUD water treatment facility, whose water source included one of the contaminated drinking water wells.

### 6.2.3 Focus on southern portion of the Lake Tahoe Basin

Impact of MTBE contamination from LUFT sites

South Lake Tahoe and Meyers are two towns located adjacent to each other, overlying the same alluvial aquifer system, in the southern portion of the Lake Tahoe Basin. As of July 1998, 20 of 26 active gasoline UST sites located in these two towns have had MTBE detections reported in groundwater. The following LUFT statistics were compiled for the South Lake Tahoe and Meyers area by Lisa Dernboch of the Lahontan RWQCB as of January 1998:

Number of sites with MTBE>35 $\mu g \cdot L^{-1}$: 9

Number of sites with MTBE>10,000 $\mu g \cdot L^{-1}$: 4

Number of sites with MTBE plumes > 500 ft in length: 3

Number of sites that threaten surface waters: 5

Number of sites that impact or threaten drinking water wells: 4

The towns of South Lake Tahoe and Meyers obtain all of their public drinking water from groundwater wells within the aquifer system underlying these two towns, with most of the water provided by STPUD. STPUD first began to test for the prescence of MTBE in their drinking water wells in 1996. All operational wells have been tested for the presence of MTBE at least once per year. As of August 1998, 34 of the 35 STPUD wells had been tested for the presence of MTBE, with a lower detection limit of 0.5 to 1.0 $\mu g \cdot L^{-1}$. As of August 1998, three STPUD public drinking

water wells have been contaminated with MTBE at levels ranging from 1 to 26 $\mu g \cdot L^{-1}$. Eight additional STPUD wells and three motel wells are threatened with MTBE contamination from nearby plumes. STPUD determines whether a well is threatened by MTBE based on information about the proximity of a plume that contains MTBE, the source MTBE concentration level, site hydrogeology, and well construction details. Due to the presence or threat of MTBE contamination, as of August 1998, 10 STPUD wells have been shut down and one well is running at half capacity, reducing total STPUD capacity by over 20 percent, and prompting STPUD to implement water usage restrictions for it's customers starting in late July 1998. A summary description and chronology of MTBE impacts to STPUD wells has been published in a regional newspaper (Bourelle, 1998).

Plume histories and characteristics

As of August 1998, five gasoline LUFT sites have been identified as sources for MTBE plumes that have contaminated or threatened eleven STPUD and three motel wells. These 5 LUFT sites are included in the analysis below, as well as two additional sites for which contractor's reports were available that included analysis of MTBE levels. The data below was obtained from STPUD (Rick Hydrick, personal communication, 1998) and 7 contractors' reports (Delta Environmental Consultants, Inc., 1998; Pinnacle Environmental Solutions, 1998; Secor Intl. Inc., 1998; Terra Vac Corporation, 1998a and 1998b; Broadbent and Associates, Inc., 1998c; HSI Geotrans, 1997).

The first date of a gasoline spill or leakage is not known for any of the seven LUFT sites; leaks were first detected between 1989 and 1997. The earliest date for which MTBE test results were found for any of these sites was during the first quarter of 1995. At each site, on the first occasion where groundwater samples were checked for MTBE, MTBE was detected in some samples. For the seven LUFT sites, MTBE has been detected at maximum levels ranging from 3,300 to 91,500 $\mu g \cdot L^{-1}$ in nearby groundwater. MTBE or BTEX plume boundaries are here defined near the limit of detectable MTBE or BTEX (usually near 0.5 to 1.0 $\mu g \cdot L^{-1}$). MTBE plume lengths have ranged from >250 ft to >1,500 ft at these sites. Benzene plume lengths have ranged from <40 ft to >1050 ft at these sites. At all sites, MTBE plumes were comparable in size to or larger than benzene plumes. Remediation has been initiated and is continuing at 5 of these sites. Limited data available at 4 sites shows that sampled MTBE levels fluctuate over time in most wells at these sites, whether or not remediation had been initiated.

Three LUFT sites have been identified as threatening, but not contaminating, five STPUD wells. One LUFT site had an MTBE plume of length <300 ft that extended to about 180 ft from STPUD Helen wells #1 and #2 (Delta Environmental Consultants, Inc., 1998). Another LUFT site has an MTBE plume of length >640 ft extending to within 500 ft of STPUD wells Backrock #1 and #2, and to within 140 ft of a motel well (Broadbent and Associates, Inc., 1998c). Another LUFT site had an MTBE plume approximately 500 ft long to within 1500 ft of the STPUD Paloma well (HSI Geotrans, 1997), which has a very high pumping capacity (2,500 gpm).

MTBE has contaminated three STPUD wells; Arrowhead wells #1 and #2 and Tata Lane well #4. Two LUFT sites have been identified as sources of MTBE contamination at these three STPUD drinking water wells. One of these LUFT sites is located 1,300 ft from Arrowhead wells #1 and #2 (combined pumping capacity 805 gpm). Two plumes originate at this LUFT site (Secor Intl. Inc., 1998). One of the plumes is oriented in the direction of the regional water table gradient. The direction of the second plume is oriented at a right angle to the direction of the first plume, with migration toward the Arrowhead wells. The prescence of two plumes originating from the same LUFT is likely related to previous seasonal pumping patterns at the Arrowhead wells. The second LUFT site is located 1,500 ft from Tata well #4 (pumping capacity 70 gpm), at a 45 degree angle upgradient to the regional surface water gradient (Pinnacle Environmental Solutions, 1998). Tata well #4 is contaminated with MTBE, whereas Tata wells #1,2, and 3, located about 1,000 ft from Tata #4, are threatened by the same MTBE plume.

The Tata Lane well #4 was screened between 85 and 125 ft below ground surface (bgs), with a standing water level of 57 ft bgs, and a water level of 86 ft bgs when pumping at 60 gpm. Arrowhead well #1 was screened between 67 and 130 ft bgs, with a standing water level of 30 ft bgs, and a water level of 53 ft bgs when pumping at 180 gpm. Thus both Tata and Arrowhead wells draw some water from near the top of the aquifer while pumping. By contrast, Arrowhead well #2 was screened between 218 ft and 268 ft bgs, with a standing water level of 60 ft bgs, and a water level of 85 ft bgs when pumping at 630 gpm. However, a gravel pack extends from 55 ft to 268 ft bgs around this well, so that shallow groundwater can be drawn in through the gravel pack. Thus, all three wells have drawn from shallow groundwater. Additionally, a vertical (downward) component of movement of an MTBE plume has been documented (Pinnacle Environmental Solutions, 1998), with MTBE detected as far as 95 ft bgs (about 80 ft below the water table) at a distance of about 900 ft from a LUFT site and 600 ft from STPUD Tata Lane well #4.

### 6.2.4 Summary of LUFT site data in Tahoe Basin

Gasoline LUFT sites that have contaminated groundwater with MTBE are ubiquitous in the Lake Tahoe Basin. In the California side of the Lake Tahoe Basin, 29 of 43 active gasoline LUFT sites have reported MTBE in groundwater. Approximately 67 percent of these LUFT sites have been determined to impact or threaten surface water or ground water. Although Nevada has not required MTBE analysis at gasoline LUFT sites, analysis of MTBE levels was performed at two LUFT sites in the Nevada side of the Lake Tahoe Basin. MTBE was detected in groundwater at both of these sites.

Analysis of drinking water for MTBE has not been required in Nevada, and MTBE monitoring data for drinking water wells has not been received by the Nevada Bureau of Health Protection Services. On the California side of the Tahoe Basin, a few small water systems near LUFT sites have been monitored for MTBE, and MTBE levels have been below detection. However, eleven large public water wells operated by STPUD have been contaminated or threatened by MTBE plumes.

All the STPUD drinking water wells are located within the urbanized area of the southern portion of the Tahoe Basin, and tap into a regional aquifer system consisting primarily of unconsolidated glaciofluvial deposits. Regional horizontal shallow groundwater velocities are on the order of 100 ft/year. Five gasoline LUFT sites have been identified as sources of plumes containing MTBE which contaminate or threaten the eleven STPUD wells. MTBE plume lengths have ranged from >250 ft to >1,500 ft, and are comparable in size to or larger than benzene plumes at all these LUFT sites. As of September 1998, three STPUD wells have been contaminated with MTBE. Each of these three wells is located 1,300 to 1,500 ft from a LUFT site, and each has drawn shallow groundwater from near the water table. MTBE has been detected as deep as 80 ft below the water table near one of these LUFT sites.

## 7.0 FUTURE IMPACTS OF LUFT PLUMES

In this section, future impacts of MTBE LUFT plumes are estimated through the application of analytical and numerical models of groundwater flow and transport. In a general analysis of MTBE plume growth, stochastic analytical modeling of MTBE plume behavior as compared to benzene plume behavior suggests how risks of MTBE impacts from LUFT sites might increase between 1995 and 2010 and beyond. The benzene is assumed to sorb and biodegrade, while no sorption and biodegradation are assumed for MTBE. Additionally, highly-resolved, three-dimensional numerical simulations of MTBE plume development demonstrate the potential for vertical plume migration in a semiconfined aquifer setting. These analyses pertain mainly to alluvial aquifers consisting of unconsolidated to semi-consolidated materials (sand, gravel, silt and clay).

The question of whether MTBE will biodegrade significantly in groundwater is still a topic of debate and research. Converse and Schroeder (1998; this report) show that MTBE can degrade significantly in biologically active soils in the laboratory. Nevertheless, the MTBE plume behaviors noted by Happel et al. (1998), Landmeyer et al. (1998), and by the current investigation in the Tahoe Basin, among others, strongly indicate that most of the MTBE plumes are not degrading appreciably. Further, we have found no definitive, field studies demonstrating degradation of MTBE in groundwater. Virtually all groundwater in California resides in geologic, alluvial or consolidated rocks, which typically contain much less biological activity, and hence less potential for biodegradation, than do surficial “soils.” This is presumably a key reason for the disparity between field observations in aquifers and laboratory observations in soils. Consequently, we decided the prudent course in these modeling experiments was to assume no biodegradation of MTBE. Although the short-term (~5-10 yr) risks to groundwater supply due to MTBE LUFT plumes are already obviously formidable, the ultimate long-term risks may hinge on whether the compound will biodegrade in situ.

## 7.1 GENERALIZED ANALYSIS OF MTBE PLUME GROWTH

To assess potential future growth in the risks posed by MTBE in groundwater, we constructed a statistical-analytical groundwater model that accounts for the dominant transport processes and calibrated the model using benzene and MTBE plume length data from Happel et al. (1998). Technical details are given in Appendix H. The model predicts future growth in MTBE plume lengths, which we use as relative measures of risk. The model accounts for three-dimensional spreading of contaminant plume concentrations as affected by groundwater flow, time, dispersion, source concentration and size, sorption, and biodegradation as well as expected statistical distributions (i.e., site-to-site variability) for each of these factors. The model considers 5,000 to 8,000 reasonable combinations of the transport factors to generate 5,000 to 8,000 simulated plumes, which, as shown in Figure 9, conform to the statistical distribution of benzene plume lengths that were estimated for 1995-96 site data by Happel et al. (1998). Then, by turning off the sorption and biodegradation functions and modifying the source input concentrations and time of transport, the model reproduced the statistical distribution of MTBE plume lengths estimated by Happel et al. (1998) for 1995-96 site data (Fig. 10). Finally, by running the model into the future, approximate growth rates of MTBE plume lengths and, in turn, MTBE risks to groundwater were estimated (Fig. 11).

The model simulations indicate that average plume lengths for MTBE in groundwater estimated for 1995-1996 will potentially increase by a factor of 3 to 4 by the year 2010, and potential exists for continued growth further into the future (Fig. 11). Thus, extrapolating on the basis of the estimated 0.3 percent and 1.2 percent (percentage of public supply wells known to be impacted by MTBE today), we estimate that the risk of public water supply wells being impacted could increase to between 1 percent and 5 percent (100 to 700 wells) by 2010. The model results suggest that the larger MTBE plumes will exceed 2,000 ft in length. Indeed, information from the Tahoe Basin and elsewhere in California indicate that plumes exceeding 1,000 ft in length already exist. Actual risks to groundwater supplies may therefore grow faster than indicated by this model.

Average modeled plume volumes (volume of groundwater >5 $\mu \cdot gL^{-1}$ MTBE) range from 1 ac-ft for 1995-1996 to approximately 10 ac-ft for 2010. Because, however, MTBE is highly recalcitrant and mobile in groundwater, the actual volumes of groundwater impacted by such plumes will be much greater. Assuming water supply wells within 2,000 ft horizontally and 200 ft vertically of the edge of an MTBE plume will potentially capture MTBE, the actual impacted volumes of groundwater due to a LUFT plume (either in 1995-96 or 2010) are on the order of 100,000 ac-ft.

## 7.2 VERTICAL MIGRATION

Professional and academic hydrogeologists widely accept the idea that dissolved contaminants in groundwater can migrate to considerable depths in the vertical plane. Nevertheless, there persists considerable skepticism among many who deal with LUFT problems about whether such vertical migration could be significant. This thinking has been reinforced by the fact that relatively few public water supply wells have been impacted by BTEX compounds from LUFT's. Accordingly, LUFT site investigations of BTEX plumes have typically limited exploration and monitoring wells to shallow depths, approximately 20 ft below the water table, because of the notion that vertical migration is unlikely and because of the concern that deeper borings would potentially serve as pathways for vertical migration.

Many benzene plumes have no doubt migrated to deeper intervals than the depths of investigations at LUFT sites, but, luckily, natural attenuation mechanisms of sorption and biodegradation as well as dispersion have limited the ultimate impacts on water supply wells. If a similar strategy is applied to site investigation and cleanup of MTBE plumes, the outcome will be potentially far more damaging to water resources and well-water quality.

To illustrate the potential for vertical migration of MTBE in groundwater, flow and transport calculations were made using the Lawrence Livermore National Laboratory (LLNL) study site as a test case. Previous, highly resolved characterizations of the 3-D heterogeneity at this site (Carle and Fogg, 1996, 1997; Carle et al., 1998; Fogg et al., 1998) provide an excellent basis for 3-D simulations of flow and transport in a predominantly fine-grained (50-60 percent silt and clay beds), horizontally layered site. The system consists of semiconfined aquifers, which interconnect vertically where channel sands come in contact with each other. The modeling procedure consisted of three stages: (1) construct a 3-D geostatistical realization of the subsurface geology, (2) solve for a groundwater velocity field using the computer code MODFLOW (McDonald and Harbaugh, 1988), and (3) simulate using a highly accurate random-walk solution of the advection-dispersion equation (LaBolle et al., 1996, 1998), transport of a non-sorbing, conservative contaminant within the flow field.

The geostatistcal simulations were composed of four sedimentary material types that were assigned the following values of hydraulic conductivity (K), which were calibrated to observed time-drawdown from an aquifer pumping test by Carle

(1996): debris flow, 0.432 m/d; floodplain, 4.32E-05 m/d; levee, 0.173 m/d; and channel, 5.18 m/d. Boundary conditions of the flow model include recharge from above and general head boundaries on the remaining 5 sides of the domain, resulting in a regional horizontal hydraulic gradient of approximately 0.002. Recharge rate applied to the top of the model is 0.34 cm/yr. A pumping well located at the center of the 3-D block was continuously pumping at a rate of 75 $m^3/d$. The groundwater flow model solved for a steady state velocity field, subsequently used in transport simulations to predict the migration of a non-sorbing, conservative contaminant, with the MTBE source located toward the upstream end of the domain near the water table. The source was released as an instantaneous pulse consisting of 60,000 particles.

Simulation results (Fig. 12) show significant vertical migration of the contaminant, despite the presence of many fine-grained layers to limit vertical flow. The leading edge of the plume represents a relative concentration of $10^{-5}$ ($C/C_0$). For MTBE source concentrations ($C_0$) on the order of $10^5$ $\mu g \cdot L^{-1}$, $C/C_0 = 10^{-5}$ represents a concentration (C) of 1 $\mu g \cdot L^{-1}$. The plume seeks vertical pathways through the complex, alluvial network. Many alluvial aquifer systems in California have larger recharge rates and are much coarser-grained than the LLNL site used in this example. At such sites, the rates of vertical migration would be faster by factors of at least 2 to 10.

