Occurrence of Methyl Tertiary-Butyl Ether (MTBE) in Groundwater at Leaking Underground Storage Tank Sites in Washington

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EXECUTIVE SUMMARY

Methyl tertiary-butyl ether (MTBE) is a volatile oxygen-containing organic compound which is added to gasoline to promote a more complete combustion, thereby reducing air pollution and enhancing octane rating. Widespread use of this chemical has resulted in frequent detection of MTBE in groundwater throughout the United States; in some cases, it has forced production wells to shut down. The majority of these contaminations comes from leaking underground storage tanks and spills of gasoline during refining and distribution. Unlike the BTEX components of gasoline, MTBE is difficult to biodegrade, readily dissolves in water, and can move rapidly through soil and groundwater.

The United States Environmental Protection Agency (USEPA) currently considers MTBE as a possible human carcinogen, and has issued a 'Drinking Water Advisory' of 20-40 parts per billion (ppb), primarily based on aesthetic considerations. There is still no national health-based drinking water standard. Most states, including the District of Columbia, now have groundwater cleanup or action levels. Washington has proposed a cleanup level of 20 ppb for groundwater, but information on the occurrence and distribution of MTBE in the state's groundwater is currently unavailable. The primary objective of this study is to assess the occurrence and concentrations of MTBE in Washington's groundwater, and to determine, based on the findings, whether the occurrence and concentrations are significant enough to warrant regulatory action to protect public health and the environment.

Seventy LUST sites were selected based on LUST site distribution within the state. One monitoring well was sampled from each of the selected sites and analyzed for MTBE, benzene, toluene, ethylbenzene, and xylenes. Eight of the 70 groundwater samples showed no detection of any petroleum hydrocarbon compound of interest. Of the 62 sites that showed contamination, 30 sites, or 48%, reported detectable levels of MTBE, while 26 sites, or 42%, had concentrations at or above a threshold limit of 1 μg/L. In addition, 24% reported MTBE concentrations above the proposed MTCA Method A cleanup level of 20 μg/L. The highest MTBE concentration reported was 7150 μg/L. The average concentration of all samples, which equaled or exceeded the threshold concentration of 1 μg/L, was 441 μg/L, with a median of 13 μg/L. Detection rates for the BTEX components were more frequent, occurring in 90%, 66%, 61%, and 68% for benzene, toluene, ethylbenzene and xylenes, respectively. Average concentrations were also higher, compared to that of MTBE at 1992 μg/L, 3943 μg/L, 657 μg/L, and 2251 μg/L for benzene, toluene, ethylbenzene and xylenes respectively. While a strong correlation was observed between benzene, toluene, ethylbenzene, and xylene concentrations (ρ = 0.83-0.97), benzene and MTBE concentrations showed no perceptible correlation (ρ = 0.26).

Analysis of conditional probabilities of detection among the chemicals indicates that toluene, ethylbenzene, and xylenes are highly associated with benzene. The probability of detecting benzene, given any of these compounds, is approximately 96%. The analysis also demonstrates that individual BTEX components are usually found together at the same site, with conditional probabilities ranging from 0.8 to 0.95. The conditional probability of detecting MTBE given benzene detection was 0.45; however, the conditional probability of detecting benzene given MTBE detection was 0.96. This implies that for almost all the sites where MTBE was detected, benzene was also present. In addition, benzene concentrations

exceeded those of MTBE at 15 of the 24 sites (63%) where benzene and MTBE co-occurred. This suggests that the most downgradient monitoring wells selected at each site for this study were generally at the tail end of the MTBE plume. Thus MTBE concentrations, especially those from older release sites reported in this study, might not represent the actual distribution of MTBE concentrations resulting from the LUST sites.

As of May 2000, Washington State has about 6000 regulated LUST sites. Among these sites, 1900, or 32%, are reported to have impacted groundwater. Given an MTBE occurrence rate of 42 % at sites where petroleum hydrocarbons have impacted shallow groundwater, there may potentially be over 800 point sources of MTBE resulting from known leaking underground storage tanks. This number may be significantly higher because: a) some of the sites reported as soil only impact may also have impacted groundwater; b) MTBE plumes may have migrated past the monitoring well networks at some of the older sites; c) existing MTBE plumes may have been missed since only one well per site was sampled for the study, and d) higher quantitation limits (50-1000 µg/L) for MTBE were used in analyzing 15% of the contaminated samples, and the resulting less-than values were counted as negative detections.

Based on the findings of this study, it is concluded that data collected was insufficient to ascertain the severity of potential MTBE impact to drinking water sources from these sites; nevertheless, it clearly shows that potential risk exist. Efforts should therefore be made to ensure that MTBE does not cause harm to public health or the environment.

Recommendations submitted for immediate consideration include the following: a) Testing for MTBE should be included in all LUST site investigations and monitoring activities, including tank closures. Possible exceptions may be given when, after initial assessment of both soil and groundwater, it is determined that MTBE is not present in the subsurface, b) Testing for MTBE should be performed using USEPA Method 8260B, to avoid false-positive reporting, with minimum detection levels of 15 µg/kg and 5 µg/L for soil and groundwater respectively, and c) Results must be submitted to Ecology in both hard copy form and electronically in a spreadsheet format, preferably excel.

It is also recommended that six months (2 quarters) after the implementation of the above, all MTBE data submitted to the Department of Ecology should be compiled and analyzed. The results may then be used to assess the severity of the problem and to determine any further regulatory actions.

INTRODUCTION

Methyl tertiary-butyl ether (MTBE) is a volatile oxygen-containing organic compound produced from methanol and isobutylene. MTBE was initially used in gasoline as a replacement for lead. Since late 1970s, it has been used as an octane enhancer in conventional gasoline[(1)]. Because it promotes a more complete combustion of gasoline, MTBE is used at higher concentrations, 10 to 15 percent by volume, as a fuel oxygenate to reduce levels of carbon monoxide and ozone in the air. In 1992, several Northeast and Mid-Atlantic states began using MTBE as fuel oxygenate to meet the requirements of The Clean Air Act Amendments of 1990[(2)]. Large-scale use of MTBE in the nation actually began in 1995 with the introduction of reformulated gasoline (RFG) which contains 11-15 percent MTBE by volume[(3)]. Ethanol (EtOH) is another commonly used oxygenate in RFG, but MTBE is favored because of its low cost and other favorable characteristics[(4)].

Widespread use of this chemical has resulted in frequent detection of MTBE in groundwater throughout the United States. In Santa Monica, California, MTBE contamination has forced seven drinking water wells, supplying 50% of the water for the city, to be removed from service[(5)]. The majority of these contaminations comes from leaking underground storage tanks (LUST) and spills of gasoline during refining and distribution. The nationwide concern over MTBE is based on its physical and chemical characteristics, which are unlike those of other gasoline constituents such as benzene, toluene, ethylbenzene and xylenes. Because of its relatively high mobility and high solubility, MTBE in gasoline readily dissolves in water, up to 6300 parts per million[(5)], and can move rapidly through soil and groundwater. Available kinetic information indicates that it is resistant to microbial decomposition and may be difficult to biodegrade[(6-10)].

