Methyl tertiary-Butyl Ether (MTBE) Occurrence in Iowa

A Report for the 2000 Session of the Seventy-Eighth General Assembly

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Executive Summary

The Iowa Legislature passed 1999 Iowa Acts, House File 772 that contains a provision requiring soil and groundwater samples collected at leaking underground storage tank (LUST) site investigations after July 1, 1999 be analyzed for methyl tertiary-butyl ether (MTBE). This law was in response to growing national concern over MTBE contamination in groundwater and drinking water supplies. The primary objective is to determine MTBE presence and concentration in Iowa's soil and groundwater. Based on the findings, the secondary objective is to determine whether the occurrence and levels are significant to warrant regulatory action in order to protect public health and the environment.

A total of 3,257 samples were collected from 603 LUST sites from July 1, 1999, through December 17, 1999. Groundwater samples obtained from monitoring wells at LUST sites comprise the majority of the data. Samples from soil, plastic water lines, drinking water wells, non-drinking water wells, surface waters, sumps, and treatment system influent and effluent were also included in the data set.

Approximately 32% of the 2,569 groundwater samples collected reported MTBE levels above the quantitation limit of 15 micrograms per liter (μg/L). Nearly 29% of the groundwater samples showed MTBE levels above the United States Environmental Protection Agency's (USEPA) lower Health Advisory Level (HAL) of 20 μg/L. However, of the LUST sites sampled, approximately 55% sites detected levels above the lower HAL. The highest reported concentration of MTBE in groundwater was **99,400 μg/L**. The average concentration of samples that equaled or exceeded 15 μg/L was **613 μg/L**. Utilizing all samples the average groundwater concentration was 200 μg/L. Considering only the maximum MTBE concentration reported for a site, the average concentration in groundwater for all LUST sites was 574 μg/L.

Of the 635 soil samples collected, approximately 60% reported MTBE levels above the quantitation limit of 0.015 milligrams per kilogram (mg/kg). Approximately 22% of the samples reported MTBE levels above 10 mg/kg. The highest soil concentration was reported as **less than 5,000 mg/kg**. The average concentration of samples that equaled or exceeded 0.015 mg/kg was **122.5 mg/kg**. Utilizing all samples the average concentration for soil was 72.9 mg/kg. Considering only the maximum MTBE concentration reported for a site, the average MTBE maximum concentration in soil for all LUST sites was 138 mg/kg.

Water samples were also collected from 53 various receptors (drinking water wells, plastic water lines, etc.). Of these, only five samples had a concentration greater than the laboratory's quantitation limit of 15 μg/L. One sample from a private drinking water well in northeast Iowa showed MTBE concentrations (23.7 μg/L) above the USEPA's lower HAL (20 μg/L).

Based on these findings, the department recommends regulating MTBE as a chemical of concern. This would entail, under the current risk-based corrective action (RBCA) program, determining which exposure pathways should be considered and establishing MTBE target levels

specific to those pathways. Testing for MTBE during standard LUST site investigations would continue. Possible exceptions might be warranted when 1) the release under investigation is determined to be a semi-volatile petroleum substance (e.g., diesel, waste oil); and 2) after an initial assessment of a release, it is determined MTBE is not present in the subsurface. Considering the second exception, testing for MTBE during tank closure activities is recommended. If MTBE is regulated, the department recommends sites previously classified as No Action Required not be reopened unless a public health or environmental risk can be traced to a particular site.

Overview

Methyl tertiary-butyl ether (MTBE), an additive to gasoline, has been detected in many drinking water supplies across the country, including Iowa. In August 1987, Well #1 of the Fayette Municipal Water Supply in Iowa was restricted to emergency, or standby use only status, and later permanently closed due to the detection of MTBE. More recently, MTBE was detected at low levels in water samples collected from Ida Grove water supply wells. MTBE, a fuel supplement intended to reduce harmful motor vehicle emissions, ironically is causing groundwater contamination and public health concerns.