Despite the fact that the contaminant was released as a pulse rather than continuously in time, much contaminant mass lags back near the source location even after several decades of elapsed time (Fig. 12). This is the result of matrix diffusion into fine-grained strata, and is consistent with observations of contaminant distribution (TCE) at the LLNL site.

The plume in Figure 12 represents spatially continuous distributions of dissolved contaminant. The isolated “bubbles” represent areas where the number of “particles” per cell is approximately 1, such that the continuous plume characteristics are not fully mapped in the graphic.

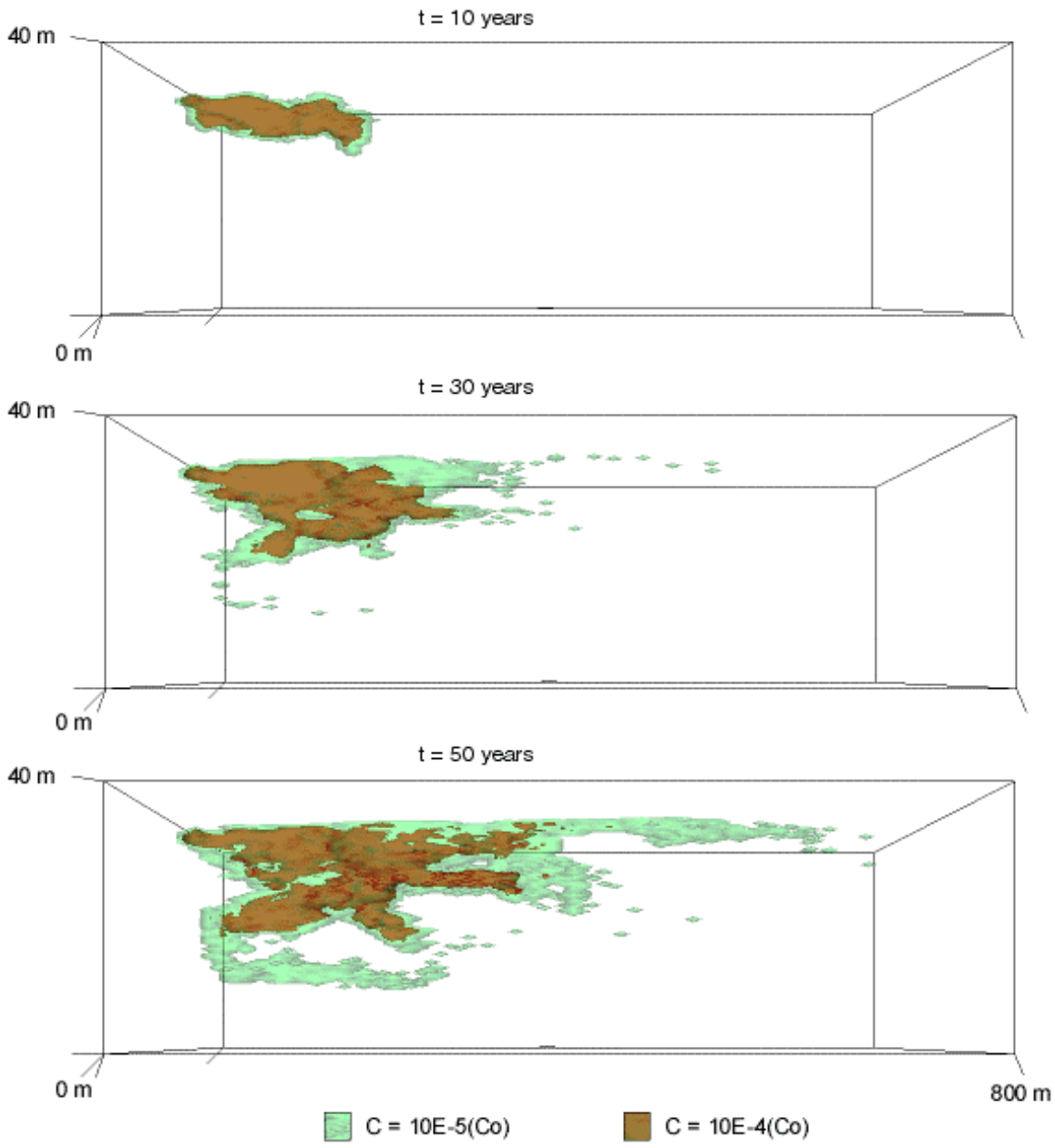


**Figure 12. 3-D simulated MTBE plume snap shots at (top to bottom) 10, 30, and 50 yr. Total thickness of the box is 40.5 m, and total length is 810 m. Regional flow is left to right. Screened interval of the pumping well is located in the center of the domain at a depth of 20 m.**

## 7.3 Remediation Costs

While no cleanup goals have been established by the Regional Boards or the State Water Resources Control Board thus far for MTBE in groundwater, the Department of Health Services has proposed a secondary maximum contaminant level of 5 ppb based on taste and odor considerations. The adoption of a maximum

contaminant level, will allow the Regional Boards to evaluate MTBE site concentrations against an established drinking water standard. Regional Boards require remediation of contamination to protect the beneficial uses of groundwater. If the Regional Board has designated drinking water as a beneficial use for the affected groundwater resources, then cleanup and/or monitoring will be required until it can be shown that the remaining contamination will not pose a threat to the beneficial use of the groundwater within a reasonable period of time. Given the mobility and recalcitrance of MTBE, it is likely that investigation and remediation will be required for many MTBE groundwater contaminated sites.

Using a maximum site concentration of 50 to 500 ppb MTBE as a cleanup goal, there are an estimated 1,700 to 2,500 sites (48 to 70 percent of 3,486) that are currently contaminated with MTBE and which will require active remediation and/or containment to prevent migration of the contamination to unaffected groundwater resources. The costs associated with investigation and remediation are highly site specific and dependent on 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 that is contained in the contaminated plume.

Some generalized estimates for investigation costs were obtained from industry representatives. These costs ranged from $30,000 to $500,000 for a single aquifer impacted with a 250 ft plume and groundwater table depths ranging from 20 to 100 ft. For a contaminated site where a second aquifer may be contaminated with a 250 ft 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 ft plume, the costs range from $150,000 to $2.5 million. Treatment costs associated with extraction, treatment, and disposal or re-injection, range from $250,000 to $1 million per site. 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 plumes 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.

Assuming an average of $100,000 to $500,000 per site, the total cost of remediating 1,673 to 2,435 sites, could be on the order of $170,000,000 to $1,200,000,000. Actual cost of site characterization, monitoring, extraction, and water treatment at individual sites will depend greatly on lateral extent and depth of the contaminated aquifer(s). A comprehensive analysis of the increased LUFT site remediation costs due to MTBE plumes is beyond the scope of this investigation. As a first approximation, however, one might assume these costs to be directly proportional to the plume size (e.g., WSPA, 1998). Longer, deeper plumes would require proportionately greater numbers of borings, monitoring wells and extraction

wells in addition to greater water treatment volumes. Thus, if a MTBE plume is twice the length of a benzene plume at a site, approximately double the number of borings and wells would be required, thereby roughly doubling the site characterization costs and treatment volumes. If the MTBE plume is also deeper than the benzene plume, costs could jump substantially higher owing to increases in drilling costs with depth of investigation, particularly at LUFT sites where vertical contamination along well-bore pathways is of concern.

Given recent observations on MTBE plume behavior (Happel et al., 1998; Landmeyer et al., 1998; this study) as well as model simulations presented herein, we believe a reasonable, first-order estimate of increases in costs of MTBE plume remediation would be 1.5- to 2-times that of benzene plume remediation. If the MTBE plume contaminates or threatens more than one aquifer, incremental costs at that site could be even higher. Because of the greater tendency for the BTEX compounds to sorb, it is possible that extraction of a MTBE plume by pumping would proceed faster as compared to a benzene plume. This advantage, however, could already by negated by the relatively rapid growth of MTBE plumes. Importantly, if groundwater remediation efforts are delayed for too long at sites with MTBE plumes in typical alluvial aquifer systems, substantial volumes of MTBE can migrate into immobile regions (e.g., silts and clays; sediment clasts), thereby mimicking the chemical sorption effect that occurs with the BTEX compounds, but without subsequent biodegradation. Once MTBE enters immobile regions of the subsurface, it is available to slowly "bleed" out of these regions for many years to come.

## 7.4 Characterization of MTBE Contamination

There are no specific requirements or standards of care that are available to provide guidance for the investigation and remediation of MTBE contaminated sites. While the SWRCB's LUFT Manuel provides guidance for the investigation of petroleum compounds and additives, it was last updated in 1989 (SWRCB, 1989), and does not include many of the methods that must be used to assess the vertical and horizontal extent of MTBE groundwater contamination plumes. MTBE is highly mobile and does not attach to soil particles or biodegrade as do the BTEX compounds which are also found in petroleum fuels. The level of technical expertise required to characterize a MTBE plume is much higher than required to investigate plumes involving petroleum compounds that degrade and sorb to soil because of the greater site characterization needed to determine risks. An update of the 1989 LUFT Field Manual would greatly enhance the quality and consistency of investigations throughout California.

## 7.5 Regulatory Costs

Increased regulatory cost is another, less conspicuous economic impact of MTBE LUFT plumes. State and local agencies that are already stretched to the limit in their ability to regulate LUFT site characterization and clean up, would be burdened with increased monitoring and review tasks.

# 8.0 CONCLUSIONS

## 8.1 GENERAL IMPACTS

The major sources of MTBE groundwater contamination in California identified during this assessment include leaking underground fuel tanks (LUFT's), above ground storage tanks, petroleum pipelines, and surface spills. The numerous leaking underground storage tanks containing gasoline throughout California clearly pose the greatest risk to groundwater quality. MTBE contamination has been detected in the groundwater most often in areas where consumption of gasoline containing MTBE is high and where there are high numbers of active and leaking underground storage tanks sites.

A total of 5,738 open LUFT sites in California have groundwater that was contaminated by gasoline. Of these, 3,180 sites (55 percent) have detectable levels (at least 0.5 to 20 $\mu g \cdot L^{-1}$) of MTBE in groundwater. This total does not represent *all* the groundwater MTBE sites caused by LUFT sources because not all of the sites have been monitored for MTBE, and some sites were closed before MTBE monitoring was conducted. Open sites that have not yet investigated the possibility of groundwater contamination and that are still classified as "soil only" sites will not yet have been monitored for MTBE in the groundwater. A total of 3,841 MTBE "soil only", "groundwater" and "other" sites have been reported thus far.

We anticipate that at least 250 additional MTBE sites from leaking gasoline tanks that have contaminated groundwater and will be discovered through the 1998 tank upgrade efforts.

Concentrations of MTBE in groundwater at LUFT sites range from less than 100 $\mu g \cdot L^{-1}$ to more than 1,000,000 $\mu g \cdot L^{-1}$. More specifically, 36 percent of the sites have concentrations less than 100 $\mu g \cdot L^{-1}$, 48 percent of the sites have concentrations less than 500 $\mu g \cdot L^{-1}$, 80 percent of the sites have concentrations less than 10,000 $\mu g \cdot L^{-1}$, and 4.5 percent of the sites have maximum MTBE concentrations in excess of 100,000 $\mu g \cdot L^{-1}$. Given the transport behavior of MTBE, these concentrations will likely increase in the future.

As of September 1998, 35 of 2,988 public supply wells which were tested for MTBE showed MTBE detects. This sample of 2,988 wells constitutes 21 percent of California's PWS wells. We estimate that 0.3 percent to 1.2 percent of public water supply wells (65 to 165 wells) in the State have detectable levels of MTBE. The number of impacted private wells may be on the order of 1,000.

## 8.2 TAHOE BASIN

Analysis of non-point and point sources of MTBE contamination of groundwater in the Tahoe Basin indicates LUFT sites to be the primary sources. Snow samples collected June 5, 1998 at 8,600 ft elevation downwind from an urbanized area of Lake Tahoe contained no detectable MTBE ($<0.1$ $\mu g \cdot L^{-1}$). Low levels of shallow contamination are evident in Pope Marsh near the Lake Tahoe shoreline, and are attributed to inflow from the Lake to the groundwater system.

Many gasoline LUFT sites have contaminated groundwater with MTBE in the Lake Tahoe Basin. In the California side of the Lake Tahoe Basin, 29 of 43 active gasoline LUFT sites have reported MTBE in groundwater. Approximately 67 percent of these LUFT sites have been determined to impact or threaten surface water or ground water. Although Nevada has not required MTBE analysis at gasoline LUFT sites, analysis of MTBE levels was performed at two LUFT sites on the Nevada side of the Lake Tahoe Basin. MTBE was detected in groundwater at both of these sites. Substantial lateral and vertical migration of MTBE has been observed, significantly exceeding typical dimensions of benzene plumes. These observations are consistent with results of Happel et al. (1998) and Landmeyer et al. (1998) for other parts of California and the U.S.

On the California side of the Tahoe Basin, a few small water systems near LUFT sites have been monitored for MTBE, and MTBE levels have been below detection. However, eleven large public water wells operated by STPUD have been contaminated or threatened by MTBE plumes.

### 8.3 FUTURE IMPACTS

A groundwater modeling technique was developed for assessing relative risks of benzene and MTBE plumes. The model is capable of simulating the full range of site conditions found in typical alluvial aquifers in California. Simulation experiments indicate that by the year 2010, MTBE plumes will potentially grow 3 to 4 times larger than 1995 benzene plumes at the same or comparable sites. The model suggests that the largest MTBE plumes will exceed 2,000 ft in length. Observations indicate that several plumes are approaching this extent already.

The growth of MTBE plumes to greater lateral distances as well as greater depths into the subsurface will result in substantially increased LUFT site remediation costs. Rough approximations suggest that remediation costs at sites containing MTBE contamination will increase by a factor of 1.5 to 2 or more, as compared to sites having only BTEX contamination.

## 9.0 RECOMMENDATIONS

All petroleum contaminated sites should be immediately monitored for MTBE contamination. Despite monitoring requirements by the RWQCB's all potentially contaminated sites have not been identified. It is necessary when MTBE is detected that a thorough vertical and horizontal assessment of the contamination be performed in order to characterize the extent of MTBE contamination so that appropriate actions may be taken. Remediation at MTBE contaminated sites should proceed as soon as possible to prevent further migration of the contamination that will impact a greater volume of California's groundwater resources.

Update the 1989 LUFT Field Manual to provide guidance for California's consulting industry, responsible parties, and regulatory agencies so that thorough and cost effective investigation and remedial actions will occur more frequently. The SWRCB Cleanup Fund under the direction of Regional Boards should conduct investigations of sites selected to represent California's diverse hydrogeologic

settings. These case studies should then be used to supplement an updated LUFT Field Manual.

Update the SWRCB Leaking Underground Storage Tank Information System (LUSTIS) with information such as: identification of MTBE contaminated sites and the number of supply wells that are contaminated by "W" sites. The LUSTIS database was not designed specifically to track sites where remaining contamination exists at closed sites. Additional summary information of closed sites where there is remaining contamination is necessary, so that cumulative impacts of the remaining contamination can be periodically evaluated.

Better information management and transfers between the agencies responsible for groundwater quality and management is needed. The primary agencies involved include, the State Water Resources Control Board, the nine Regional Water Quality Control Boards, the 20 Local Oversight Program agencies, the 103 Local Implementing Agencies, the State Fire Marshall, the Department of Health Services and 15 district offices, the 34 Local Primacy Agencies, and the Department of Water Resources. Designate one agency responsible for monitoring California's drinking water quality so that information obtained from a variety of agencies can be stored on one database that is accessible to the public. The DHS is responsible for ensuring that the public is served water that meets the maximum contaminant levels established, not necessarily to ensure that future supplies are protected. The Regional Boards are responsible for water quality, although are not always consulted when MTBE detections are reported in PWS wells. Currently, there is no way to track the number of supply wells that are contaminated with a variety of substances and discovered during investigations by RWQCB's and LOP's or by other agencies, such as Department of Toxic Substance Control.

A statewide survey of California's groundwater quality should be performed. Groundwater samples from public and private wells should be collected and analyzed. A thorough scientific survey will provide information to document fully the extent of MTBE's impact on California's groundwater resources.

## 1.10 REFERENCES


Bacharowski, D., 1998, Los Angeles Regional Water Quality Control Board Personal Communication, September 1998.