Toxicity studies on rats and mice have reported carcinogenic effects from exposure to MTBE through inhalation and oral dosage[(11-15)]. Noncarcinogenic effects on both humans and animals from exposure to MTBE have also been reported[(16-20)].

Although USEPA has tentatively classified MTBE as a possible human carcinogen, there is still no national health-based drinking water standard. USEPA however, has issued a 'Drinking Water Advisory' concentration range of 20-40 parts per billion (ppb), primarily based on taste and odor considerations[(21)]. While 12 states are waiting on USEPA to set a Maximum Contaminant Level (MCL) for MTBE in drinking water, most states, including the District of Columbia, now have groundwater cleanup or action levels. Three states, including Washington, have projected to establish cleanup levels by the end of the year 2000.

Though the use of MTBE is not prohibited, the chemical has not been used as an oxygenate in Washington as extensively as it has been in other states. There is only one documented use of MTBE as a fuel oxygenate in Washington; however, it is likely that the chemical has been used in gasoline for other purposes in the state. In the King County area, MTBE levels above the lower limit of the USEPA's Drinking Water Advisory of 20 ppb were found in groundwater at some of the lust sites that the chemical was tested for in 1998. MTBE had also been identified at LUST sites in Vancouver (southwest region), Yakima (central region), and in the Spokane area (eastern region). In addition, low level MTBE contamination had been associated with a release from the Yellowstone Pipeline near Spokane. The Washington State Department of Ecology has proposed a cleanup level of 20 ppb for groundwater.

Nevertheless, information on the occurrence and distribution of MTBE in the state's groundwater is limited to the results of the United States Geological Survey (USGS) studies in the Puget Sound basin and Central Columbia Plateau, which show that most ambient shallow groundwater aquifers contain no MTBE[(22)]. Similar information at LUST sites, major point sources of MTBE contamination, is practically unavailable.

METHOD OF STUDY

Determination of Study Area

Study areas were selected primarily based on LUST density. These areas also tend to be the most populated areas of the state. Distribution of LUST sites by regions is shown in both Table 1 and Figure 1.

Table 1. Lust Site Distribution by Regions

Region	# of Lust Sites	%of Lust Sites	# of Lust Sites With Groundwater Impacted	% of Lust Sites With Groundwater Impacted
Central	564	9.6	171	9
Eastern	670	11.4	133	7
Northwest	3130	53.1	1044	55
Southwest	1534	26.0	545	29
TOTAL	**5898**	**100**	**1893**	**100**

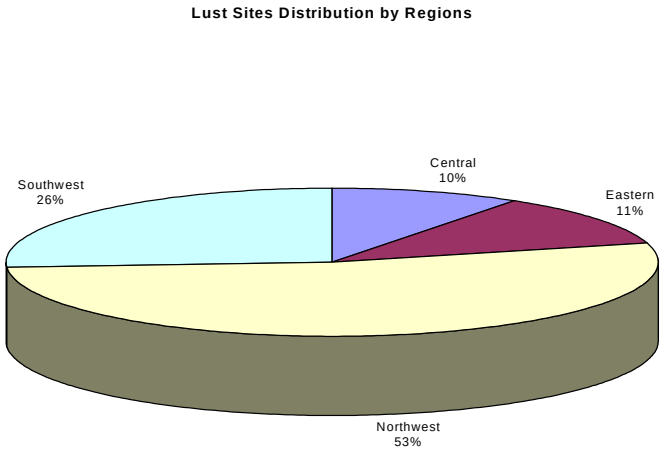
Sample Density Determination.

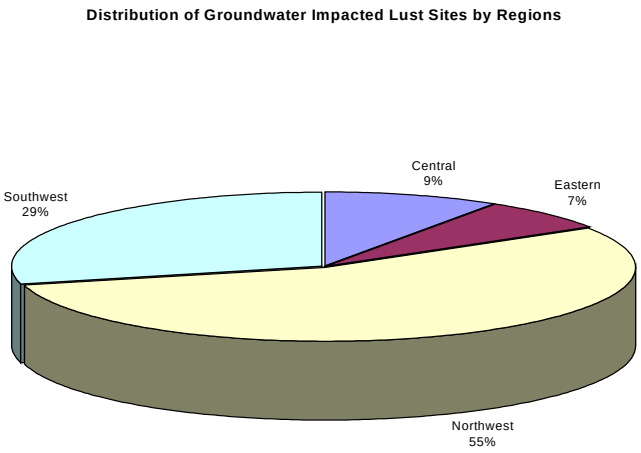
The number of samples per study area was determined based on the total number of LUST sites with groundwater contamination within the area. Sample densities for the selected areas are presented in Table 2.

Table 2. Sample Density Determination

Area	Sites/Area	% of Total Sites	Samples/Area
Seattle	320	49.5	20
Bellevue	55	8.5	8
Mill Creek/Bothell	15	2.3	1
Kirkland	30	4.6	4
Federal Way	17	2.6	4
Auburn	33	5.1	4
Port Orchard	11	1.7	2
Kent	27	4.2	6
Renton	12	1.9	4
Spokane Area	27	4.2	2
Whatcom County	50	7.7	7
Clark County	50	7.7	8
TOTALS	**647**	**100.0**	**70**

Figure 1. Distribution of Lust and Groundwater Impacted Lust Sites by Regions





The majority of study sites are located within the Seattle Metropolitan and King County urban areas. As expected, these urban areas also have the highest per county density of LUST sites**.**

Site and Well Selection Strategy

Sites within each study area were randomly selected from a pool of prior-screened sites. Two basic criteria were used to guide the site screening process: a) Groundwater must be impacted at the site, with data showing contamination, especially BTEX components, and b) There must be at least three existing monitoring wells so that local groundwater flow direction can be determined. Ecology LUST database and files were utilized in these efforts. Two to three times the number of required sites for each study area were selected in anticipation of possible denial of access by site owners. Following the review of selected site files, the most downgradient well at each site was selected.

Sampling Procedures

All groundwater samples were collected using low-flow (purging rate < 1 L /min) sampling techniques. In order to minimize cross-contamination, dedicated Teflon tubing was installed to the mid-point of the well-screen length for each well. All wells were slowly purged using a peristaltic pump until field parameters (i.e., pH, conductivity, and dissolved oxygen) had stabilized. Deeper monitoring wells were purged and sampled using disposable bailers and slow-emptying VOA dispensers.

Forty (40) ml VOA sample vials with Teflon-lined septum were used for this study. All sample vials were prepped with 0.1 ml 1:1 hydrochloric acid (HCl) as an acid preservative to prevent biodegradation. All sample vials were held at an angle during filling to minimize aeration of water. The sample vials were slightly overfilled to create an inverted meniscus at the top of the vial, capped, inverted, and tapped to check for air bubbles. All samples were immediately placed in coolers and chilled with ice to 4° C until submitted to the laboratory. Holding times were kept under 10 days.

As an added precaution, field personnel avoided self-refueling of cars on sampling days. A new pair of latex gloves was used with the collection of each sample. All sampling events were conducted between January and June, 2000.

Analytical Procedure

All groundwater samples were analyzed for BTEX and MTBE using USEPA Method 8260A. Detection limits were 1 µg/L for benzene, toluene, ethylbenzene and MTBE, and 2 µg/L for xylenes. Sample analysis was performed by the USEPA/Ecology Environmental Laboratory in Manchester, Washington.