Boughton, C.J., and M.S. Lico, 1998, Volatile organic compounds in Lake Tahoe, Nevada and California, USGS Fact Sheet FS-055-98, July-September 1997.

Boughton, C.J., T.G. Rowe, K.K. Allander and A. Robledo, 1997, Stream and ground-water monitoring program, Lake Tahoe Basin, Nevada and California. USGS Fact Sheet FS-100-97.

Bourelle, A., 1998, MTBE: South shore battles insidious fuel additive, Tahoe Daily Tribune, August 28-30, 1998.

Broadbent and Associates (Reno, NV), 1998, Fourth quarter 1997 groundwater monitoring and remediation report, Payless Gas, 463-770 Main St., Janesville, California, January 8, 1998.

Broadbent and Associates (Reno, NV), 1998a, First Quarter, 1998 Ground-water Monitoring and Remediation System Report, Project #95529, Stateline, Nevada.

Broadbent and Associates (Reno, NV), 1998b, Additional characterization, first quarter, 1998, ground-water monitoring and corrective action plan/report, Tahoe Tom's Service Station, South Lake Tahoe, California Project #96521.

Bruce, B.W. and P.B. McMahon, 1996, Shallow ground-water quality beneath a major urban center: Denver, Colorado, USA, Journal of Hydrology, 186, p. 129-151.

CAEPA (California Environmental Protection Agency), 1998, MTBE (methyl tertiary butyl ether) briefing Paper, April 24, 1997 (updated March 30, 1998).

California Energy Commission, 1998, Downloaded July 13, 1998 www.energy.ca.gov/statistics/gasoline~stations/index.html.CHP (California Highway Patrol), 1997, Incident Report N005, May 19, 1997.

Cambria Environmental Technology, Inc. (Sonoma, CA), 1998, Quarterly monitoring report, second quarter, 1998, WIC #227-4782-0102, Incline Village, Nevada.

Carle, S.F., 1996, A transition probability-based approach to geostatistical characterization of hydrostratigraphic architecture, PhD dissertation, University of California, Davis, 182 p.

Carle, S.F. and G.E. Fogg, 1996, Transition probability-based indicator geostatistics. Mathematical Geology, v. 28, no. 4, p. 453-476.

Carle, S.F. and G.E. Fogg, 1997, Modeling spatial variability with one- and multi-dimensional continuous-lag Markov chains, Mathematical Geology, 29(5), p. 891-918.

Carle, S.F., E.M. LaBolle, G.S. Weissmann, D. Van Brocklin and G.E. Fogg, 1998. Geostatistical simulation of hydrostratigraphic architecture: a transition probability/Markov approach, *in* Concepts in Hydrogeology and Environmental Geology, No. 1, SEPM (Society for Sedimentary Geology) Special Publication, p. 147-170.

Carrier, P. and D. Hench, 1998, Governor King won't Commit to using reformulated gas, Portland Press Herald, May 22, 1998.

CCRWQCB (Central Coast Regional Water Quality Control Board), 1998, MTBE report to public water system operators, San Luis Obispo CA, July 21, 1998.

Converse, B.M. and E. D. Schroeder, 1998, Estimated cost associated with biodegradation of methyl tertiary-butyl ether (MTBE), This report.

Couch, K. and T. Young, 1998, Leaking underground storage tanks (UST's) as point sources of MTBE to groundwater and related MTBE-UST compatibility issues, This report.

Delta Environmental Consultants, Inc. (Rancho Cordova, CA), 1998, Technical report required by amended cleanup and abatement order, Project No. D093-901, August 1998.

DHS (Department of Health Services), 1998a, Correspondence from California Department of Health Services Division of Drinking Water and Environmental Management Acting Small Water Coordinator to Directors of Environmental Health Local Primacy Agencies. April 1998.

DHS (Department of Health Services), 1998b, Correspondence from California Department of Health Services Division of Drinking Water and Environmental Management Acting Small Water Coordinator to Directors of Environmental Health Local Primacy Agencies, July 10, 1998.

DHS (Department of Health Services) Policy, 1997, California Department of Health Services Division of Drinking Water and Environmental Management Policy Memo 97-003 "Implementation of MTBE monitoring requirement". February 11, 1997.

DHS (Department of Health Services) San Diego District, 1996, California Department of Health Services San Diego District Correspondence from District Engineer, Toby Roy, to Linda Mazur, California Air Resources Board, October 8, 1996.DHS (Department of Health Services) Santa Barbara District, 1998, Correspondence from John Curphey, Calleguas water system report (excerpts received March 26, 1998).

Dominico, P.A. and G.A. Robbins, 1985. A new method of contaminant plume analysis. Ground Water, v. 23, p. 476-485.

Domenico, P.A. and F.W. Schwartz, 1998. Physical and Chemical Hydrogeology. John Wiley and Sons, New York, 506 p.

Fogg, G.E., C.D. Noyes and S.F. Carle, 1998, Geologically-based model of heterogeneous hydraulic conductivity in an alluvial setting, Hydrologeology Journal, 6(1), p. 131-143.

Gaffney, K.A., 1998, Correspondence to New York Assemblyman Thomas DiNapoli. March 24, 1998.

Gelhar, L.W., C. Welty, and K.R. Rehfeldt, 1992, A critical review of data on field-scale dispersion in aquifers. Water Resources Res., 28(7), p. 1955-1974.

Green, C.T. and Fogg, G.E., 1997, Hydrogeologic Factors in Wetland Function at Subalpine Pope Marsh, Lake Tahoe, Proceedings of the Fifth National Watershed Conference, Reno, Nevada.

Green, C.T., 1998, Integrated Studies of Hydrogeology and Ecology of Pope Marsh, Lake Tahoe, MS Thesis, University of California, Davis, 99 p.

Hemond, H.F. and E.J. Fechner, 1994, Chemical Fate and Transport in the Environment, Academic Press San Diego, 338 p.

Happel, A.M., E.H. Beckenbach and R.U. Halden, 1998, An evaluation of MTBE impacts to California groundwater resources, Lawrence Livermore National Laboratory UCRL-AR-130897, June 11, 1998, 68 p.

Hench, D., 1998, Tests show contaminant declining at test well, Portland Press Herald, May 20, 1998.

Hitzig, R., P. Kostecki and D. Leonard, 1998, Study reports LUST programs are feeling effects of MTBE releases, Soil and Groundwater Cleanup, August/September, p. 15-19.

Hoff, J. T., F. Wania, D. Mackay and R. Gillham, 1995, Sorption of Nonpolar Organic Vapors by Ice and Snow, Environ. Sci. Technol., 29(8), p. 1982-1989.

HSI Geotrans (Reno, NV), 1997, Summary of recent investigations, Terrible Herbst and Muffler Palace LUFT sites, South Lake Tahoe, California, December 1997.

Kings County, 1998, Correspondence (e-mails and fax) from Loretta A. Tucker, Kings County Environmental Health, July 1998.

LaBolle, E.M., G.E. Fogg and A.F.B. Tompson, 1996. Random-walk simulation of transport in heterogeneous porous media: Local mass-conservation problem and implementation methods. Water Resources Research, 32(3), p. 583-393.

LaBolle, E.M., J. Quastel and G.E. Fogg, 1998. Diffusion theory for transport in porous media: Transition probability densities of diffusion processes corresponding to advection-dispersion equations. Water Resources Research, 34(7), p. 1685-1693.

Landmeyer, J.E., F.H. Chapelle, P.M. Bradley, J.F. Pankow, C.D. Church and P.G. Tratnyek, 1998, Fate of MTBE relative to benzene in a gasoline-contaminated aquifer (1993-1998), accepted April 17, 1998 for publication in Ground Water Monitoring and Remediation.

Los Angeles County Department of Health Services Environmental Health, 1998, Correspondence from Jose Reynoso responding to SB521 information requests, July 21, 1998.

Los Angeles Regional Water Quality Control Board, 1998, California Regional Water Quality Control Board, Los Angeles Region Methyl Tertiary Butyl Ether (MTBE) Reporting Requirements, SB521, April 15, 1998.

Martineau, P., 1997, Fuel leak in tiny town spreads health fears, Sacramento Bee, May 27, 1997.

Martineau, P., 1997, Pipe spill tests ordered, Sacramento Bee, June 26, 1997.

McDonald, M.G. and A.W. Harbaugh, 1988. A modular three-dimensional finite-difference groundwater flow model. U.S. Geological Survey, Techniques of Water-Resources Investigations 06-A1, 576 p.

MWD, 1997, Metropolitan Water District of Southern California Memorandum: Methyl tert-butyl ether (MTBE) action plan update, May 19, 1997.

Montgomery, J.H. and L.M. Welkom, 1990, Groundwater Chemicals Desk Reference, Lewis Publishers, Chelsea, Michigan, 640 p.

Moran, D., 1997, Correspondence to New York State Legislative Director John Turner, December 1, 1997.

New York State Department of Health, 1998, Center for Environmental Health Division of Environmental Protection Fact Sheet, July 8, 1998.

OEHHA (Office of Environmental Health Hazard Assessment), 1998, Draft public health goal for methyl tertiary butyl ether (MTBE) in drinking water, April 1998.

Palisade Corporation, 1997, @RISK, Advanced risk analysis for spreadsheets, (manual and software), Newfield, N.Y., 318 p.

Pankow, J.F., N.R. Thomson, R.L Johnson, A.L Baehr and J.S. Zogorski, 1997, The urban atmosphere as a non-point source for the transport of MTBE and other volatile organic compounds (VOCs) to shallow groundwater, Environmental Science and Technology, 31, p. 2821-2828.

Pinnacle Environmental Solutions (Cameron Park, CA), 1998, Groundwater assessment report, USA Station No. 7 South Lake Tahoe, California, Project 20A41-001.003, June 1998.

Rice, D.W., R.D. Grose, J.C. Michaelson, B.P. Dooher, D.H. MacQueen, S.J. Cullen, W.E. Kastenberg, L.E. Everett and M.A. Mariño, 1995a, Recommendations to improve the cleanup process for California's leaking underground fuel tanks, Lawrence Livermore National Laboratory, UCRL-AR-121762.

Rice, D.W., R.D. Grose, J.C. Michaelson, B.P. Dooher, D.H. MacQueen, S.J. Cullen, W.E. Kastenberg, L.E. Everett and M.A. Mariño, 1995b, California leaking underground fuel tank (LUFT) historical case analyses, Lawrence Livermore National Laboratory, UCRL-AR-122207.

Santa Ana Regional Water Quality Control Board, 1998, MTBE database.

Santa Clara Valley Water District, 1997, MTBE model letter: Request for plume definition, investigation, and cleanup, November 12, 1997, (Downloaded: http://www.scvwd.dst.ca.us).

Santa Clara Valley Water District, 1998a, News release: Water supplies safe despite detection of gasoline additive in well and treatment plants, January 23, 1998 (Downloaded: http://www.scvwd.dst.ca.us).

Santa Clara Valley Water District, 1998b, Agenda memorandum: Agreement with Levine-Fricke-Recon to perform a pilot study to investigate operating underground storage tanks and Methyl Tertiary-Butyl Ether (MTBE) occurrence, August 25, 1998.

Schelbe, J., 1998, Panel closes pipeline probe, Vacaville Reporter, January 2, 1998.Secor Intl. Inc. (Carson City, NV), 1998, Report of findings soil and groundwater investigation, Myers Beacon Station, Project #3I002-001-03, June 1998.

Seek, B., 1998, San Luis Obispo County Division of Environmental Health Personal Communication, April 1998.

Senate Office of Research, 1998, Clean air versus clean water: Does California need MTBE?, California Senate Office of Research, February.

Simeroth, D., 1998, California Air Resources Board, Personal Communication, Sacramento, CA, July 1998.

Squillace, P.J., J.S. Zogorski, W.G. Wilber and C.V. Price, 1995, A preliminary assessment of the occurrence and possible sources of MTBE in ground water of the United States, USGS Open-File Report 95-456.

Squillace, P.J., J.S. Zogorski, W.G. Wilber and C.V. Price, 1996a, Preliminary assessment of the occurrence and possible sources of MTBE in groundwater of the United States, 1993-1994, Environ. Sci. and Technol., (30)6, p. 1721-1730.

Squillace, P.J., J.F. Pankow, N.E. Korte, and J.S. Zogorski, 1996b, Envirionmental Fate and Behaviour of MTBE. USGS Fact Sheet FS-203-96.

Squillace, P.J., Pankow, J.F., Korte, N.E., and Zogorski, J.S., 1997, Review of the environmental behavior and fate of methyl tert-butyl ether. Environmental Toxicology and Chemistry, 16, 9, September 1997.

State of Maine Bureau of Health, Bureau of Waste Management and Remediation and Department of Conservation Maine Geological Survey, 1998, The presence of MTBE and other gasoline compounds in Maine's drinking water: A preliminary report, October 13, 1998 (downloaded www.state.me.us\boh).

Stauffer, T.B., C.P. Antworth, J.M. Boggs and W.G. MacIntyre, 1994, A natural gradient tracer experiment in a heterogeneous aquifer with measured in situ biodegradation rates: A case for natural attenuation, *in* Proceedings of Symposium on Intrinsic Bioremediation of Ground Water, Denver, CO, August 30 to September 1, 1994, p. 73-84.

SWRCB (State Water Resources Control Board), 1989, State of California Leaking Underground Fuel Tank Task Force leaking underground fuel tank field manual – guidelines for site assessment, cleanup and underground storage tank closure. October 1989.

SWRCB (State Water Resources Control Board), 1998a, California State Water Resources Control Board Leaking Underground Storage Tank Information System (LUSTIS) Database, Sacramento CA, April 1998.

SWRCB (State Water Resources Control Board), 1998b, California State Water Resources Control Board Leaking Underground Storage Tank Information System (LUSTIS) Database, Sacramento, CA, July 1998.

SWRCB (State Water Resources Control Board), 1998c, California State Water Resources Control Board Clean Water Programs leak prevention report, Sacramento CA, August 1998.

SWRCB (State Water Resources Control Board), 1998d, California State Water Resources Control Board Clean Water Programs above ground storage tank inventory, Sacramento CA, September 1998.

Terra Vac Corp. (San Leandro, CA), Second quarter 1998 operations, maintenance, and monitoring report, former Jet Thru Car Wash, South Lake Tahoe, California, Project 30-0192, May 1998.

Terra Vac Corp. (San Leandro, CA,) 1998, Second quarter 1998 monitoring, Former Chevron Station 9-2450, South Lake Tahoe, California, Project 30-0223, June 1998.

Turkel, T. 1998, Maine to Test Water Supplies for Gas Additive, Portland Press Herald, May 15, 1998.

United States Census Bureau 1990, 1990 Decennial census results: American housing survey: water sources (Downloaded 1998; www.census.gov).

USEPA (United States Environmental Protection Agency), 1997, United States Environmental Protection Agency Office of Underground Storage Tanks Correction Action Database, Washington DC, Second Half Fiscal Year 1997.

Whitter, J., 1998, Central Valley Regional Water Quality Control Board, Fresno, Personal Communication, July, 1998.

WSPA (Western States Petroleum Association), 1998, Correspondence to Department of Health Services Office of Regulations, comments on Department of Health Services proposed secondary maximum contaminant limit for MTBE, September 8, 1998.

Zogorski, J.S., A. Morduchowitz, A.L. Baehr, B.J. Bauman, D.L. Conrad, R.T. Drew, N.E. Korte, W.W. Lapham, J.F. Pankow and E.R. Washington, 1996, Fuel oxygenates and water quality, Interagency Assessment of Oxygenated Fuels, Washington DC, Office of Science and Technology Policy, Executive Office of the President.

Zogorski, J.S., G.C. Delzer, D.A. Bender, P. J. Squillace, T.J. Lopes, A.L. Baehr, P.E. Stackelber, J.E. Landmeyer, C.J. Boughton, M.S. Lico, J.F. Pankow, R.L. Johnson and N.R. Thomson, 1998, MTBE: Summary of findings and research. U.S. Geological Survey, Proceeding of the 1998 Annual Conference of the American Water Works Association (in press).

# APPENDIX A: RESPONSES OF CALIFORNIA MUNICIPALITIES AND WATER PURVEYORS TO THE MTBE PROBLEM

Resolutions have been passed and adopted by numerous agencies across the state in response to concerns that the water quality of drinking supplies may be negatively affected by MTBE. A brief but not exhaustive summary of the concerned agencies has been included:

Alameda County Flood Control and Water Conservation District, Resolution No. 97-1850, "Resolution that the Board of Directors of Zone 7 of Alameda County Flood Control and Water Conservation District, Exercises its Duties as the Manager of the Groundwater Basin by Recommending that the Addition of MTBE to Motor Vehicle Fuels be Discontinued and that a More Environmental Responsible Fuel Additive be Employed to Reduce Harmful Exhaust Emissions", March 19, 1997.

Board of Directors of the El Dorado County Water Agency, Resolution No. W A 6-98, (Water Agency Board of Directors of the County of El Dorado, in the State of California requests and supports the ban of the use of MTBE in areas where drinking water sources are vulnerable to contamination by MTBE) September 22, 1998.

Board of Supervisors of the County of El Dorado, Resolution No. 241-98, (Board of Supervisors of the County of El Dorado, in the State of California, requests and supports the ban of the use of MTBE in areas where drinking water sources are vulnerable to contamination by MTBE), September 22, 1998.

Board of Supervisors of the County of Napa, State of California, Resolution No. 98-132, "Resolution of the Board of Supervisors of the County of Napa, State of California, Supporting Efforts to Remove or Limit the Level of MTBE and Other Ether Oxygenates in Water Supplies and Motor Vehicle Fuels", September 29, 1998.

Board of Supervisors of the County of Sonoma, State of California, Resolution No. 98-1289, "Resolution of the Board of Supervisors of the County of Sonoma, State of California, Requesting the Governor and the Legislature to Prohibit the Use of Methyl Tertiary-Butyl Ether (MTBE) or Other Ether Oxygenates in Motor Fuel and Employ a More Environmentally Responsible Fuel Additive to Reduce Harmful Exhaust Emissions, and Supporting Senator Dianne Feinstein's Federal Legislation S. 1576", October 6, 1998.

City Council of Los Altos Hills, Resolution No. 68-98, "A Resolution of the Town of Los Altos Hills Requesting Governor Wilson to Prohibit the Use of Methyl Tertiary-Butyl Ether in Gasoline", August 19, 1998.

City Council of Los Altos, Resolution No. 98-24, "Resolution of the City Council of the City of Los Altos Entreating Governor Pete Wilson to Protect the Drinking Water of Los Altos, by Prohibiting the Use of MTBE in Gasoline", August 18, 1998.

City Council of Gilroy, Resolution 98-41, "Resolution of the City Council of the City of Gilroy Requesting Governor Pete Wilson to Prohibit the Use of Methyl Tertiary-Butyl Ether (MTBE) in California's Gasoline", August 3, 1998.

City Council of Milpitas, Resolution 6810, "A Resolution of the City Council of the City of Milpitas Requesting the Governor to Prohibit the Use of Methyl Tertiary-Butyl Ether or Other Ether Oxygenates in Gasoline", September 1, 1998.

City Council of Monte Sereno, Resolution 1868, "A Resolution of the City Council of the City of Monte Sereno Requesting the Governor and the Legislature to Prohibit the Use of Methyl Tertiary-Butyl Ether or Other Ether Oxygenates in Motor Fuel" July 21, 1998.

City Council of Morgan Hill, Resolution 5213, "A Resolution of the City Council of the City of Morgan Hill Requesting the Governor and the Legislature to Prohibit the Use of Methyl Tertiary-Butyl Ether or Other Ether Oxygenates in Motor Fuel." August 5, 1998.

City Council of San Bruno, Resolution 1997-22, "Resolution of the City Council of the City of San Bruno Objecting to the Sale of Gasoline Products Containing Methyl Tertiary Butyl Ether (MTBE)", April 14, 1997.

City Council of Santa Clara, Resolution No. 6456, "A Resolution of the City Council of the City of Santa Clara Requesting the Governor and the Legislature to Prohibit the Use of Methyl Tertiary-Butyl Ether or Other Ether Oxygenates in Motor Fuel", June 23, 1998.

City Council of South Lake Tahoe, Resolution No. 1998-74, "Resolution Supporting the South Tahoe Public Utility District in its Efforts to Maintain the City's Water Supply" October 6, 1998.

County of Amador, Resolution No. 98-089, "Resolution Requesting and Supporting the Ban of the Use of Methyl Tertiary Butyl Ether (MTBE), March 10, 1998.

Mesa Consolidated Water District, Resolution No. 1207, "A Resolution of the Board of Directors of the Mesa Consolidated Water District Urging the Governor and Legislature to Prohibit the Use of Methyl Tertiary-Butyl Ether Gasoline", August 27, 1998.

Santa Clara County Board of Supervisors, "Resolution that the Santa Clara Board of Supervisors is Actively Supporting Measures to Remove or Limit the Level of MTBE in the Water Supply", May 12, 1998.

Santa Clara Valley Water District, Resolution No. 98-10, "Requesting Governor Pete Wilson to Prohibitive the Use of Methyl Tertiary-Butyl Ether in Gasoline", February 17, 1998.

South Tahoe Public Utility District, Resolution No. 2660-98, "A Resolution of the Board of Directors of the South Tahoe Public Utility District Urging the Governor of the State of California to Employ His Executive Powers to Achieve the

Removal of MTBE and Other Oxygenates as Additives to Gasoline in the State of California", March 19, 1998.

South Tahoe Public Utility District, Resolution 2681-98, "A Resolution of South Tahoe Public Utility District Entreating Governor Pete Wilson to Protect the Drinking Water of South Lake Tahoe, by Prohibiting the Use of MTBE in Gasoline", July 16, 1998.

Town Council of Los Gatos, Resolution 1998-139, "Resolution of the Town Council of the Town of Los Gatos to Prohibit the Use of Methyl Tertiary-Butyl Ether (MTBE) or Other Ether Oxygenates in Motor Fuel", September 8, 1998.

Water Advisory Committee of Orange County, "Resolution Concerning MTBE", (recommended actions to be taken by local, state and federal officials to immediately address the MTBE issue), September 19, 1998.

# APPENDIX B: RESPONSES OF AGENCIES AND WATER DISTRICTS TO THE MTBE PROBLEM

The Metropolitan Water District of Southern California initiated an MTBE action plan in February 1997 that included a regional assessment of groundwater resource vulnerability to MTBE impacts. The assessment included the mapping of MTBE sources, such as leaking underground storage tanks and petroleum pipelines, and the mapping of drinking water production wells.

Placer County Water Agency described in a briefing paper dated September 3, 1997, an example of the agency's response to a ruptured pipeline. On February 1, 1995, a pipeline ruptured in Rocklin California releasing approximately 12,000 gallons of fuel contaminating surrounding soil and underground utilities including a Water Agency Zone 1 water main carrying drinking water to homes in Rocklin. The California Department of Health Services declared the situation hazardous to the public water systems and mandated that 640 ft of an existing PVC 12-inch water main be replaced due to the spill's proximity. The PVC main was taken out of service and replaced by a petroleum resistant ductile iron pipe with special petroleum resistant seals and gaskets. The agency further states only after a great deal of effort and did the Sierra Pacific Pipeline Partners pay all related costs and expenses incurred as a result of the rupture. Placer County Water Agency put forth the question "Who can water suppliers turn to for financial payment of costs to perform sampling, testing and remediation of MTBE tainted surface and groundwater sources and drinking water supplies? in a position paper dated June 24, 1997.

The Alameda County Flood Control and Water Conservation District on December 8, 1997 stated in correspondence to Senator Barbara Boxer that the Local Oversight Agency regulating underground storage tank sites did not inform the District of a MTBE plume that was known since October 1995 to be rapidly progressing toward a drinking water well because "It was not in our contract to inform" Zone 7.

The Santa Clara Water Valley District has developed a groundwater protection strategy to address concerns related to MTBE and on August 25, 1998 entered into an agreement with Levine-Fricke-Recon to review fuel leak and underground storage tank system records for sites where underground storage tanks have been upgraded to meet 1998 requirements and to collects samples to determine the occurrence of MTBE at facilities with operating underground storage tanks systems where releases have never been reported. This pilot study is in response to concerns that the 1998 upgraded tank systems are not able to detect releases sufficiently to protect groundwater resources.

# APPENDIX C: RESPONSES TO QUESTIONS POSED TO REGIONAL BOARDS ON JUNE 30, 1998

**What was the date MTBE monitoring was first required by your agency?**

Region Board 1 North Coast Region: June 1996.

Regional Board 2 San Francisco Bay: May 2, 1995.

Regional Board 3 Central Coast: November 27, 1996 notified all responsible parties.

Regional Board 4 Los Angeles: October 1995.

Regional Board 5 Central Valley: Spring 1997 (MTBE) and July 18, 1997 (oxygenates).

Regional Board 6 Lahontan: Internal Memo June 20, 1996 requesting site specific MTBE monitoring.

Regional Board 7 Colorado River Basin: June 27, 1997 notified all responsible parties to include MTBE data in their lab analysis.

Regional Board 8 Santa Ana: March 16, 1996. Regional Board 9 San Diego: January 1, 1998

**What is the detection limit that your agency requires?**

Region Board 1 North Coast Region: Less than or equal to 1 $\mu g \cdot L^{-1}$ (water)

Regional Board 2 San Francisco Bay: 5 $\mu g \cdot L^{-1}$

Regional Board 3 Central Coast: None specified.

Regional Board 4 Los Angeles: 5 $\mu g \cdot Kg^{-1}$ for soil; 2 $\mu g \cdot L^{-1}$ for water, and 5 $\mu g \cdot L^{-1}$ for soil gas samples.

Regional Board 5 Central Valley: 0.5 $\mu g \cdot L^{-1}$ in water and 5 $\mu g \cdot Kg^{-1}$ in soil. If these detection limits cannot be achieved, an explanation is required.

Regional Board 6 Lahontan: 20 $\mu g\ L^{-1}$ minimum, although generally achieve 5 $\mu g \cdot L^{-1}$.

Regional Board 7 Colorado River Basin: Detection limit is 1 $\mu g \cdot L^{-1}$.

Regional Board 8 Santa Ana: At least 20 $\mu g \cdot L^{-1}$, although generally achieve 10 $\mu g \cdot L^{-1}$.

Regional Board 9 San Diego: No minimum detection limit. In general, detection limits that are reported are 5 $\mu g \cdot L^{-1}$ for water and 1 $\mu g \cdot kg^{-1}$ in soil samples for Method 8020.

**What are the analytical method(s) that your agency require(s)?**

Region Board 1 North Coast Region: For drinking water wells EPA method 524.2 and for monitoring wells EPA method 8260 (modified for oxygenates). The detection limits for the modified 8260 have been 0.5 $\mu g \cdot L^{-1}$ for MTBE, ETBE, DIPE and TAME.

Regional Board 2 San Francisco Bay: EPA Method 8020 or 8260.

Regional Board 3 Central Coast: EPA Method 8020 or 8260.

Regional Board 4 Los Angeles: EPA Method 8020 or 8240B/8260A is acceptable for MTBE analysis. However, if EPA Method 8020 detects MTBE, it must be confirmed and quantified by EPA Method 8240B or 8260A to reduce false positives.

Regional Board 5 Central Valley: EPA Method 8260 using the EPA Method protocols, plus the standards for the oxygenates required for analysis.

Regional Board 6 Lahontan: EPA Method 8260 for MTBE screen or EPA Method 8260 for better quantification to reduce false positives.
Regional Board 7 Colorado River Basin: Recommend EPA Method 8260.
Regional Board 8 Santa Ana: EPA Method 8020
Regional Board 9 San Diego: EPA Method 8020 for screening and Method 8260 for confirmation.

**What are the requirements for testing alternative oxygenates?**

Region Board 1 North Coast: Require that all oxygenates be analyzed by 8260 or 524.2. These methods do not include ethanol or methanol. (MTBE, ETBE, DIPE, and TAME).
Regional Board 2 San Francisco Bay:
Testing or Monitoring:
Ether Oxygenates - EPA 8020 or 8260 **a**; Pre-closure EPA 8260
TBA - EPA 8020 or 8260 **b**; Pre-closure EPA 8260
Lead - 8260 or 8010 **c**; Pre-closure EPA 8010.
**a.** If TPH is >5 mg/l (e.g. source area) use EPA 8260
**b.** If TPH is >5 mg/l (e.g. source area) use EPA 8260 and
**c.** If concentrations decline below 8260 detection limits use 8010.
Regional Board 3 Central Coast: Not required at this time.
Regional Board 4 Los Angeles: When no water supply well is impacted, no testing for alternative oxygenates are required. If a water supply well is impacted, MTBE, DIPE, ETBE, TAME, and TBA are all required to be tested in soil and groundwater samples.
Regional Board 5 Central Valley: Alternative oxygenate analysis is required. In order to test for methyl and ethyl alcohol, high performance liquid chromatography may be required because detection limits for EPA Method 8260 are in the order of >2000 $\mu g \cdot L^{-1}$. EPA Method 8260 is acceptable for TBA even though the detection limit is 100 $\mu g \cdot L^{-1}$.
Regional Board 6 Lahontan: Not required at this time.
Regional Board 7 Colorado River Basin: Not required at this time.
Regional Board 8 Santa Ana: Not required at this time.
Regional Board 9 San Diego: Not required at this time. If specifically noted in a previous analytical result(s), then continued monitoring is generally required.

**What if any are the policies developed by your agency for MTBE/oxygenates in soil or groundwater?**

Region Board 1 North Coast Region: No policies developed.
Regional Board 2 San Francisco Bay: No policies developed.
Regional Board 3 Central Coast: No policy has been formally adopted, although recently internal guidelines have been developed but are not available for public review.
Regional Board 4 Los Angeles: "Review Procedure for UST Sites with MTBE" dated April 29, 1997. This document is a guideline for Regional Board staff's use and is available to the public. RWQCB staff is currently updating the

document. The revision will consider MTBE data obtained from leaking underground storage tank sites, MTBE fate and transport in the environment, and MTBE potential impact on groundwater resources. The RWQCB will address these significant issues surrounding the discharges of gasoline containing MTBE into the environment, because the RWQCB understands that there are no plans by the SWRCB to develop the "Draft Policy for Investigation and Clean up of Petroleum Discharges to Soil and Groundwater (January 21, 1997)".

Regional Board 5 Central Valley: No policies have been developed, although two guidance letters have been developed. Correspondence dated July 18, 1997 and August 30, 1997.

Regional Board 6 Lahontan: No policies have been developed, although the region has prepared two guidance documents: a January 5, 1998 fact sheet regarding petroleum hydrocarbon cleanup for soils and a January 28, 1998 region specific prioritization criteria which includes MTBE.

Regional Board 7 Colorado River Basin: No policies developed.

Regional Board 8 Santa Ana: No policies developed.

Regional Board 9 San Diego: No policies developed.

**What do the concentrations listed within your agency's database represent?**

Region Board 1 North Coast Region: The MTBE concentration listed represents the overall maximum. The RWQCB 1 database also lists the TAME, TBA, ETBE, and DIPE concentrations if analyzed.

Regional Board 2 San Francisco Bay: The MTBE concentration in the Region 2 database and that are reported to the water purveyors was based on the last reported (current) concentration. A field maximum MTBE has been added to the database, but the quarterly updates will continue to be based on the current MTBE concentrations.

Regional Board 3 Central Coast: The MTBE that is reported on the database is the maximum quarterly detected currently. Data from monitoring reports are reviewed quarterly and the database is updated with the quarterly maximum.

Regional Board 4 Los Angeles: The MTBE concentration listed represents the overall maximum at the site among the multiple wells and over the duration of all monitoring events. The maximum concentration is updated when quarterly groundwater monitoring reports are reviewed.

Regional Board 5 Central Valley: The maximum concentration found is recorded and retained in the LUSTIS database. A system of values is reported with ranges up to >5000 $\mu g \cdot L^{-1}$. One value is designated "refused to report" and used for instances when a responsible does not disclose the concentrations detected. The Central Valley database also lists the concentration range for TAME, TBA, Ethanol, ETBE, and DIPE.

Regional Board 6 Lahontan: Maximum concentration that was most currently reported. Updated as new information becomes available.

Regional Board 7 Colorado River Basin: Maximum concentration detected.