Quality control samples included laboratory reagent blanks, trip blanks, and spike samples. As part of the quality assurance and control, five split samples were analyzed by Centrum Laboratory in California. Relative Percent Differences (RPD) were all less than 10.

RESULTS

Data Presentation

Complete analytical data for the study is presented in Table A-1 in Appendix A. Although petroleum hydrocarbon compounds have been detected in all the selected study sites in the past, eight sites had no detection for all the chemicals of concern during this sampling event. Simple statistical analysis of the data was therefore based on the sixty-two sites that showed, at least, one chemical of concern at or above its corresponding threshold limit. The revised data is presented in Table A-2. Threshold limits are 1 μg/L for benzene, toluene, ethylbenzene and MTBE, and 2 μg/L for xylenes.

It should be noted that in analyzing highly contaminated samples, higher quantitation limits were often used. In such cases, interfering compounds mask relatively lower MTBE concentrations. MTBE concentrations were consequently reported as less-than values. Contrary to the usual practice of assigning concentration values equal to one-half the reported detection limits for statistical analysis, less-than values were considered as negative detection in this study. Statistical determinations regarding MTBE are therefore conservative.

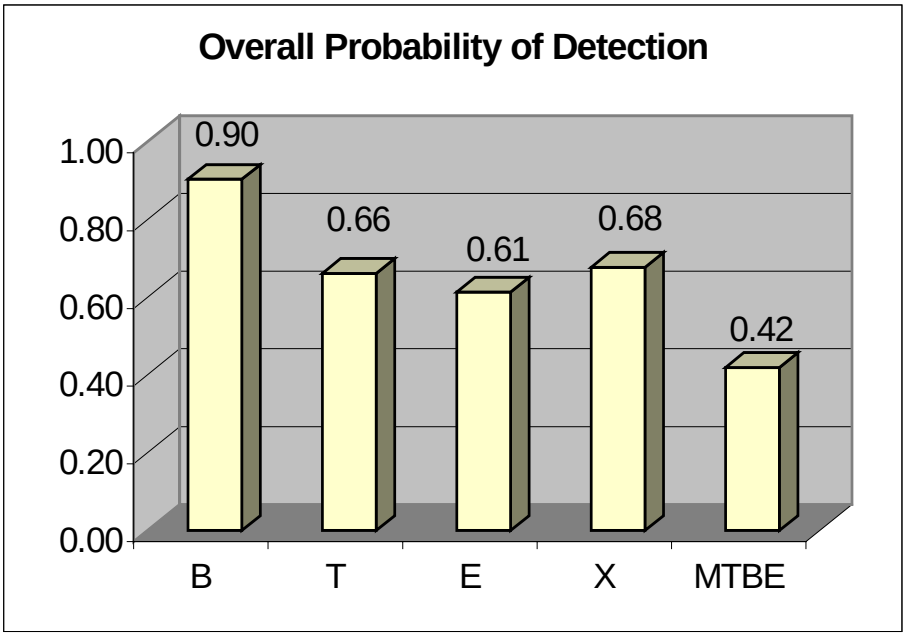
Results and Discussions

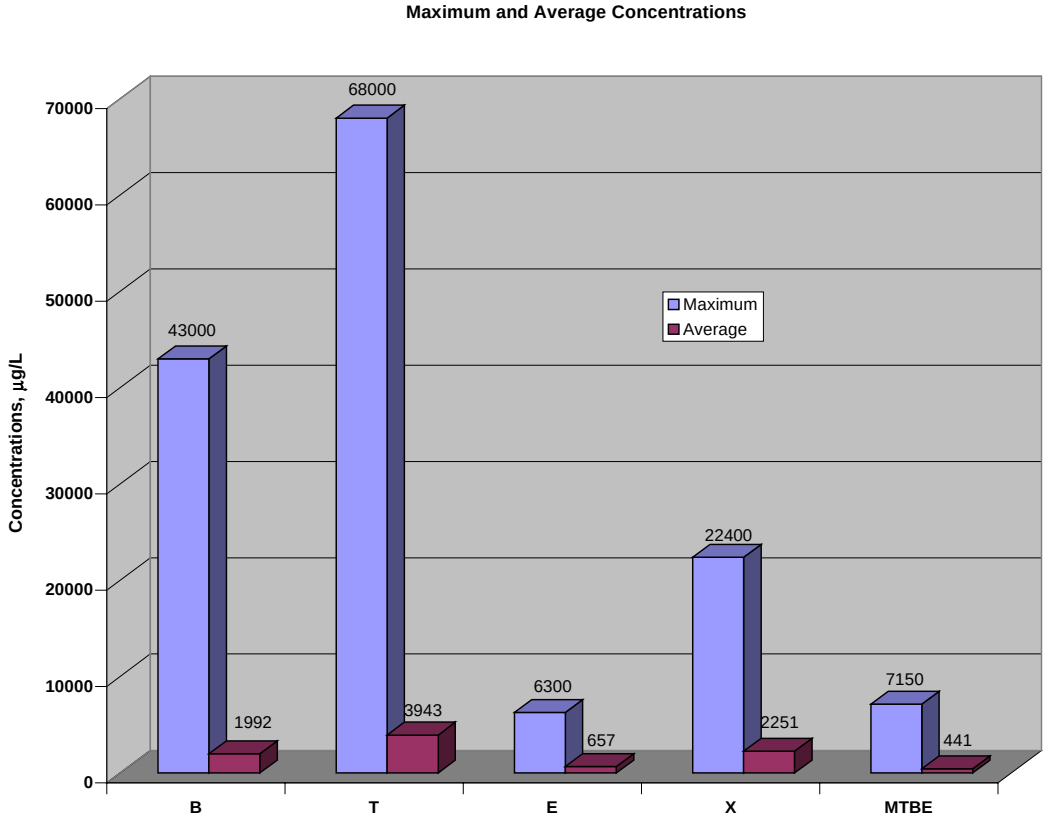
Monitoring wells from 70 LUST sites, the majority being from the Seattle/King County areas, were selected, sampled, and analyzed for BTEX and MTBE compounds. Of the 62 sites, that showed contamination, 30 sites, or 48%, reported detectable levels of MTBE, while 26 sites, or 42%, had concentrations at or above a threshold limit of 1 μg/L. In addition, 24% reported MTBE concentrations above the proposed MTCA Method A cleanup level of 20 μg/L. The highest MTBE concentration reported was 7150 μg/L. The average concentration of all samples, which equaled or exceeded the threshold concentration of 1 μg/L, was 441 μg/L, with a median of 13 μg/L.

Table 3. Statistical Summary of BTEX and MTBE Concentrations and Detections

	B	T	E	X	MTBE
Number of Detections(out of 62 contaminated Sites)	59	48	47	47	30
Threshold Concentrations, mg/L	1	1	1	2	1
Number of Detections >=Threshold Concentration	55	41	38	42	26
Average Concentrations, mg/L	1992	3,943	657	2,251	441
Maximum Concentrations, mg/L	43000	68,000	6,300	22,400	7,150
Median Concentrations, mg/L	151	18	86	87	13

Figure 2. Overall Probabilities of Detection Above Threshold Concentrations and Maximum and Average Concentrations for BTEX and MTBE





Detection rates for the BTEX components at or above threshold concentrations were more frequent, occurring in 90%, 66%, 61%, and 68% for benzene, toluene, ethylbenzene and xylenes, respectively *(Table 5)*. Average concentrations were higher, compared to that of MTBE, at 1992 µg/L, 3943 µg/L, 657 µg/L, and 2251 µg/L for benzene, toluene, ethylbenzene and xylenes, respectively.