Regional Board 8 Santa Ana: The MTBE concentrations that are reported on the database represents the maximum for the quarter and overall maximums.

Regional Board 9 San Diego: The concentrations represent the highest one time detection of MTBE from the initial sampling results. The listed concentration does not change as MTBE increases or decreases with time. Note that RWQCB 9 does not include in their database information from Orange and Riverside Local Oversight Program Agencies. Information from these agencies regarding their database was not provided for inclusion in this report.

*Responses received:*

Regional Board 1: E-mail July 15, 1998
Regional Board 2: E-mail September 2, 1998
Regional Board 3: Telephone conversations (August 24 and 26 1998)
Regional Board 4: Fax September 21, 1998
Regional Board 5: Telephone and e-mail (September 11, 1998 and September 14, 1998)
Regional Board 6: Telephone conversation July 24, 1998 and correspondence dated August 20, 1998
Regional Board 7: Correspondence dated July 14, 1998
Regional Board 8: Telephone conversation July 23, 1998
Regional Board 9: Correspondence dated September 10, 1998

# APPENDIX D: EPA SURVEY OF STATE LUST PROGRAMS

The United States Environmental Protection Agency (US EPA) with the University of Massachusetts conducted a survey study in early 1998 to assess the sources and impacts associated with the use of MTBE in petroleum fuels (Hitzig et al., 1998). The states having areas that use reformulated gasoline include: California, Arizona, Texas, Wisconsin, Illinois, Indiana Kentucky, Virginia, Pennsylvania, Maryland, Delaware, New Jersey, New York, Connecticut, Rhode Island, Massachusetts, New Hampshire, and the District of Columbia (DC).

The survey was sent to LUFT Programs in all fifty states and to the DC. The response summaries include the DC as a state. Only California and Indiana did not respond. Twenty-seven of the states require analysis for MTBE at sites where petroleum products leaked from underground storage tanks, and an additional 8 states request or receive MTBE analytical results more than 20 percent of the time. The majority of states responding indicated that MTBE is detected at more than 20 percent of the LUFT sites, with a third of the states indicating that MTBE is detected at more than 80 percent of the sites. Information from states using reformulated gas provides further correlation between the amount of MTBE in gasoline and the frequency that MTBE is detected at LUFT sites. The most frequent response from states using reformulated gasoline to the question "how often is MTBE detected at LUFT sites" was from 80-100 percent of the time. Figure 1-D illustrates the frequency that MTBE is detected at leaking underground storage tanks sites.

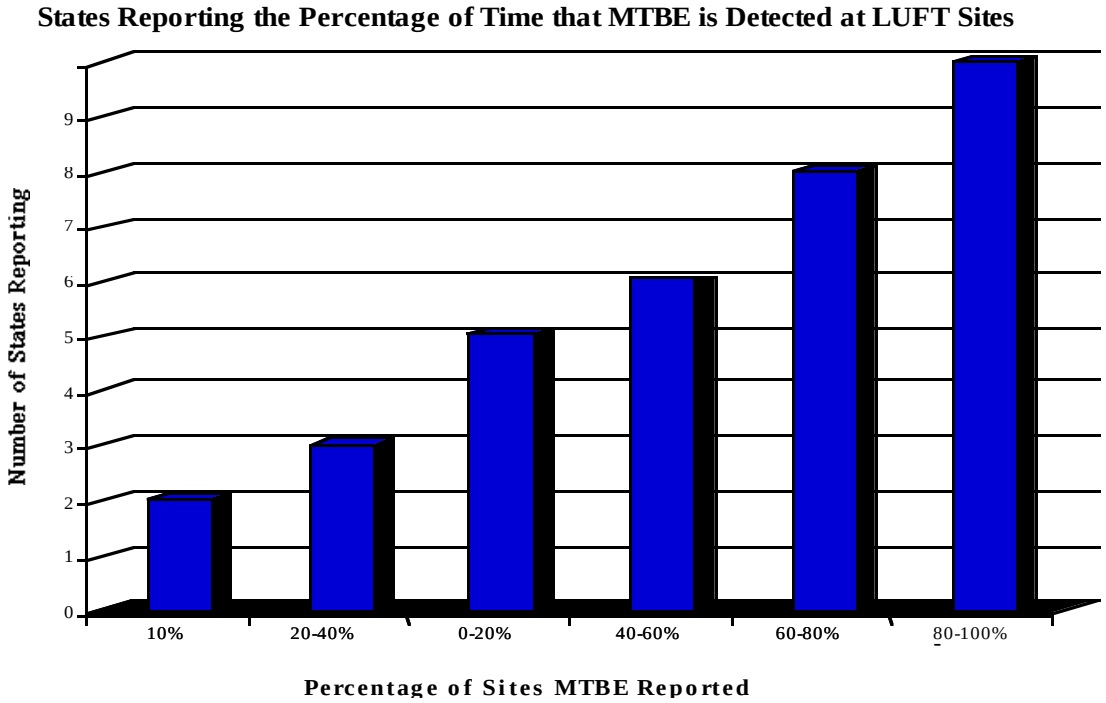


**Figure D1. Percentage of LUFT sites reporting MTBE contamination (Hitzig et al., 1998)**

Nineteen states reported that MTBE had contaminated a public drinking water well (a well serving more than 25 connections) and 25 states reported that MTBE had contaminated a private well.

Figure D2 shows numbers of private wells and public wells that were reported in the EPA and University of Massachusetts survey.

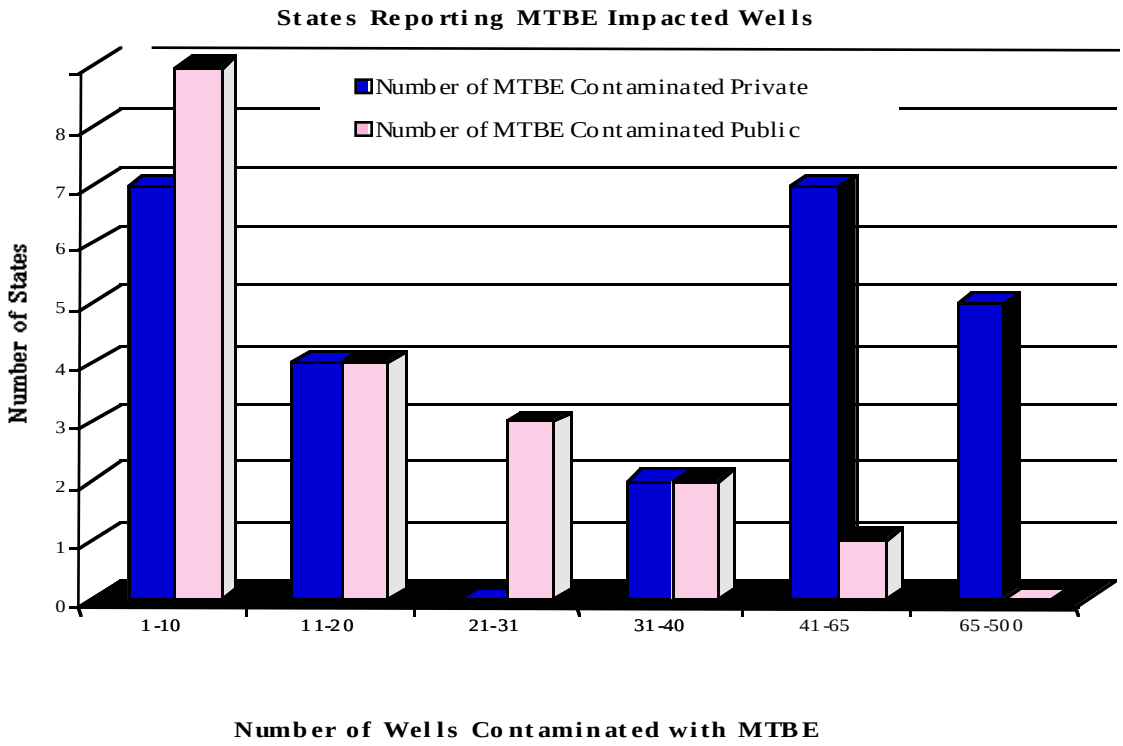


**Figure D2. Wells contaminated with MTBE in twenty five states (Hitzig et al., 1998)**

Five states reported MTBE detections at concentrations more than 20 $\mu g \cdot L^{-1}$, at sites where petroleum products, other than gasoline were detected in groundwater. These products included diesel, jet fuel, heating oil, aviation fuel, and waste oil. When questioned by the surveyors, petroleum industry representatives stated that MTBE is not added deliberately to these fuels, but is inadvertently added when these fuels pass through the same distribution system as had previously held gasoline. The survey summary stated that because of MTBE mixing with these other fuels, it might be necessary to perform analysis for MTBE at all petroleum sites.

Most states have not assessed the increased costs associated with MTBE remedial efforts, although state staff did indicate that there are increased costs when sites are contaminated depending on whether the state used reformulated gas or not. The same reasons for MTBE's use in California in reformulated gas (i.e., adds oxygen, mixes well, is inexpensive to produce) apply in other states, explaining why MTBE is often associated with reformulated gasoline. In states where reformulated gasoline is used, MTBE concentrations detected are higher, further increasing the

costs of remediation. The increased costs associated with higher concentrations relate to MTBE's higher mobility, lower sorption and lower biodegradation, which leads to greater volumes of water impacted at higher concentrations. Forty percent of the states where reformulated gas is used estimated that remediation costs increase between 20 and 100 percent, while only 7.5 percent of the states where reformulated gas is not used estimated the same cost increase.

The most effective soil remediation technology indicated by survey responders was soil vapor extraction and the most effective groundwater remediation methods were first air sparging and then pump-and-treat.

Finally, the importance of compliance and enforcement of the December 22, 1998 underground storage tank upgrade requirements was stressed as a means to prevent MTBE from causing significant impacts on drinking water supplies.

**Actions by the States**

In New York, there is a categorical drinking water standard of 50 $\mu g \cdot L^{-1}$ which is under review following the issuance of a consumer acceptance advisory from the US EPA ranging from 20 to 40 $\mu g \cdot L^{-1}$. The New York State Department of Health has an ongoing water quality surveillance program which has analyzed approximately 800 public water systems since 1995, and approximately 4 percent had detectable concentrations of MTBE (New York Department of Health, 1998).

The New York Department of Health has undertaken a survey of private wells in two areas of the state; one considered an area of low MTBE use, and another considered an area of high MTBE use. The results of this survey should be available later in 1998.

Information was obtained from two New York Counties, Nassau and Suffolk. In February 1998, Nassau County, notified each of the 54 public water systems that, effective April 1, 1998, MTBE monitoring would be required on a quarterly basis at each well and on a semi-annual basis in their distribution systems (Gaffney, 1998). Nassau County will be reviewing the data obtained from water systems and Health Department sampling in an effort to determine the extent of MTBE contamination in the source and drinking water. Suffolk County reported using data through April 1998 that 230 private well samples and 55 public wells had detectable concentrations of MTBE (Moran, 1997).

Maine's Governor, Augus King, in May 1998 ordered the testing of 800 public water supplies and 1,000 private wells be tested for MTBE within the year (Turkel, 1998). The State worked with the U. S. Geological Survey to determine which of the private wells should be sampled to give the state the best cross-section of its domestic water supplies (Hench, 1998). Numerous areas of the State had reported wells with concentrations in excess of Maine's 35 $\mu g \cdot L^{-1}$ maximum contaminant level for MTBE (Carrier and Hench, 1998). On October 13, 1998 the report of the study was released (State of Maine, 1998).

# APPENDIX E: REGULATORY AGENCIES

*Local Oversight Program Agencies*

**Alameda**
Tom Peacock, Manager
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Environmental Health Services
Environmental Protection (LOP)
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Alameda, CA 94502-6577
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**Humboldt**
Brian Cox, Administrative Rep.
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Division Environmental Health
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Eureka, CA 95501
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**Kern**
Karen Geye, Contract Administrator
County of Kern
Environmental Health Services Dept.
2700 M Street Bakersfield, CA 93301
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FAX (805) 862-8701

**Merced**
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Merced County Dept. of Public Health
Division of Environmental Health
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777 W 22nd Street Merced, CA 95340
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**Napa**
Ms. Jackie Bertaina, Senior HMS
Napa County Department of Env. Mgt.
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1195 Third Street, Room 101
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FAX (707) 253-4545

**Orange**
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Orange County Health Care Agency
Division of Environmental Health
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**Riverside**
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Department of Environmental Health
Hazardous Materials Management Div.
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**Sacramento**
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**San Bernardino**
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County of San Bernardino
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**City and County of San Francisco**
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**San Joaquin County**
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**San Mateo**
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County Remedial Oversight Program
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**Santa Barbara**
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**Santa Clara Valley Water District**
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**Stanislaus**
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Ted Garcia (209) 525-6732

**Tulare**
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Health & Human Services Agency
Health Services Branch
Environmental Health Services Division
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**Ventura**
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## Department of Health Services Drinking Water Program

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601 North 7th Street, MS 92
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or (916) 327-6092 (8) 467-6092

**Berkeley Technical Unit**
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Berkeley, CA 94704
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| District Offices | Offices and Counties Served | |
|---|---|---|
| **Monterey (5) & San Francisco (4) Districts**<br>2151 Berkeley Way, Room 458<br>Berkeley, CA 94704<br>(510) 540-2158 (8) 540-2158<br>FAX (510) 540-2152 (8) 571-2152 | **Monterey**<br>Monterey<br>San Benito<br>Santa Cruz<br>Santa Clara | **San Francisco**<br>San Mateo<br>San Francisco<br>Marin<br>Contra Costa<br>Solano<br>Alameda |
| **Merced (11) & Visalia (12) Districts**<br>5545 East Shields Avenue<br>Fresno, CA 93727<br>(209) 297-3883 (8) 451-3883<br>FAX (209) 297-3873 (8) 451-3873<br>or (209) 297-5423 (8) 451-5423 | **Merced**<br>Merced<br>Madera<br>Fresno<br>Mariposa<br>Tuolumne | **Visalia**<br>Kings<br>Tulare<br>Kern |
| **Hollywood (7) & Metropolitan (15) Districts**<br>1449 West Temple Street, Room 202<br>Los Angeles, CA 90026<br>(213) 580-5723 (NoATSS)<br>FAX (213) 580-5711 or (213) 580-3125 | **Hollywood**<br>Los Angeles | **Metropolitan**<br>Los Angeles |
| **Lassen (2) & Shasta (1) Districts**<br>415 Knollcrest Drive, Suite 110<br>Redding, CA 96002<br>(916) 224-4800 (8) 441-4800<br>FAX (916) 224-4844 (8) 441-4844 | **Lassen**<br>Lassen<br>Butte<br>Plumas<br>Tehama<br>Glenn<br>Colusa<br>Sutter<br>Yuba<br>Sierra | **Shasta**<br>Shasta<br>Modoc<br>Siskiyou<br>Del Norte<br>Humbolt<br>Trinity |

**Sacramento (9) District**
8455 Jackson Road, Suite 120,
Sacramento, CA 95826
(916) 229-3126 (8) 424-3126
FAX (916) 229-3127 (8) 424-3127

**Sacramento**
Sacramento
Yolo
El Dorado
Placer
Nevada
Alpine

**San Bernardino (13) District**
Government Center - 4th Floor
464 West Fourth Street, Suite 437
San Bernardino, CA 92401
(909) 383-4328 (8) 670-4328
FAX (909) 383-4745 (8) 670-4745

**San Bernardino**
San Bernardino
Inyo
Mono

**Santa Barbara (6) District**
530 E. Montecito Street, Room 102
Santa Barbara, CA 93103
Mail: P.O. Box 4339
Santa Barbara, CA 93140-4339
(805) 963-8616 (No ATSS)
FAX (805) 962-0927 (No ATSS)

**Santa Barbara**
Santa Barbara
San Luis Obispo
Ventura

**San Diego (14) District**
1350 Front Street, Room 2050
San Diego, CA 92101
(619) 525-4159 (8) 625-4159
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**San Diego**
San Diego
Riverside
Imperial

**Santa Ana (8) District**
28 Civic Center Plaza, Room 325
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(714) 558-4410 (8) 657-4410
FAX (714) 567-7262 (8)657-7262

**Santa Ana**
Orange

**Santa Rosa (3) District**
50 D Street, Suite 200
Santa Rosa, CA 95404-4752
(707) 576-2145 (8) 590-2145
FAX (707) 576-2722 (8) 590-2722

**Santa Rosa**
Sonoma
Napa
Lake
Mendocino

**Stockton (10) District**
31 East Channel Street, Room 270
Stockton, CA 95202
(209) 948-7696 (8) 423-7696
FAX (209)948-7451 (8) 423-7451

**Stockton**
San Joaquin
Stanislaus
Calaveras
Amador

## Local Primacy Agencies

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**Amador County**
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**Butte County**
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**Calaveras County**
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San Andreas, CA 95249
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Fax (209) 754-6722

**Contra Costa County**
Kenneth Stuart, Director
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Health Division
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**El Dorado County**
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Environmental Management Dept.
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**Fresno County**
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**Imperial County**
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**Kings County**
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**Los Angeles County**
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**Madera County**
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**Marin County**
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**Merced County**
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**Mono County**
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**Monterey County**
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**Napa County**
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**Nevada County**
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**Placer County**
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**Sacramento County**
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**San Bernardino County**
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**San Luis Obispo County**
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225 Camino Del Remedio
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# APPENDIX F: DISCREPANCIES IN DATA ON CONTAMINATION OF DRINKING WATER WELLS BY MTBE

In the process of using Department of Health Services (DHS) data, we encountered some problems that, if addressed, would assist future water quality survey efforts. For example, the Local Primacy Agencies (LPA's) have system classifications that do not match the DHS inventory. Public Water Systems (PWS) are classified as Community, Non-Community Non-Transient, Non-Community Transient, State Small and Recycled. State Small water systems are included, although these systems are not considered public water systems. Nevertheless, the DHS regulates State Small water systems in counties that do not have a LPA. The Community PWS are subclassified as large or small depending on the number of connections. Large Community Water Systems have 200 or greater connections, while Small Community Water Systems have less than 200 connections. The DHS regulates all Large Community Water Systems, and LPA's can regulate the Small Community Water Systems. The problem with system designations not matching occurs when evaluating the systems required to test for MTBE as an unregulated compound. If a LPA considers a system to be a Non-Community Water System, State Small or Recycled System, testing is not going to be requested, regardless of the designation by DHS. Efforts were initiated to reconcile these problems, but insufficient time was available during the short time frame of this project to complete this task.