Correlation between concentrations of MTBE and BTEX components was evaluated to assess the relationship between the occurrence and magnitude of the chemicals *(Table 5)*. While a strong correlation was observed between benzene, toluene, ethylbenzene, and xylenes (ρ = 0.83-0.97), benzene and MTBE concentrations showed essentially no perceptible correlation (ρ = 0.26).

Table 4. Threshold Concentrations and Overall Probabilities of Detection Above Threshold Concentrations of Benzene, Toluene, Ethylbenzene, Xylenes and MTBE (62 of 70 Sites showing contamination)

Compound	Threshold Concentration (µg/L)	Total Detections Above Threshold Concentration	Probability of Detection Above Threshold
Benzene	1	56	0.90
Toluene	1	41	0.66
Ethylbenzene	1	38	0.61
Xylenes	2	42	0.68
MTBE	1	26	0.42

These results demonstrate that while the presence of benzene may indicate the occurrence of toluene, ethylbenzene and xylenes, it is not predictive of the presence of MTBE at a given site.

Table 5. Concentration Correlation Coefficients Between Benzene, Toluene, Ethylbenzene, Xylenes, and MTBE

	Benzene	Toluene	Ethylbenzene	Xylenes	MTBE
Benzene	1.00				
Toluene	0.97	1.00			
Ethylbenzene	0.83	0.85	1.00		
Xylenes	0.88	0.90	0.89	1.00	
MTBE	0.26	-0.06	-0.10	0.12	1.00

In addition to evaluating correlation between concentrations, the nature of co-occurrence of benzene and MTBE at individual sites was assessed by examining conditional probabilities of detection above the stated threshold concentrations *(Table 6)*.

Table 6. **Conditional Probabilities of Detection: Probability of Detection of Row Analyte above Threshold Concentration given Detection of Column Analyte above Threshold Concentration**

	Benzene	Toluene	Ethylbenzene	Xylenes	MTBE
Benzene		0.98	0.97	0.95	0.96
Toluene	0.75		0.92	0.83	0.54
Ethylbenzene	0.65	0.80		0.83	0.42
Xylenes	0.73	0.85	0.95		0.54
MTBE	0.45	0.37	0.32	0.38	

This analysis indicates that toluene, ethylbenzene, and xylenes are highly associated with benzene, given their detection at the respective threshold concentrations. The probability of detecting benzene, given any of these compounds, is approximately 96%. The analysis also demonstrates that individual BTEX components are usually found together at the same site, with conditional probabilities ranging from 0.8 to 0.95. The most interesting findings are the conditional probabilities of benzene and MTBE in relation to the other. The conditional probability of detecting MTBE, given benzene detection at or above 1 μg/L, was 0.45. However, the conditional probability of detecting benzene, given MTBE detection at or above 1 μg/L, was 0.96. This implies that for almost all the sites where MTBE was detected, benzene was also present. In addition, benzene concentrations exceeded those of MTBE at 15 of the 24 sites (63%) where benzene and MTBE co-occurred. These results do not appear to support expected MTBE plume behavior. Given the high mobility, high solubility, and high recalcitrance of MTBE in relation to benzene, it is expected that MTBE plume, with relatively higher concentrations, may migrate farther from the point of release than benzene. This behavior has been demonstrated in Long Island[23] and at the Borden Aquifer Site[24]. The results, however, suggest that the most downgradient monitoring wells selected at each site for this study were generally at the tail end of the MTBE plume. This assessment is highly probable, considering the current monitoring well networks at LUST sites, which are not designed to characterize MTBE plumes, and the ages of the releases (80% were reported 5 years ago or longer). Thus MTBE concentrations, especially those from older release sites reported in this study, may not represent the actual distribution of MTBE concentrations resulting from releases at those sites.

As of May 2000, Washington State has about 6000 regulated LUST sites. Among these sites, 1900, or 32%, are reported to have impacted groundwater. Given an MTBE occurrence rate of 42 % at sites where petroleum hydrocarbons have impacted shallow groundwater, there may potentially be over 800 point sources of MTBE resulting from known leaking underground storage tanks. This number may be significantly higher because: a) some of the sites reported as soil-only impact may also have impacted groundwater; b) MTBE plumes may have migrated past the monitoring well networks at some of the older sites; c) existing MTBE plumes may have been missed since only one well per site was sampled for the study, and d) higher quantitation limits (50-1000 μg/L) for MTBE were used in analyzing 15% of the contaminated samples and the resulting less-than values were counted as negative detections.

MTBE concentrations reported in this study are relatively low compared to reported values in states like California[25], Iowa[26], and Idaho[27] where concentrations above 15,000 µg/L have been reported. When interpreting or comparing MTBE concentrations of groundwater at LUST sites, several factors need to be considered. Given the high solubility and high mobility of MTBE, and spatially limited monitoring well networks at LUST sites, date of release becomes the most important factor. Monitoring well networks at LUST sites are likely to adequately characterize MTBE plumes from a relatively new release. This is evident in the case of Site No. 61 and Site No. 62, where release reporting dates and MTBE concentrations are 1998; 5150 µg/L and 1999; 7150 µg/L, respectively. MTBE concentrations also exceed those of benzene in both cases. This trend was not generally observed in the data form the older sites. Furthermore, only one of five older sites, which have previously reported MTBE contamination in 1998, showed any detection during this study.

The generally low MTBE concentrations observed in this study may be due to the age of the releases at the selected sites (80% were reported between 1995 and 1989). These concentrations may represent MTBE concentrations at the tail end of plumes as suggested by the conditional probability analysis. They do not therefore necessarily minimize potential risks posed to drinking water sources from LUST sites.

CONCLUSIONS

MTBE was detected above a threshold concentration of 1 µg/L in groundwater at approximately 42% of LUST sites tested. Nearly 25% of these sites exceeded the proposed MTCA Method A cleanup standard of 20 µg/L. These percentages indicate that there may be potentially over 800 point sources of MTBE resulting from known LUST sites in the state. This number may be significantly higher because: a) some of the sites reported as soil-only impact may also have impacted groundwater; b) MTBE plumes may have migrated past the monitoring well networks at some of the older sites; c) existing MTBE plumes may have been missed since only one well per site was sampled for the study, and d) higher quantitation limits (50-1000 µg/L) for MTBE were used in analyzing 15% of the contaminated samples, and the resulting less-than values were counted as negative detections.

MTBE concentrations reported were generally low. The low concentrations, however, do not minimize the potential risk to drinking water sources. Given the limited size of most LUST sites, and the high solubility, mobility, and recalcitrance of MTBE, many MTBE plumes may completely migrate off-site without degradation, and may eventually attenuate through dilution with their masses remaining practically constant. MTBE masses from multiple plumes in high LUST density areas therefore, may cumulatively impact a major drinking water source. This means water sources in regions with high LUST density, like the Puget Sound area, are at the greatest risk. In addition, analysis of the data in relation to the presence and magnitude of benzene concentrations suggests the possibility of higher MTBE concentrations.