Another problem was that of the LPA designation for testing results listed in the DHS WQI database. The DHS has recently begun accepting analytical results from the LPA's for inclusion in the WQI database. There were instances where the LPA's reported results differed from what was included in the WQI database (San Bernardino) and where the LPA designation was not included in the WQI database (El Dorado). The data used in the evaluation of testing results for the LPA's was that provided by the LPA's unless there were results not provided by LPA's but listed in the WQI database. For the final count of the wells and systems tested, an assumption was made that if a system or well was not designated in the WQI database as regulated by an LPA, that it was regulated by the DHS. The available information did not allow a determination of which data was most accurate; however, since the LPA's submit inventory data to the DHS, it was assumed that the DHS data was reliable.

The final problem encountered was the multiple counting of groundwater wells. Water from wells occasionally goes through a treatment system. The source water from the well is tested and then may be tested following treatment, counting as two wells, where actually there was only one well tested. An assumption was made for the final count that each well designated on the WQI database was a separate and distinct well. The WQI database that was used for the final count of systems tested was obtained on September 17, 1998 from the DHS web site.

# APPENDIX G: SURVEY RESULTS, LOCAL PRIMACY AGENCY REGULATED GROUNDWATER SYSTEMS

There are 34 Local Primacy Agencies of which each was contacted by telephone and by correspondence. The correspondence included a copy of the September 11, 1997 DHS Policy Memo 97-003 Revision: Implementation of MTBE Monitoring Requirement. For most if not all of the agencies contacted, this was the first exposure to the policy. Only 14 counties designated as Local Primacy Agencies responded: Amador, Contra Costa, Imperial, Kings, Los Angeles, Merced, Riverside, San Bernardino, San Joaquin, San Luis Obispo, Tulare, Tuolumne, Yolo, and Yuba. Each LPA responded differently to the request for information regarding their vulnerability assessment and groundwater system testing results.

Imperial County indicated that the systems which they regulated could not afford the extra testing and that they had not performed a vulnerability assessment, but when they did they would forward their analysis DHS.

Los Angeles County indicated that none of their systems were deemed vulnerable and forwarded analytical results obtained.

Riverside County indicated that none of the 318 systems that they regulated was vulnerable and that none had performed MTBE analysis.

San Joaquin County indicated that all of the systems tested met standards, when none had been established.

San Luis Obispo had three wells with detectable concentrations of MTBE, but these were the only systems tested or deemed vulnerable. A referral was made to the Central Coast Regional Water Quality Control Board, but these site have not been identified on subsequently prepared Water Purveyors Report.

Tuolumne County indicated that they had notified the vulnerable systems and would forward the results by September 15, 1998. No results were received by October 20, 1998.

Yolo County provided a copy of the letter they sent to the vulnerable systems of which 40 percent of the systems requiring testing comprised. Many of these have not yet submitted results.

Amador, Contra Costa, and Yuba counties indicated that the vulnerable systems had been tested and forwarded the results.

Kings County indicated that they initially deemed 14 systems within 2,000 ft of a potential source of contamination pursuant to the September 1997 DHS Implementation Policy; however, only three were located within 2000 ft of a known gasoline release site. In response to a subsequent correspondence from DHS staff received by the County on May 15, 1998, only three systems were deemed vulnerable. The DHS letter received by the county altered the definition of vulnerable source from one which is located within 2000 ft of a tank site known to

have operated at some time after 1979, to one which is located within 2000 ft of a known release of MTBE to groundwater (Kings County, 1998).

There are 4304 groundwater systems regulated by a LPA. The 4304 groundwater systems include systems required to monitor for MTBE as an unregulated compound and 362 (8 percent) non-community transient systems which are not required to monitor unregulated compounds, unless deemed vulnerable. Only 132 PWS regulated by the LPA's have reported sampling. Three (2 percent) of the 132 systems tested were non-community transient public water systems.

The importance of the differences between non-community transient and non-community non-transient systems is blurred in reality, especially when several LPA's indicated that the systems that they consider most vulnerable are non-community transient systems, due to the proximity of the a gasoline station. Many rural gasoline stations have associated non-community transient public water systems. The information which was included with the LPA responses suggested that LPAs may be regulating systems they consider to be other than what the system may be recorded as on the PWS inventory.

Tables G1, G2, G3 and G4 summarize the testing results for DHS regulated wells, LPA regulated wells as well as total wells statewide and the DHS systems inventory.

## Table G1. Testing summary of DHS regulated PWS wells.

| County | DHS GW PWS Systems tested | DHS PWS well tested | DHS abandoned ina or ag wells reporte (MTBE not detecte | DHS tested abandoned, inactive or wells | DHS MTBE Detect | Total DHS PWS GW Systems | Total DHS PWS wells | %DHS GW System teste | %DHS wells tested |
|---|---|---|---|---|---|---|---|---|---|
| Alameda | 4 | 24 | 1 | 23 | 0 | 23 | 62 | 1% | 1% |
| Alpine | 0 | 0 | 0 | 0 | 0 | 3 | 5 | 0% | 0% |
| Amador | 3 | 6 | 0 | 6 | 0 | 6 | 15 | 1% | 0% |
| Butte | 3 | 3 | 0 | 3 | 0 | 14 | 102 | 1% | 0% |
| Calaveras | 5 | 6 | 0 | 6 | 0 | 4 | 9 | 1% | 0% |
| Colusa | 0 | 0 | 0 | 0 | 0 | 34 | 57 | 0% | 0% |
| Contra Costa | 3 | 6 | 0 | 6 | 0 | 6 | 30 | 1% | 0% |
| Del Norte | 0 | 0 | 0 | 0 | 0 | 41 | 56 | 0% | 0% |
| El Dorado | 4 | 40 | 0 | 40 | 5 | 6 | 48 | 1% | 1% |
| Fresno | 8 | 137 | 8 | 129 | 0 | 32 | 191 | 1% | 5% |
| Glenn | 1 | 1 | 0 | 1 | 0 | 37 | 60 | 0% | 0% |
| Humboldt | 5 | 8 | 0 | 8 | 0 | 81 | 116 | 1% | 0% |
| Imperial | 0 | 0 | 0 | 0 | 0 | 8 | 12 | 0% | 0% |
| Inyo | 2 | 5 | 0 | 5 | 0 | 20 | 39 | 0% | 0% |
| Kern | 30 | 104 | 5 | 99 | 1 | 375 | 765 | 5% | 4% |
| Kings | 2 | 3 | 0 | 3 | 0 | 7 | 36 | 0% | 0% |
| Lake | 6 | 8 | 0 | 8 | 0 | 74 | 91 | 1% | 0% |
| Lassen | 1 | 1 | 0 | 1 | 0 | 51 | 74 | 0% | 0% |
| Los Angeles | 120 | 826 | 29 | 797 | 13 | 140 | 910 | 20% | 28% |
| Madera | 6 | 25 | 0 | 25 | 0 | 18 | 102 | 1% | 1% |
| Marin | 2 | 5 | 1 | 4 | 0 | 18 | 43 | 0% | 0% |
| Mariposa | 2 | 7 | 1 | 6 | 0 | 54 | 102 | 0% | 0% |
| Mendocino | 5 | 10 | 0 | 10 | 0 | 104 | 184 | 1% | 0% |
| Merced | 7 | 35 | 2 | 33 | 0 | 15 | 86 | 1% | 1% |
| Modoc | 0 | 0 | 0 | 0 | 0 | 21 | 33 | 0% | 0% |
| Mono | 0 | 0 | 0 | 0 | 0 | 10 | 25 | 0% | 0% |
| Monterey | 7 | 41 | 1 | 40 | 0 | 32 | 152 | 1% | 1% |
| Napa | 2 | 4 | 0 | 4 | 0 | 6 | 17 | 0% | 0% |
| Nevada | 1 | 2 | 0 | 2 | 0 | 9 | 37 | 0% | 0% |
| Orange | 30 | 134 | 4 | 130 | 0 | 60 | 260 | 5% | 5% |
| Placer | 9 | 11 | 1 | 10 | 0 | 26 | 56 | 2% | 0% |
| Plumas | 4 | 7 | 1 | 6 | 0 | 122 | 162 | 1% | 0% |
| Riverside | 40 | 260 | 19 | 241 | 3 | 63 | 539 | 7% | 9% |
| Sacramento | 24 | 202 | 4 | 198 | 1 | 39 | 435 | 4% | 7% |
| San Benito | 7 | 13 | 1 | 12 | 0 | 55 | 87 | 1% | 0% |
| San Bernardino | 64 | 409 | 29 | 380 | 3 | 89 | 909 | 11% | 14% |
| San Diego | 8 | 15 | 0 | 15 | 0 | 35 | 104 | 1% | 1% |
| San Francisco | 2 | 3 | 0 | 3 | 2 | 2 | 3 | 0% | 0% |
| San Joaquin | 14 | 53 | 0 | 53 | 1 | 27 | 191 | 2% | 2% |
| San Luis Obispo | 12 | 54 | 0 | 54 | 0 | 32 | 162 | 2% | 2% |
| San Mateo | 3 | 10 | 0 | 10 | 0 | 10 | 59 | 1% | 0% |
| Santa Barbara | 16 | 66 | 0 | 66 | 0 | 25 | 119 | 3% | 2% |
| Santa Clara | 18 | 109 | 0 | 109 | 0 | 120 | 350 | 3% | 4% |
| Santa Cruz | 7 | 30 | 0 | 30 | 0 | 16 | 104 | 1% | 1% |
| Shasta | 0 | 0 | 0 | 0 | 0 | 20 | 62 | 0% | 0% |
| Sierra | 0 | 0 | 0 | 0 | 0 | 37 | 43 | 0% | 0% |
| Siskiyou | 1 | 1 | 1 | 0 | 0 | 85 | 122 | 0% | 0% |
| Solano | 6 | 10 | 0 | 10 | 0 | 64 | 93 | 1% | 0% |
| Sonoma | 25 | 45 | 1 | 44 | 1 | 367 | 518 | 4% | 2% |
| Stanislaus | 12 | 87 | 0 | 87 | 0 | 23 | 206 | 2% | 3% |
| Sutter | 1 | 1 | 0 | 1 | 0 | 63 | 87 | 0% | 0% |
| Tehama | 1 | 1 | 0 | 1 | 0 | 112 | 157 | 0% | 0% |
| Trinity | 0 | 0 | 0 | 0 | 0 | 46 | 59 | 0% | 0% |
| Tulare | 15 | 57 | 3 | 54 | 0 | 38 | 243 | 3% | 2% |
| Tuolumne | 3 | 5 | 0 | 5 | 0 | 22 | 69 | 1% | 0% |
| Ventura | 28 | 62 | 0 | 62 | 1 | 88 | 192 | 5% | 2% |
| Yolo | 1 | 1 | 0 | 1 | 0 | 9 | 70 | 0% | 0% |
| Yuba | 6 | 6 | 0 | 6 | 1 | 5 | 37 | 1% | 0% |
| TOTALS | 586 | 2,959 | 112 | 2,847 | 32 | 2,949 | 8,957 | 100% | 100% |

**Table G2. Testing summary of LPA regulated PWS wells.**

| County | LPA test systems | LPA test wells | LPA MTBE Detects | Total LP GW Systems | Total LP Wells | %LPA GW Systems tested | % LPA wells tes |
|---|---|---|---|---|---|---|---|
| Alameda | Not a Local Primacy Agency | | | | | | |
| Alpine | 0 | 0 | 0 | 31 | 31 | 0% | 0% |
| Amador | 0 | 0 | 0 | 48 | 58 | 0% | 0% |
| Butte | 3 | 3 | 0 | 81 | 81 | 2% | 2% |
| Calaveras | 0 | 0 | 0 | 48 | 59 | 0% | 0% |
| Colusa | Not a Local Primacy Agency | | | | | | |
| Contra Costa | 10 | 10 | 0 | 120 | 120 | 7% | 7% |
| Del Norte | Not a Local Primacy Agency | | | | | | |
| El Dorado | 4 | 4 | 0 | 121 | 125 | 3% | 3% |
| Fresno | 0 | 0 | 0 | 278 | 410 | 0% | 0% |
| Glenn | Not a Local Primacy Agency | | | | | | |
| Humboldt | Not a Local Primacy Agency | | | | | | |
| Imperial | 0 | 0 | 0 | 32 | 39 | 0% | 0% |
| Inyo | 0 | 0 | 0 | 108 | 117 | 0% | 0% |
| Kern | Not a Local Primacy Agency | | | | | | |
| Kings | 7 | 7 | 0 | 37 | 47 | 5% | 5% |
| Lake | Not a Local Primacy Agency | | | | | | |
| Lassen | Not a Local Primacy Agency | | | | | | |
| Los Angeles | 31 | 31 | 0 | 130 | 180 | 22% | 22% |
| Madera | 0 | 0 | 0 | 159 | 159 | 0% | 0% |
| Marin | 0 | 0 | 0 | 20 | 20 | 0% | 0% |
| Mariposa | Not a Local Primacy Agency | | | | | | |
| Mendocino | Not a Local Primacy Agency | | | | | | |
| Merced | 0 | 0 | 0 | 108 | 132 | 0% | 0% |
| Modoc | Not a Local Primacy Agency | | | | | | |
| Mono | 0 | 0 | 0 | 95 | 95 | 0% | 0% |
| Monterey | 1 | 1 | 0 | 401 | 424 | 1% | 1% |
| Napa | 0 | 0 | 0 | 3 | 5 | 0% | 0% |
| Nevada | 1 | 1 | 0 | 68 | 71 | 1% | 1% |
| Orange | Not a Local Primacy Agency | | | | | | |
| Placer | 0 | 0 | 0 | 76 | 87 | 0% | 0% |
| Plumas | Not a Local Primacy Agency | | | | | | |
| Riverside | 0 | 0 | 0 | 318 | 318 | 0% | 0% |
| Sacramento | 0 | 0 | 0 | 168 | 169 | 0% | 0% |
| San Benito | Not a Local Primacy Agency | | | | | | |
| San Bernardino | 29 | 29 | 0 | 20 | 21 | 21% | 21% |
| San Diego | 0 | 0 | 0 | 180 | 181 | 0% | 0% |
| San Francisco | Not a Local Primacy Agency | | | | | | |
| San Joaquin | 10 | 12 | 0 | 335 | 396 | 7% | 9% |
| San Luis Obispo | 3 | 3 | 3 | 168 | 168 | 2% | 2% |
| San Mateo | 0 | 0 | 0 | 23 | 23 | 0% | 0% |
| Santa Barbara | 0 | 0 | 0 | 101 | 118 | 0% | 0% |
| Santa Clara | Not a Local Primacy Agency | | | | | | |
| Santa Cruz | 0 | 0 | 0 | 62 | 120 | 0% | 0% |
| Shasta | 0 | 0 | 0 | 189 | 227 | 0% | 0% |
| Sierra | Not a Local Primacy Agency | | | | | | |
| Siskiyou | Not a Local Primacy Agency | | | | | | |
| Solano | Not a Local Primacy Agency | | | | | | |
| Sonoma | Not a Local Primacy Agency | | | | | | |
| Stanislaus | 0 | 0 | 0 | 207 | 270 | 0% | 0% |
| Sutter | Not a Local Primacy Agency | | | | | | |
| Tehama | Not a Local Primacy Agency | | | | | | |
| Trinity | Not a Local Primacy Agency | | | | | | |
| Tulare | 2 | 2 | 0 | 304 | 382 | 1% | 1% |
| Tuolumne | 0 | 0 | 0 | 86 | 116 | 0% | 0% |
| Ventura | Not a Local Primacy Agency | | | | | | |
| Yolo | 2 | 2 | 0 | 85 | 87 | 1% | 1% |
| Yuba | 36 | 36 | 0 | 94 | 107 | 26% | 26% |
| TOTALS | 139 | 141 | 3 | 4304 | 4963 | 100% | 100% |