Data collected was insufficient to ascertain the severity of potential impact to drinking water sources from these sites. Nevertheless, it clearly shows that potential risks exist. Efforts should therefore be made to ensure that MTBE does not cause harm to public health or the environment.

Based on the findings of this study, the following recommendations are being submitted for immediate consideration:

- Testing for MTBE should be included in all LUST site investigations and monitoring activities, including tank closures. Possible exceptions may be given when, after initial assessment of both soil and groundwater, it is determined that MTBE is not present in the subsurface.

- Testing for MTBE should be performed using USEPA Method 8260B, to avoid false-positive reporting, with minimum detection levels of 15 µg/kg and 5 µg/L, for soil and groundwater, respectively.

- Results must be submitted to Ecology in both hard copy form and electronically (*spreadsheet format, preferably Excel*).

It is also recommended that six months (2 quarters) after implementation of the above, all MTBE data submitted to the Department of Ecology should be compiled and analyzed. The results may then be used to assess the severity of the problem and to determine any further regulatory actions.

References

(1) U.S. Environmental Protection Agency. *Use and Distribution of MTBE and Ethanol.* Office of Underground Storage Tanks: Washington DC, January 1998, EPA 510-F-97-016

(2) Clean Air Act Amendments of 1990, Title II, Part A, Section 211

(3) Wiggleswort, T. Chem. Ind. 10: 408, 1999

(4) Zogorski, J.S., et al. Fuel Oxygenates and Water Quality, Interagency Assessment of Oxygenated Fuels. Washington D.C., Office of Science Technology Policy, Executive Office of the President. 20, 1997

(5) Johnson, R., et al. *MTBE: To What Extent Will Past Releases Contaminate Community Water Supply Wells?* Environ. Sci. & Techn. News. 3A-9A, May 1, 2000

(6) Fujiwara, T.; Kinoshita, T.; et al. 1984. *Biodegradation and bioconcentration of Alkylethers*. Yukagaku 33*:* 111-114

(7) Jensen, H.M. and E Arvin. Contaminated Soils '90. F. Arndt, M. Hinsenveld and W, I. van den Brink, Eds; Kluwer Academic Publishers: Dordrecht, The Netherlands, 445- 448, 1990

(8) Mormile, M.R., S. Liu, and J.M. Sulflita. *Anaerobic biodegradation of gasoline oxygenates: extrapolation of information to multiple sites and redox conditions*. Environ. Sci. Tech., 28:1727-1732, 1994

(9) Suflita, J.M. and M.K. Mormile. *Anaerobic biodegradation of known and potential gasoline oxygenates in the terrestrial subsurface*. Environ. Sci. Tech. 27: 976-978, 1993

(10) Yeh, C.K. and J.T. Novak. *Anaerobic Biodegradation of Gasoline Oxygenates in Soils.* Water Environmental Research 66(5): 744-752, 1994

(11) Belpoggi, F., Softriff, M., Maltoni, C. *Methyl tertiary-Butyl Ether (MtBE) - a Gasoline Additive - Muses Testicular and Lymphohaematopoietic Cancers in Rats.* Toxicol. Ind. Health. 11(2): 119-149. 1995

(12) Belpoggi, F., Softriff, M., Filippini, F., Maltoni, C., 1997. *Results of Long-term Experimental Studies on the Carcinogenicity of Methyl tertiary-Butyl Ether.* Annals NY Acad. Sci. 837:77-95

(13) Belpoggi, F., Soffriti, M., Maltoni, C. *Pathological Characterization of Testicular Tumors and Lymphomas-Leukaemias, and of Their Precursors Observed in Sprague-Dawley Rats Exposed to Methyl tertiary-Butyl Ether (MTBE).* Eur. J. Oncol. 3(3):201-206. 1998

(14) Bird, M.G., Burleigh-Flayer, H.D., Chun, J.S., Douglas, J.F., Kneiss, J.J., Andrews,. L.S., 1997

(15) Chun, J.S., Burleigh-Flayer, H.D., Kintigh, W.J. *Methyl tertiary-butyl ether: vapor inhalation oncogenicity study in Fisher 344 rats.* Bushy Run Research Center Report No. 91N0013B. November 13. Union Carbide Chemicals and Plastics Company, Inc., submitted to the U.S. EPA under TSA Section 4 Testing Consent Order 40 CFR 799.5000 with cover letter dated November 19, 1992. EPA/OPTS#442098. Export, PA: Bushy Run Research Center

(16) Tyl, R.W., Neeper-Bradley, T.L. *Developmental toxicity study on inhaled Methyl tertiary-butyl ether (MTBE) in CD-1 mice*. Final Report. July 20. Bushy Run Research Center Report No. 51-266. Submitted to the U.S. EPA with cover letter dated July 26, 1989. TSCATS/403186. EPA/OTS/M0-8913432. No. FYI-OTS-0889-0689. Export, PA: Bushy Run Research Center

(17) Moser, G.J., Wolf, D.C., Sar, M., Gaido, K.W., Janszen, D., Goldsworthy, T.L., *Methyl tertiary-Butyl Ether-Induced Endocrine Alterations in Mice Are Not Mediated Through The Estrogen Receptor*. Toxicol. Sci. 41(1): 77-87. 1998

(18) Daughtrey, W.C., Gill, M.W., Pritts, I.M., Douglas, J.F., Kneiss, J.l., Andrews, L.S. *Nenrotoxicological Evaluation of Methyl tertiary-Butyl Ether in Rats*. J. Appl. Toxicol. 17(S1) S57-S64. 1997

(19) Bevan, C., Tyl, R.W., Neeper-Bradley, T.L, Fischer, L.C., pansen, R.D., Douglas, J.F., Andrews, L.S.,. *Developmental Toxicity Evaluation of Methyl tertiary-Butyl Ether (MTBE) by Inhalation in Mice and Rabbits*. J. Appl. Toxicol. 17(S1): S21-S29. 1997b

(20) Begley, Ronald, and Rotman, David. Health Complaints Fuel Federal Concerns Over MTBE. Chemical Week. (152) 10, 7. 1993

(21) U.S. Environmental Protection Agency. *Drinking Water Advisory- Consumer Acceptability Advice and Health Effects Analysis on Methyl Tertiary-Butyl Ether*. Washington, D.C., Office of Water, EPA-822-F-97-009. 1997

(22) Ebbert, Jim., Chief Puget Sound Basin NAWQA, USGS, Personal Communication, 2000

(23) Weaver, J.W., Haas, J.E., Sosik, C.B. *Characteristics of Gasoline Releases in the Water Table Aquifer of Long Island*. Presented at the National Ground Water Association/American Petroleum Institute conference, 1999 Petroleum Hydrocarbons Conference and Exposition, Nov.17-19, Houston, Texas

(24) Hubbard, C.E.; Barker, J.F.; O'Hannesin, S.F.; Vandegriendt, M.; and R.W. Gillham. *Transport and Fate of Dissolved Methanol Methyl-Tertiary-Butyl-Ether, and Monoaromatic Hydrocarbons in a Shallow Sand Aquifer.* AP1 Publication Number 4601; American Petroleum Institute, Health and Environmental Science Department: Washington, D.C., 1994

(25) Happel, A.M., Bechenbach, E.H, and R.U. Halden. *An Evaluation of MTBE Impacts to California Groundwater Resources*. Report submitted to the California State Water Resources Control Board, 43-63, June 11, 1998

(26) Iowa Department of Natural Resources, Underground Storage Tank Section. *Methyl tertiary-Butyl Ether (MTBE) Occurrence in Iowa*. A Report for the 2000 Session of the Seventy-Eighth General Assembly. February 2000

(27) Idaho Division of Environmental Quality, Watershed and Aquifer protection Bureau. *An Evaluation of Methyl Tert-Butyl Ether (MTBE) in Groundwater at Leaking Underground Storage Tank Sites*. Groundwater Quality Report, February, 1999

APPENDIX A.

Table A-1. MTBE and BTEX Groundwater Concentrations for all Sampled Sites by Cities.

Site No.	Latitude Degrees	Longitude Degrees	City	Site ID	B ug/l	T ug/l	E ug/l	X ug/l	MTBE ug/l	Release Report Date
1	47 36' 36" N	122 12' 23" W	Bellevue	5100	**5720**	**13,900**	**2,350**	**10,200**	**<500**	02/15/91
2	47 35' 43" N	122 11' 51" W	Bellevue	5258	**7530**	**18,400**	**3,330**	**16,200**	**<1000**	05/03/93
3	47 37' 2" N	122 10' 52" W	Bellevue	100678	**26500**	**40,400**	**3,620**	**16,200**	**<1000**	06/07/90
4	47 37' 3" N	122 12' 14" W	Bellevue	9557	**1560**	**1,330**	**314**	**1,080**	**8**	11/22/89
5	47 37' 51" N	122 9' 13" W	Bellevue	8679	**409**	**29**	**145**	**215**	**0.45**	11/30/94
6	47 37' 2" N	122 11" 5" W	Bellevue	8739	**2**	**0.25**	**0.95**	**3.7**	**16**	08/09/89
7	47 36' 30" N	122 8' 35" W	Bellevue	9561	**194**	**2**	**3**	**0.2**	**0.14**	11/09/90
8	47 36' 4" N	122 13' 36" W	Bellevue	9560	**59**	**8**	**130**	**205**	**<5**	08/07/89
1	47 42' 31" N	122 10' 38" W	Kirkland	6895	**44**	**2**	**<5**	**<10**	**3.3**	08/17/90
2	47 42' 13" N	122 10' 36" W	Kirkland	9556	**43**	**6**	**407**	**72**	**0.6**	12/23/91
3	47 42' 14" N	122 12' 37" W	Kirkland	10144	**34**	**26**	**374**	**1540**	**<10**	01/13/93
4	47 40' 45" N	122 10' 52" W	Kirkland	10142	**358**	**1.6**	**44**	**115**	**<1**	01/15/93
1	47 18' 1" N	122 13' 21" W	Auburn	6900	**<1**	**<1**	**<1**	**<2**	**<1**	04/20/90
2	47 23' 16" N	122 13' 50" W	Kent	10145	**4,530**	**3,540**	**984**	**3,690**	**<1000**	04/20/94
3	47 19' 14" N	122 17' 8" W	Auburn	9510	**2.9**	**2.8**	**2.3**	**13**	**<1**	04/05/91
4	47 20' 35" N	122 13' 19" W	Auburn	6888	**692**	**<50**	**<50**	**<100**	**126**	10/10/95
5	47 19' 35" N	122 13' 16" W	Auburn	97606	**330**	**669**	**1850**	**5950**	**<100**	12/04/90
1	47 32' 2" N	122 34' 39" W	Port Orchard	10883	**34**	**57**	**32**	**51**	**<1**	01/31/89
2	47 31' 52" N	122 40' 8" W	Port Orchard	4012	**0.5**	**0.5**	**0.5**	**1**	**0.5**	01/29/98
1	48 43' 53" N	122 28' 26" W	Bellingham	8394	**<1**	**<1**	**<1**	**<1**	**<1**	08/19/98
2	48 44' 41" N	122 27' 51" W	Bellingham	10850	**<1**	**<1**	**<1**	**<2**	**<1**	09/03/97
3	48 57' 48" N	122 43' 47" W	Blaine	435	**<1**	**<1**	**<1**	**<2**	**<1**	06/07/91
4	48 59' 53" N	122 44' 16" W	Blaine	8472	**200**	**16**	**<50**	**<50**	**455**	06/21/90
5	48 53' 31" N	122 29' 8" W	Linden	1447	**3.2**	**38**	**243**	**639**	**1**	01/25/90
6	48 50' 37" N	122 17' 17" W	Everson	9910	**7**	**1.2**	**0.4**	**2.3**	**<1**	01/05/95
7	48 59' 13" N	123 4' 2" W	Point Robert	100646	**1260**	**1380**	**324**	**1950**	**105**	03/29/94
1	47 37' 6" N	122 21' 12" W	Seattle	8421	**1.3**	**0.55**	**0.35**	**0.85**	**37**	06/21/89
2	47 31' 12" N	122 15' 49" W	Seattle	8701	**13**	**<1**	**<1**	**<2**	**<1**	06/26/89
3	47 40' 51" N	122 15' 48" W	Seattle	8668	**265**	**1.4**	**4.4**	**2.8**	**<1**	07/24/95
4	47 40' 23" N	122 23' 15" W	Seattle	8666	**1**	**<1**	**<1**	**<2**	**1**	12/01/95
5	47 32' 16" N	122 16' 54" W	Seattle	97593	**264**	**4.6**	**86**	**3.8**	**<1**	09/09/98
6	47 35' 1" N	122 19' 43" W	Seattle	8746	**6.7**	**<10**	**0.72**	**<20**	**364**	02/10/93
7	47 42' 18" N	122 20' 39" W	Seattle	8776	**<1**	**<1**	**<1**	**<2**	**<1**	06/08/89
8	47 42' 29" N	122 19' 2" W	Seattle	1498	**6.2**	**<5**	**<5**	**<10**	**128**	10/02/89
9	47 33' 45" N	122 22' 48" W	Seattle	10140	**503**	**31**	**164**	**42**	**<100**	01/13/93
10	47 39' 47" N	122 18' 50" w	Seattle	5046	**176**	**66**	**44**	**102**	**<5**	01/04/90
11	47 38' 19" N	122 18' 5" W	Seattle	403305	**0.17**	**<1**	**<1**	**0.22**	**<1**	01/21/97
12	47 31' 2" N	122 22' 10" W	Seattle	9516	**14**	**0.27**	**1.1**	**<2**	**<1**	10/04/91
13	47 42' 30" N	122 19' 53" W	Seattle	9563	**170**	**67**	**3860**	**1260**	**0.61**	10/07/91
14	47 29' 7" N	122 15' 20" W	Seattle	9554	**676**	**1740**	**310**	**1020**	**<10**	10/22/91
15	47 41' 23" N	122 20' 39" W	Seattle	9502	**<1**	**<1**	**<1**	**26**	**<1**	11/27/91
16	47 28' 16" N	122 20' 3" W	Seattle	9574	**550**	**1**	**0.94**	**2**	**<1**	04/13/92
17	47 32' 16" N	122 16' 54" W	Seattle	9524	**234**	**46**	**216**	**47**	**<100**	11/27/91