## Table G3. Testing summary of PWS wells by county and statewide.

| County | Total PWS Systems Tested | Total PWS Wells Tested | Total PWS Systems | Total PWS Wells | Total Detect wells | % GW Systems tested County | % PWS Wells tested County | % Wells with detects County | Statewide GW systems tested | Statewi % PWS wells tested | Statewi % PWS wells wi MTBE detectio |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Alameda | 4 | 23 | 23 | 62 | 0 | 17% | 37% | 0% | 0% | 0% | 0.00% |
| Alpine | 0 | 0 | 34 | 36 | 0 | 0% | 0% | 0% | 0% | 0% | 0.00% |
| Amador | 3 | 6 | 54 | 73 | 0 | 6% | 8% | 0% | 0% | 0% | 0.00% |
| Butte | 6 | 6 | 95 | 183 | 0 | 6% | 3% | 0% | 0% | 0% | 0.00% |
| Calaveras | 5 | 6 | 52 | 68 | 0 | 10% | 9% | 0% | 0% | 0% | 0.00% |
| Colusa | 0 | 0 | 34 | 57 | 0 | 0% | 0% | 0% | 0% | 0% | 0.00% |
| Contra Costa | 13 | 16 | 126 | 150 | 0 | 10% | 11% | 0% | 0% | 0% | 0.00% |
| Del Norte | 0 | 0 | 41 | 56 | 0 | 0% | 0% | 0% | 0% | 0% | 0.00% |
| El Dorado | 8 | 44 | 127 | 173 | 5 | 6% | 25% | 3% | 0% | 0% | 0.04% |
| Fresno | 8 | 129 | 310 | 601 | 0 | 3% | 21% | 0% | 0% | 1% | 0.00% |
| Glenn | 1 | 1 | 37 | 60 | 0 | 3% | 2% | 0% | 0% | 0% | 0.00% |
| Humboldt | 5 | 8 | 81 | 116 | 0 | 6% | 7% | 0% | 0% | 0% | 0.00% |
| Imperial | 0 | 0 | 40 | 51 | 0 | 0% | 0% | 0% | 0% | 0% | 0.00% |
| Inyo | 2 | 5 | 128 | 156 | 0 | 2% | 3% | 0% | 0% | 0% | 0.00% |
| Kern | 30 | 99 | 375 | 765 | 1 | 8% | 13% | 0% | 0% | 1% | 0.01% |
| Kings | 9 | 10 | 44 | 83 | 0 | 20% | 12% | 0% | 0% | 0% | 0.00% |
| Lake | 6 | 8 | 74 | 91 | 0 | 8% | 9% | 0% | 0% | 0% | 0.00% |
| Lassen | 1 | 1 | 51 | 74 | 0 | 2% | 1% | 0% | 0% | 0% | 0.00% |
| Los Angeles | 151 | 828 | 270 | 1,090 | 13 | 56% | 76% | 1% | 2% | 6% | 0.09% |
| Madera | 6 | 25 | 177 | 261 | 0 | 3% | 10% | 0% | 0% | 0% | 0.00% |
| Marin | 2 | 4 | 38 | 63 | 0 | 5% | 6% | 0% | 0% | 0% | 0.00% |
| Mariposa | 2 | 6 | 54 | 102 | 0 | 4% | 6% | 0% | 0% | 0% | 0.00% |
| Mendocino | 5 | 10 | 104 | 184 | 0 | 5% | 5% | 0% | 0% | 0% | 0.00% |
| Merced | 7 | 33 | 123 | 218 | 0 | 6% | 15% | 0% | 0% | 0% | 0.00% |
| Modoc | 0 | 0 | 21 | 33 | 0 | 0% | 0% | 0% | 0% | 0% | 0.00% |
| Mono | 0 | 0 | 105 | 120 | 0 | 0% | 0% | 0% | 0% | 0% | 0.00% |
| Monterey | 8 | 41 | 433 | 576 | 0 | 2% | 7% | 0% | 0% | 0% | 0.00% |
| Napa | 2 | 4 | 9 | 22 | 0 | 22% | 18% | 0% | 0% | 0% | 0.00% |
| Nevada | 2 | 3 | 77 | 108 | 0 | 3% | 3% | 0% | 0% | 0% | 0.00% |
| Orange | 30 | 130 | 60 | 260 | 0 | 50% | 50% | 0% | 0% | 1% | 0.00% |
| Placer | 9 | 10 | 102 | 143 | 0 | 9% | 7% | 0% | 0% | 0% | 0.00% |
| Plumas | 4 | 6 | 122 | 162 | 0 | 3% | 4% | 0% | 0% | 0% | 0.00% |
| Riverside | 40 | 241 | 381 | 857 | 3 | 10% | 28% | 0% | 1% | 2% | 0.02% |
| Sacramento | 24 | 198 | 207 | 604 | 1 | 12% | 33% | 0% | 0% | 1% | 0.01% |
| San Benito | 7 | 12 | 55 | 87 | 0 | 13% | 14% | 0% | 0% | 0% | 0.00% |
| San Bernardino | 93 | 409 | 109 | 930 | 3 | 85% | 44% | 0% | 1% | 3% | 0.02% |
| San Diego | 8 | 15 | 215 | 285 | 0 | 4% | 5% | 0% | 0% | 0% | 0.00% |
| San Francisco | 2 | 3 | 1 | 3 | 2 | 100% | 100% | 67% | 0% | 0% | 0.01% |
| San Joaquin | 24 | 65 | 362 | 587 | 1 | 7% | 11% | 0% | 0% | 0% | 0.01% |
| San Luis Obispo | 15 | 57 | 200 | 330 | 3 | 8% | 17% | 1% | 0% | 0% | 0.02% |
| San Mateo | 3 | 10 | 33 | 82 | 0 | 9% | 12% | 0% | 0% | 0% | 0.00% |
| Santa Barbara | 16 | 66 | 126 | 237 | 0 | 13% | 28% | 0% | 0% | 0% | 0.00% |
| Santa Clara | 18 | 109 | 120 | 350 | 0 | 15% | 31% | 0% | 0% | 1% | 0.00% |
| Santa Cruz | 7 | 30 | 78 | 224 | 0 | 9% | 13% | 0% | 0% | 0% | 0.00% |
| Shasta | 0 | 0 | 209 | 289 | 0 | 0% | 0% | 0% | 0% | 0% | 0.00% |
| Sierra | 0 | 0 | 37 | 43 | 0 | 0% | 0% | 0% | 0% | 0% | 0.00% |
| Siskiyou | 1 | 0 | 85 | 122 | 0 | 1% | 0% | 0% | 0% | 0% | 0.00% |
| Solano | 6 | 10 | 64 | 93 | 0 | 9% | 11% | 0% | 0% | 0% | 0.00% |
| Sonoma | 25 | 44 | 367 | 518 | 1 | 7% | 8% | 0% | 0% | 0% | 0.01% |
| Stanislaus | 12 | 87 | 230 | 476 | 0 | 5% | 18% | 0% | 0% | 1% | 0.00% |
| Sutter | 1 | 1 | 63 | 87 | 0 | 2% | 1% | 0% | 0% | 0% | 0.00% |
| Tehama | 1 | 1 | 112 | 157 | 0 | 1% | 1% | 0% | 0% | 0% | 0.00% |
| Trinity | 0 | 0 | 46 | 59 | 0 | 0% | 0% | 0% | 0% | 0% | 0.00% |
| Tulare | 17 | 56 | 342 | 625 | 0 | 5% | 9% | 0% | 0% | 0% | 0.00% |
| Tuolumne | 3 | 5 | 108 | 185 | 0 | 3% | 3% | 0% | 0% | 0% | 0.00% |
| Ventura | 28 | 62 | 88 | 192 | 1 | 32% | 32% | 1% | 0% | 0% | 0.01% |
| Yolo | 3 | 3 | 94 | 157 | 0 | 3% | 2% | 0% | 0% | 0% | 0.00% |
| Yuba | 42 | 42 | 99 | 144 | 1 | 42% | 29% | 1% | 1% | 0% | 0.01% |
| TOTALS | 725 | 2,988 | 7,252 | 13,920 | 35 | | | | 10% | 21% | 0.25% |

**Table G4. Public Water System Inventory using DHS March 1998 data.**

# APPENDIX H: MODELING OF BENZENE AND MTBE PLUME GROWTH

Growth of benzene and MTBE plumes in space and time was modeled as a function of groundwater velocity, dispersion, sorption, and biodegradation (first-order decay) using the model of Domenico and Robbins (1985):

$$C(x,y,z,t) = C_0\left(\frac{1}{8}\right)\exp\left(\frac{x}{2\alpha_x}\right)\left[1-\left(1+\frac{4\lambda\alpha_x}{v}\right)^{1/2}\right]\operatorname{erfc}\left[\frac{x-vt\left(1+4\lambda\alpha_x/v\right)^{1/2}}{2\left(\alpha_x vt\right)^{1/2}}\right]$$
$$\left\{\operatorname{erf}\left[\frac{y+Y/2}{2\left(\alpha_y x\right)^{1/2}}\right]-\operatorname{erf}\left[\frac{y-Y/2}{2\left(\alpha_y x\right)^{1/2}}\right]\right\}\left\{\operatorname{erf}\left[\frac{z+Z}{2\left(\alpha_z x\right)^{1/2}}\right]-\operatorname{erf}\left[\frac{z-Z}{2\left(\alpha_z x\right)^{1/2}}\right]\right\}$$

with variables defined as follows,

*C*, solute concentration [M/L3]
$C_0$, solute concentration at source (constant in time) [M/L3]
x, y, z, spatial coordinates [L]
t, time [T]
v, average linear velocity (seepage velocity), constant in the x direction [L/T]
$\alpha_x$, $\alpha_y$, $\alpha_z$, dispersivity in *x*, *y*, and *z* directions [L]
$\lambda$, decay constant [$T^{-1}$]
*Y*, *Z*, dimensions of source area in plane perpendicular to ***v*** [L]

Linear sorption of benzene is modeled by dividing *v* by the retardation coefficient *R*,

$$R = 1+\left(\frac{1-n}{n}\right)\rho_s K_d$$

where *n* is porosity, $\rho_s$ is density of the solids, and $K_d$ is the distribution coefficient representing partitioning of benzene between the liquid and solids. $K_d$ is calculated from

$$K_d = K_{oc} f_{oc}$$

where $K_{oc}$ is the octanol-water partition coefficient for benzene and $f_{0c}$ is the weight fraction of organic carbon.

In the calculations based on this model, only *y*, $\rho_s$, $K_{oc}$, and *Z* are treated as constants (0, 2.65 g/cm$^3$, 80 cm$^3$/g [Montgomery and Welkom, 1990], and 1 m, respectively), whereas the other variables are represented with statistical probability densities in a stochastic Monte-Carlo-simulation procedure, with the exception of the distance along the longitudinal axis of the plume, *x*, which is varied deterministically. In this fashion, a full range of possible combinations of site conditions, representing mainly alluvial aquifers of California, is considered.

Transverse dispersivities $\alpha_y$ and $\alpha_z$ were set to $0.1\alpha_x$ and $0.01\alpha_x$. MTBE is modeled as a conservative solute, with no sorption ($K_{oc} = 0$) or biodegradation ($\lambda = 0$).

Stochastic simulation of plume evolution was accomplished with Microsoft® Excel and the program @RISK (Palisade Corporation, 1997). @RISK allows one to set up a spreadsheet calculation in which variables that are uncertain can be represented as statistical distributions. The program then repeatedly samples at random from each distribution, recalculates the spreadsheet, and compiles the results until convergence is achieved. In the simulations done here, convergence was declared when changes in the mean, standard deviation, and percentiles for *C* changed less than 2.5 percent among consecutive steps of 100 iterations each. Convergence was typically achieved in 5,000 to 8,000 iterations through the use of the Latin Hypercube sampling option. Some variables were assumed to be correlated, as described in Tables H1, H2, H3, and H4.

The model was calibrated by comparing simulated benzene plume lengths to Statewide estimated benzene plume lengths for 1995-96 published in Happel et al. (1998) and adjusting model parameters by small amounts until a reasonable fit was achieved. Final model input parameters for this simulation are shown in Table H1 along with explanations. The benzene plume length results are shown in Figure 9. Then, the sorption and biodegradation terms were inactivated, and the model was rerun to simulate MTBE plume lengths for 1995-96 (Fig. 10). After moderate calibration of probability densities for $C_0$ and *t* (Table H2), the model produced a reasonable match with the statistical distribution of 1995-96 MTBE plume lengths developed by Happel et al. (1998). To assess longer-term impacts of MTBE, the probability density for *t* was set to the same used in the benzene 1995-96 run (representing a more fully evolved condition of leaking tanks and plume development; Table H3), to yield plume length estimates for circa 2010 (Fig. 11). Lastly, the *t* probability density in Table H3 was increased uniformly by 10 yr (Table H4) to assess potential impacts out to approximately 2020.