Table A-1. MTBE and BTEX Groundwater Concentrations for all Sampled Sites by Cities

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Site No.	Latitude Degrees	Longitude Degrees	City	Site ID	B ug/l	T Ug/l	E ug/l	X ug/l	MTBE ug/l	Release Report Date
18	47 37' 26" N	122 20' 17" W	Seattle	8463	**0.12**	**0.32**	**<1**	**<2**	**0.22**	05/01/80
19	47 34' 22" N	122 20' 1" W	Seattle	8459	**33**	**<5**	**<5**	**3.4**	**9.4**	09/12/90
20	47 45' 28" N	122 18' 32" W	Seattle	9577	**658**	**28**	**110**	**162**	**164**	08/18/89
1	47 30' 38" N	122 17' 35" W	Tukwila	101796	**85**	**<10**	**<10**	**<10**	**22**	03/28/91
2	47 28' 12" N	122 13' 14" W	Renton	5256	**9.5**	**<1**	**<1**	**<2**	**31**	04/05/91
3	47 28' 30" N	122 12' 54" W	Renton	6890	**185**	**1.2**	**0.57**	**4.5**	**4.6**	04/12/91
4	47 30' 13" N	122 9' 48" W	Renton	9546	**0.85**	**<1**	**2.2**	**4.2**	**3.4**	11/14/91
1	47 23' 12" N	122 9' 58" W	Kent	8696	**9.8**	**18**	**2.9**	**22**	**<1**	01/10/92
2	47 23' 17" N	122 14' 52" W	Kent	8693	**<1**	**1.2**	**0.1**	**0.6**	**<1**	06/28/96
3	47 22' 39" N	122 13' 51" W	Kent	8709	**10**	**0.9**	**8.3**	**12**	**<1**	12/14/95
4	47 22' 21" N	122 12' 7" W	Kent	8748	**28**	**1.3**	**5.4**	**0.91**	**6.9**	02/23/89
5	47 22' 5" N	122 18' 13" W	Kent	200791	**63**	**0.4**	**0.34**	**2**	**47**	07/28/89
1	47 18' 59" N	122 18' 46" W	Federal Way	8779	**93**	**168**	**1020**	**3640**	**<50**	06/24/93
2	47 18' 54" N	122 18' 8" W	Federal Way	10147	**19**	**2**	**0.9**	**2.3**	**<1**	04/15/92
3	47 18' 7" N	122 21' 37" W	Federal Way	10148	**1970**	**1310**	**231**	**785**	**<1**	06/06/94
4	47 17' 23" N	122 18' 59" W	Federal Way	5080	**5620**	**13400**	**1620**	**8090**	**<100**	05/02/89
1	47 49' 15" N	122 18' 56" W	Lynnwood	8745	**43000**	**68000**	**6300**	**22400**	**<100**	12/15/89
1	45 40' 27" N	122 36' 10" W	Vancouver	10175	**5680**	**6470**	**927**	**6540**	**5.5**	07/22/93
2	45 43' 4" N	122 39' 27" W	Vancouver	2157	**340**	**7.5**	**60**	**1900**	**36**	10/03/91
3	45 41' 9" N	122 37' 29" W	Vancouver	5988	**1.9**	**1.6**	**41**	**120**	**112**	05/09/95
4	45 54' 27" N	122 44' 41" W	Woodland	5981	**4000**	**22000**	**1700**	**3700**	**113**	11/03/97
5	45 40' 55" N	122 39' 41" W	Hazel Dell	101491	**<1**	**<1**	**<1**	**<2**	**0.3**	03/18/96
6	45 43' 0" N	122 39' 6" W	Hazel Dell	200274	**<1**	**<1**	**<1**	**<2**	**<1**	07/20/88
7	45 40' 42" N	122 39' 56" W	Hazel Dell	5095	**<1**	**<1**	**<1**	**<2**	**<1**	06/09/90
8	45 40' 43" N	122 39' 42" W	Hazel Dell	10160	**11**	**0.4**	**10**	**3.6**	**1.5**	11/01/86
1	47 26' 59" N	117 7' 55"W	Rockford[(1)]	11600	**151**	**0.25**	**0.25**	**0.5**	**5150**	02/16/99
2	47 39' 14" N	118 8' 56"W	Davenport[(1)]	6678	**3170**	**33.1**	**12.5**	**25**	**7150**	11/16/98

1. Sampling independently conducted by site owner

Table A-2. MTBE and BTEX Groundwater Concentrations for Contaminated Sites.

Site No.	Latitude Degrees	Longitude Degrees	City	Site ID	B ug/l	T ug/l	E ug/l	X ug/l	MTBE ug/l	Release Report Date
1	47 36' 36" N	122 12' 23" W	Bellevue	5100	**5720**	**13,900**	**2,350**	**10,200**	**<500**	02/15/91
2	47 35' 43" N	122 11' 51" W	Bellevue	5258	**7530**	**18,400**	**3,330**	**16,200**	**<1000**	05/03/93
3	47 37' 2" N	122 10' 52" W	Bellevue	100678	**26500**	**40,400**	**3,620**	**16,200**	**<1000**	06/07/90
4	47 37' 3" N	122 12' 14" W	Bellevue	9557	**1560**	**1,330**	**314**	**1,080**	**8**	11/22/89
5	47 37' 51" N	122 9' 13" W	Bellevue	8679	**409**	**29**	**145**	**215**	**0.45**	11/30/94
6	47 37' 2" N	122 11" 5" W	Bellevue	8739	**2**	**0.25**	**0.95**	**3.7**	**16**	08/09/89
7	47 36' 30" N	122 8' 35" W	Bellevue	9561	**194**	**2**	**3**	**0.2**	**0.14**	11/09/90
8	47 36' 4" N	122 13' 36" W	Bellevue	9560	**59**	**8**	**130**	**205**	**<5**	08/07/89
9	47 42' 31" N	122 10' 38" W	Kirkland	6895	**44**	**2**	**<5**	**<10**	**3.3**	08/17/90
10	47 42' 13" N	122 10' 36" W	Kirkland	9556	**43**	**6**	**407**	**72**	**0.6**	12/23/91
11	47 42' 14" N	122 12' 37" W	Kirkland	10144	**34**	**26**	**374**	**1540**	**<10**	01/13/93
12	47 40' 45" N	122 10' 52" W	Kirkland	10142	**358**	**1.6**	**44**	**115**	**<1**	01/15/93
13	47 23' 16" N	122 13' 50" W	Kent	10145	**4530**	**3,540**	**984**	**3,690**	**<1000**	04/20/94
14	47 19' 14" N	122 17' 8" W	Auburn	9510	**2.9**	**2.8**	**2.3**	**13**	**<1**	04/05/91
15	47 20' 35" N	122 13' 19" W	Auburn	6888	**692**	**<50**	**<50**	**<100**	**126**	10/10/95
16	47 19' 35" N	122 13' 16" W	Auburn	97606	**330**	**669**	**1850**	**5950**	**<100**	12/04/90
17	47 32' 2" N	122 34' 39" W	Port Orchard	10883	**34**	**57**	**32**	**51**	**<1**	01/31/89
18	48 59' 53" N	122 44' 16" W	Blaine	8472	**200**	**16**	**<50**	**<50**	**455**	06/21/90
19	48 53' 31" N	122 29' 8" W	Linden	1447	**3.2**	**38**	**243**	**639**	**1**	01/25/90
20	48 50' 37" N	122 17' 17" W	Everson	9910	**7**	**1.2**	**0.4**	**2.3**	**<1**	01/05/95
21	48 59' 13" N	123 4' 2" W	Point Robert	100646	**1260**	**1380**	**324**	**1950**	**105**	03/29/94
22	47 37' 6" N	122 21' 12" W	Seattle	8421	**1.3**	**0.55**	**0.35**	**0.85**	**37**	06/21/89
23	47 31' 12" N	122 15' 49" W	Seattle	8701	**13**	**<1**	**<1**	**<2**	**<1**	06/26/89
24	47 40' 51" N	122 15' 48" W	Seattle	8668	**265**	**1.4**	**4.4**	**2.8**	**<1**	07/24/95
25	47 40' 23" N	122 23' 15" W	Seattle	8666	**0.8**	**<1**	**<1**	**<2**	**1**	12/01/95
26	47 32' 16" N	122 16' 54" W	Seattle	97593	**264**	**4.6**	**86**	**3.8**	**<1**	09/09/98
27	47 35' 1" N	122 19' 43" W	Seattle	8746	**7**	**<10**	**0.72**	**<20**	**364**	02/10/93
28	47 42' 29" N	122 19' 2" W	Seattle	1498	**6**	**<5**	**<5**	**<10**	**128**	10/02/89
29	47 33' 45" N	122 22' 48" W	Seattle	10140	**503**	**31**	**164**	**42**	**<100**	01/13/93
30	47 39' 47" N	122 18' 50" w	Seattle	5046	**176**	**66**	**44**	**102**	**<5**	01/04/90
31	47 38' 19" N	122 18' 5" W	Seattle	403305	**0.2**	**<1**	**<1**	**0.22**	**<1**	01/21/97
32	47 31' 2" N	122 22' 10" W	Seattle	9516	**14**	**0.27**	**1.1**	**<2**	**<1**	10/04/91
33	47 42' 30" N	122 19' 53" W	Seattle	9563	**170**	**67**	**3860**	**1260**	**0.61**	10/07/91
34	47 29' 7" N	122 15' 20" W	Seattle	9554	**676**	**1740**	**310**	**1020**	**<10**	10/22/91
35	47 41' 23" N	122 20' 39" W	Seattle	9502	**<1**	**<1**	**<1**	**26**	**<1**	11/27/91
36	47 28' 16" N	122 20' 3" W	Seattle	9574	**550**	**1**	**0.94**	**2**	**<1**	04/13/92
37	47 32' 16" N	122 16' 54" W	Seattle	9524	**234**	**46**	**216**	**47**	**<100**	11/27/91
38	47 37' 26" N	122 20' 17" W	Seattle	8463	**0.1**	**0.32**	**<1**	**<2**	**0.22**	05/01/80
39	47 34' 22" N	122 20' 1" W	Seattle	8459	**33**	**<5**	**<5**	**3.4**	**9.4**	09/12/90
40	47 45' 28" N	122 18' 32" W	Seattle	9577	**658**	**28**	**110**	**162**	**164**	08/18/89
41	47 30' 38" N	122 17' 35" W	Tukwila	101796	**85**	**<10**	**<10**	**<10**	**22**	03/28/91
42	47 28' 12" N	122 13' 14" W	Renton	5256	**9.5**	**<1**	**<1**	**<2**	**31**	04/05/91
43	47 28' 30" N	122 12' 54" W	Renton	6890	**185**	**1.2**	**0.57**	**4.5**	**4.6**	04/12/91
44	47 30' 13" N	122 9' 48" W	Renton	9546	**0.9**	**<1**	**2.2**	**4.2**	**3.4**	11/14/91
45	47 23' 12" N	122 9' 58" W	Kent	8696	**10**	**18**	**2.9**	**22**	**<1**	01/10/92

Table A-2. MTBE and BTEX Groundwater Concentrations for Contaminated Sites.

Site No.	Latitude Degrees	Longitude Degrees	City	Site ID	B ug/l	T ug/l	E ug/l	X ug/l	MTBE ug/l	Release Report Date
46	47 23' 17" N	122 14' 52" W	Kent	8693	**<1**	**1.2**	**0.1**	**0.6**	**<1**	06/28/96
47	47 22' 39" N	122 13' 51" W	Kent	8709	**10**	**0.9**	**8.3**	**12**	**<1**	12/14/95
48	47 22' 21" N	122 12' 7" W	Kent	8748	**28**	**1.3**	**5.4**	**0.91**	**6.9**	02/23/89
49	47 22' 5" N	122 18' 13" W	Kent	200791	**63**	**0.4**	**0.34**	**2**	**47**	07/28/89
50	47 18' 59" N	122 18' 46" W	Federal Way	8779	**93**	**168**	**1020**	**3640**	**<50**	06/24/93
51	47 18' 54" N	122 18' 8" W	Federal Way	10147	**19**	**2**	**0.9**	**2.3**	**<1**	04/15/92
52	47 18' 7" N	122 21' 37" W	Federal Way	10148	**1970**	**1310**	**231**	**785**	**<1**	06/06/94
53	47 17' 23" N	122 18' 59" W	Federal Way	5080	**5620**	**13400**	**1620**	**8090**	**<100**	05/02/89
54	47 49' 15" N	122 18' 56" W	Lynnwood	8745	**43000**	**68000**	**6300**	**22400**	**<100**	12/15/89
55	45 40' 27" N	122 36' 10" W	Vancouver	10175	**5680**	**6470**	**927**	**6540**	**5.5**	07/22/93
56	45 43' 4" N	122 39' 27" W	Vancouver	2157	**340**	**7.5**	**60**	**1900**	**36**	10/03/91
57	45 41' 9" N	122 37' 29" W	Vancouver	5988	**2**	**1.6**	**41**	**120**	**112**	05/09/95
58	45 54' 27" N	122 44' 41" W	Woodland	5981	**4000**	**22000**	**1700**	**3700**	**113**	11/03/97
59	45 40' 55" N	122 39' 41" W	Hazel Dell	101491	**<1**	**<1**	**<1**	**<2**	**0.3**	03/18/96
60	45 40' 43" N	122 39' 42" W	Hazel Dell	10160	**11**	**0.4**	**10**	**3.6**	**1.5**	11/01/86
61	47 26' 59" N	117 7' 55"W	Rockford[(1)]	11600	**151**	**0.25**	**0.25**	**0.5**	**5150**	02/16/99
62	47 39' 14" N	118 8' 56"W	Davenport[(1)]	6678	**3170**	**33.1**	**12.5**	**25**	**7150**	11/16/98

1. Sampling conducted independently by site owner