**Table H1. Probability densities used in modeling benzene plumes to 1995-96.**

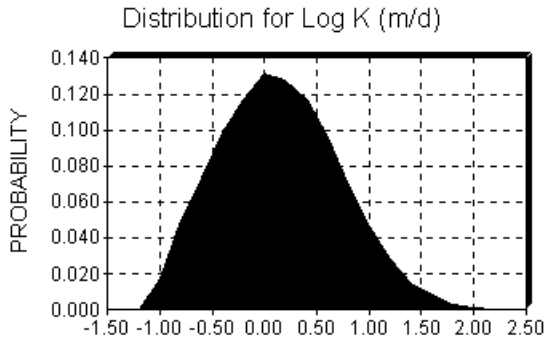
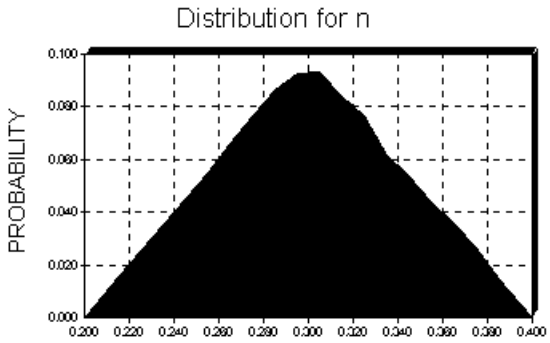
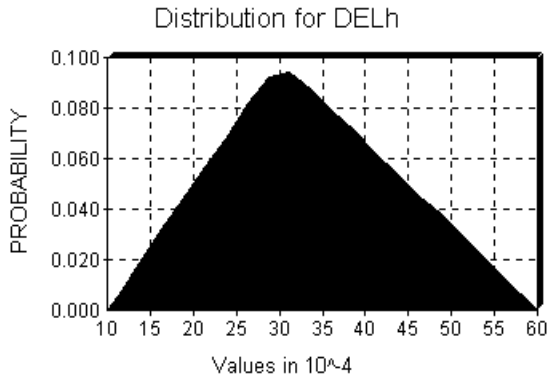
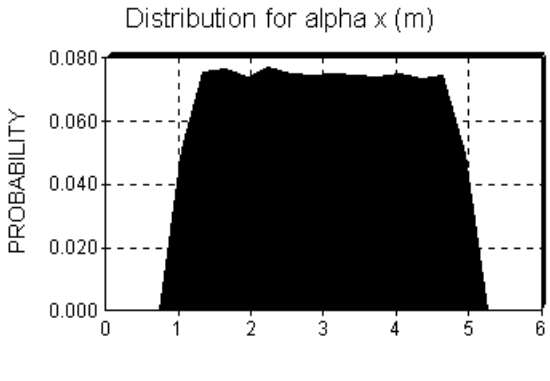
| | |
|---|---|
|  |  |
| **Variable:** Hydraulic conductivity, K (m / d); $LOG_{10}$ scale in plot.<br>**Distribution:** *Truncated Log normal (3.5, 9.5, 0.1, 100), (mean, std. dev., min., max)*<br>**Rationale:** Typical K values for aquifer materials (Domenico and Schwartz, 1998). Non-aquifer K values lower than 0.1 m / d are commonly found in the subsurface, but such sites are much less likely to impact groundwater, and would generally not have been included in data used to estimate plume length by Rice et al. (1995b) or Happel et al. (1998). | **Variable:** Porosity, n.<br>**Distribution:** *Triangular (0.2, 0.3, 0.4), (min., most likely, max.)*<br>**Rationale:** Typical range of porosity values for aquifer materials. Porosity = 0.3 is quite common in alluvial sediments (Domenico and Schwartz, 1998). |
|  |  |
| **Variable:** Hydraulic gradient, $\nabla h$.<br>**Distribution:** *Triangular (0.001, 0.003, 0.006), (min., most likely, max)*<br>**Correlation:** Dependent on K with rank-order correlation coefficient –0.9.<br>**Rationale:** Typical values for alluvial aquifer settings. Values on the order of $10^{-2}$ or more can occur beneath hilly terrain or near pumping wells, but are less likely to be maintained over significant distances in alluvial basins. Negative correlation with K assumed because lower K values tend to produce larger $\nabla h$'s | Variable: Dispersivity, $\alpha$ (m)<br>Distribution: Uniform (1, 5), (min., max.)<br>Rationale: Typical range of values for plumes on scales of 30 to 300 ft (9 to 91 m) (Gelhar et al., 1992). Larger "effective" values are possible for longer distances of transport, but depend greatly on the spatial patterns in K. |

**Table H1 Cont'd. Probability densities used in modeling benzene plumes to 1995-96.**

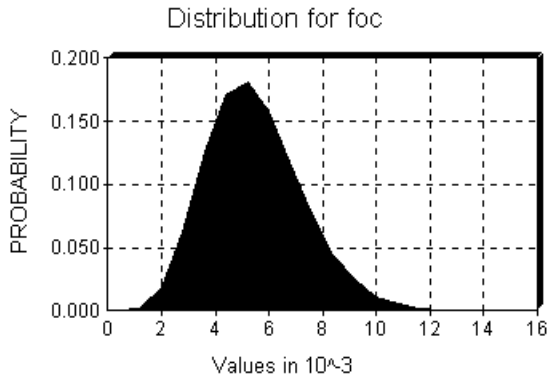
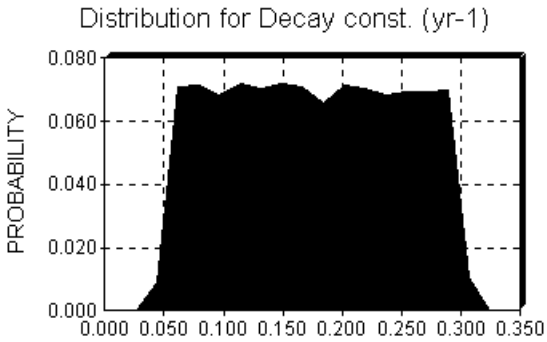
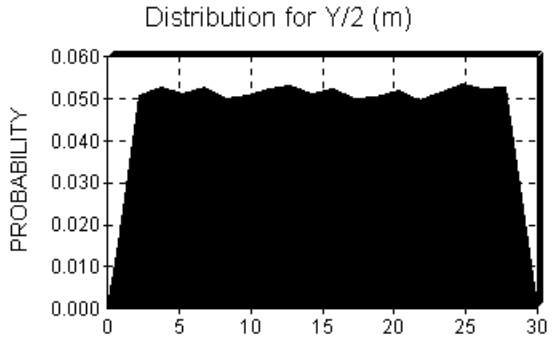
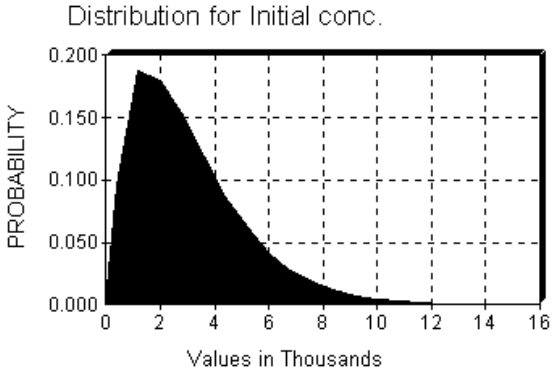
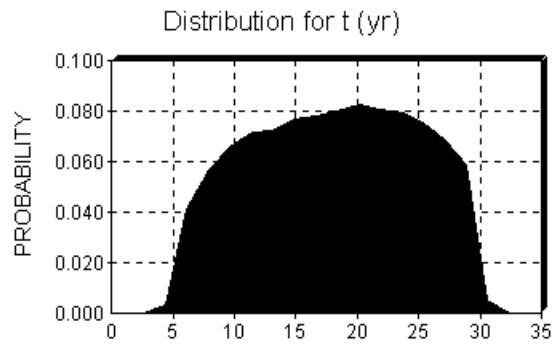
| | |
|---|---|
|  |  |
| **Variable:** Fraction (weight) of organic carbon, $f_{0c}$<br>**Distribution:** *Modified Beta (0.0002, 0.005, 0.0055, 0.03), (min., most likely, mean, max.)*<br>**Rationale:** Range of values consistent with non-glaciofluvial sediments containing significant fines (Domenico and Schwartz, 1998, Table 12.7). Such sediments typify the shallow subsurface in alluvial basins of California. | **Variable:** Decay constant, $\lambda$ ($yr^{-1}$)<br>**Distribution:** *Uniform (0.05, 0.3), (max., min.)*<br>**Rationale:** Range of values from Hemond and Fechner (1994) and Stauffer et al. (1994). Higher values have been measured in biologically active soils, but CA groundwater typically resides in less-biologically active geologic sediments. Further, this first-order decay constant applies over the entire simulated plume, representing an average of both lower and higher rates that will tend to occur in certain portions of the plume. |
|  |  |
| **Variable:** 1/2 the width of the source area, perpendicular to the velocity (m).<br>**Distribution:** *Uniform (1, 30), (min., max.)*<br>**Rationale:** Range of values assumed based on experience regarding lateral extent of free product floating on water table at LUFT sites. | **Variable:** Concentration at source, $C_0$ ($\mu g\ L^{-1}$)<br>**Distribution:** *Modified Beta (100, 1500, 3000, 30000), (min., most likely, mean, max.)*<br>**Correlation:** Dependent on K with rank-order correlation coefficient –0.9.<br>**Rationale:** Typical maximum benzene concentrations found at LUFT sites are 1000 to 3000 $\mu g\ L^{-1}$ (Rice et al., 1995b). Higher values in the "tail" are assumed based on LUFT site observations (K. Williams, personal comm., 1998). Correlates negatively with K because higher K tends to produce higher rates of recharge and hence lower concentrations. |

**Table H1 Cont'd. Probability densities used in modeling benzene plumes to 1995-96.**




**Variable:** Total time of plume migration, t (yr).
**Distribution:** *Modified Beta (5, 20, 18, 30), (min., most likely, mean, max.)*
**Correlation:** Dependent on K with rank-order correlation coefficient –0.5.
**Rationale:** Range of times since the tanks leaked and product reached the water table. Plumes migrating less than 5 yr are less likely to have been discovered in that time frame. Plumes migrating on the order of 30 years are assumed to be more likely to be discovered and contained through remedial action, hence limiting further migration; or, some 30-yr plumes might not move far because of low K or $\nabla h$ values. Some negative correlation with K assumed because plumes in high-K settings are more likely to be discovered and their spread limited by remedial action.

**Table H2. Probability densities used in modeling MTBE plumes to 1995-96.**

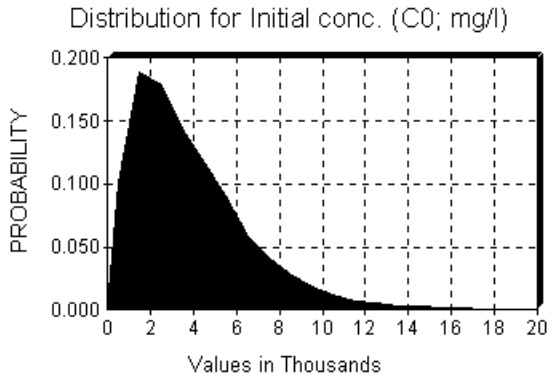
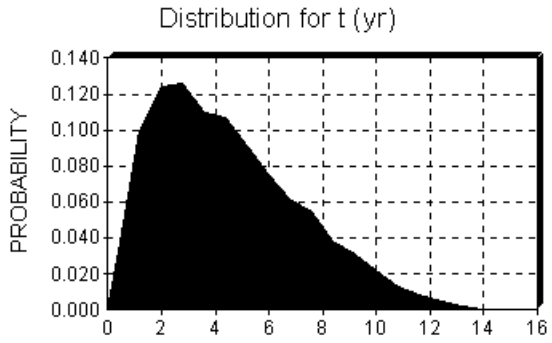
| | |
|---|---|
|  |  |
| **Variable:** Concentration at source, $C_0$ ($\mu g \cdot L^{-1}$)<br>**Distribution:** *Modified Beta (100,1800,3800,150000), (min., most likely, mean, max.)*<br>**Correlation:** Dependent on K with rank-order correlation coefficient –0.9.<br>**Rationale:** Based approximately on range of measured maximum MTBE concentrations at LUFT sites in Happel et al. (1998). Correlates negatively with K because higher K tends to produce higher rates of recharge and hence lower concentrations. | **Variable:** Total time of plume migration, t (yr).<br>**Distribution:** *Modified Beta (0.3,2.5,4.5,16), (min., most likely, mean, max.)*<br>**Correlation:** Dependent on K with rank-order correlation coefficient –0.5.<br>**Rationale:** Range of times since the tanks leaked and product containing MTBE reached the water table. Based on general history of MTBE usage in CA since 1979 – 16 years prior to 1995-96. Assumes most of the cases of acute MTBE contamination have developed within the last few years. |

**Table H3. Probability densities used in modeling MTBE plumes to 2010.**

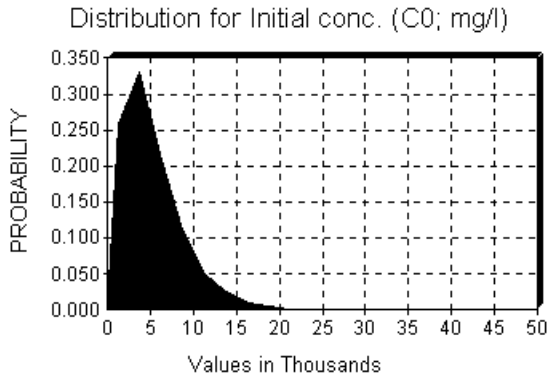
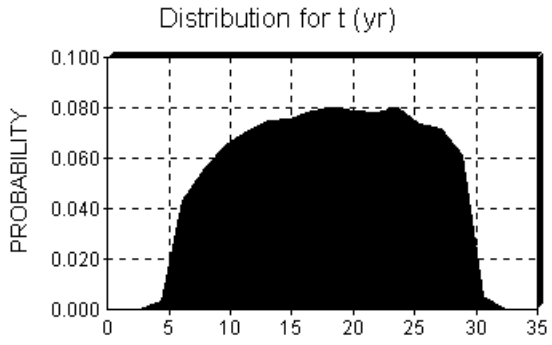
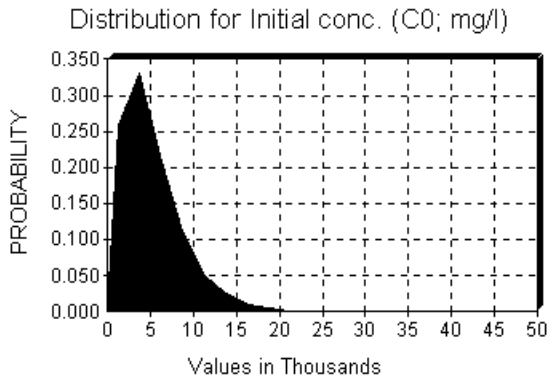
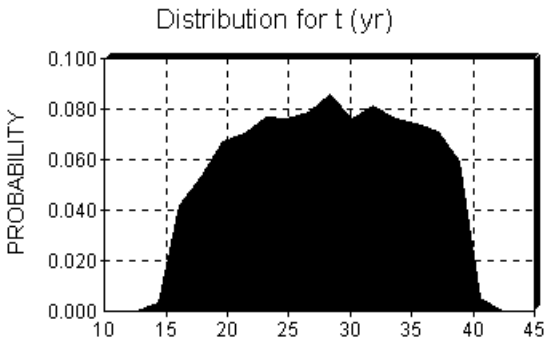
| | |
|---|---|
|  |  |
| **Variable:** Concentration at source, $C_0$ ($\mu g \cdot L^{-1}$)<br>**Distribution:** *Modified Beta (100,2500,5000,500000), (min., most likely, mean, max.)*<br>**Correlation:** Dependent on K with rank-order correlation coefficient –0.9.<br>**Rationale:** Based approximately on range of measured maximum MTBE concentrations compiled in this study. These concentrations are higher than used in the simulation of 1995-96 MTBE plumes because we anticipate that MTBE concentrations are still rising beneath LUFT site tanks. Correlates negatively with K because higher K tends to produce higher rates of recharge and hence lower concentrations. Actual probability of having concentrations above 20000 $\mu g \cdot L^{-1}$ may be much greater than indicated by this distribution. | **Variable:** Total time of plume migration, t (yr).<br>**Distribution:** *Modified Beta (5,20,18,30), (min., most likely, mean, max.)*<br>**Correlation:** Dependent on K with rank-order correlation coefficient –0.5.<br>**Rationale:** Range of times since the tanks leaked and product containing MTBE reached the water table. Same distribution used to simulate the 1995-96 benzene plumes. Thus, this simulation represents the potential MTBE plume lengths if the MTBE plumes progress as long in time as the benzene plumes apparently have. |

**Table H4. Probability densities used in modeling MTBE plumes to 2020.**

| | |
|---|---|
|  |  |
| **Variable:** Concentration at source, $C_0$ ($\mu g \cdot L^{-1}$)<br>**Distribution:** *Modified Beta (100,2500,5000,500000), (min., most likely, mean, max.)*<br>**Correlation:** Dependent on K with rank-order correlation coefficient –0.9.<br>**Rationale:** Same as MTBE 2010 run. | **Variable:** Total time of plume migration, t (yr).<br>**Distribution:** *Modified Beta (15,30,28,40), (min., most likely, mean, max.)*<br>**Correlation:** Dependent on K with rank-order correlation coefficient –0.5.<br>**Rationale:** Range of times since the tanks leaked and product containing MTBE reached the water table. Same as the MTBE 2010 run, except 10 yr added to all times. |