Background

Under the Clean Air Act Amendments (CAAA) of 1990, Reformulated Gasoline (RFG) is required to be sold in regions of the United States where ozone or carbon monoxide air quality standards are exceeded (non-attainment areas). RFG must contain at least 2% oxygen by weight per the CAAA. This requirement is met with the use of oxygenates, which the American Society for Testing and Materials (ASTM) defines as oxygen-containing, ashless, organic compounds, such as alcohols or ethers, which can be used as fuel or fuel supplements. In the late 1970s and 1980s, oxygenates were used to meet lead phaseout requirements as octane enhancers and fuel extenders.

The most commonly used oxygenates in RFG include MTBE and ethanol (EtOH). MTBE is favored over other oxygenates because of its low cost, ease of production, and favorable transfer and blending characteristics (Zogorski et al. 1997). Methanol (MeOH), ethyl tertiary-butyl ether (ETBE), tertiary-amyl methyl ether (TAME), diisopropyl ether (DIPE), and tertiary-butyl alcohol (TBA) are among the less commonly used and therefore, less studied. However, as MTBE environmental problems come to light, and with the potential for increased future use, health and environmental effects of these other oxygenates are being carefully examined.

MTBE has been used in gasoline since 1979. Originally used as an octane booster, with the RFG mandate, its use has increased substantially in non-attainment areas of the United States. The percentage of MTBE added to gasoline has also increased. MTBE comprises 10 to 15% by volume of RFG. Fortunately, levels of ozone and carbon monoxide in Iowa's air do not exceed standards set by the USEPA and therefore, the use of RFG is not mandated. According to the Iowa Department of Agriculture and Land Stewardship, and the Petroleum Marketers of Iowa (PMI), MTBE currently is not used or sold in the State of Iowa.

Physical and Chemical Properties

The fate and transport properties of MTBE in the subsurface are not fully known. The physical and chemical properties (Table 1), however, can give some insight on how MTBE may behave in the environment, as well as how to approach clean up of MTBE contaminated groundwater. The physical and chemical properties of benzene are also provided in Table 1 for comparison purposes.

- Henry's Law Constant (H) is a measure of the tendency of a dissolved compound to volatilize. Volatilization is likely to occur when a chemical's Henry's Law Constant is greater than 0.05. This property has remediation implications. For example, compared to benzene (H=0.22), MTBE (H=0.018) may be more difficult to "strip" from contaminated groundwater.

- Vapor pressure is the tendency for a compound to volatilize from its pure liquid phase. Significant volatilization occurs if a chemical's vapor pressure is greater than 100 mm Hg. For an MTBE release (v.p. ~ 250 mm Hg), vaporization of residual product from a dry soil environment can be expected. However, MTBE is highly soluble in water (~43,000 mg/L), so once in contact with groundwater or water in the pore spaces of a soil matrix, significant volatilization is not likely to occur.

- Log Koc is the normalized organic partition coefficient, and it is a measure of a chemical's adsorption to organic carbon. The higher the Koc value, the more a chemical "sticks" to carbon. In a soil with a high fraction of organic carbon, sorption can act to retard contaminant migration in groundwater.

Compared to benzene, toluene, ethylbenzene, and xylenes (BTEX), MTBE and other ether oxygenates are significantly less degradable, while ethanol and methanol are more easily degradable (Zogorski et al. 1997). MTBE has a higher solubility and lower sorption capacity than BTEX compounds. Therefore, it has the potential to generate longer plumes, higher source concentrations, and have longer persistence in the environment. This difference between BTEX compounds and MTBE can be particularly pronounced in aquifers with high organic carbon content. The longer migration distances of MTBE can increase the chances of drinking wells becoming contaminated.

Another point of interest in Iowa is the increased likelihood for shallow drinking water sources located in bedrock to become contaminated. Certain bedrock types, particularly fractured systems, may act as preferential pathways for contaminants to reach potable groundwater. This is a particular concern for northeast Iowa where fractured bedrock can be less than 50 feet below ground surface, near or in contact with petroleum releases.

Health Effects

Although there is no established drinking-water regulation for MTBE, USEPA has issued a drinking-water advisory of **20 to 40 µg/L** on the basis of taste and odor thresholds. This advisory concentration is intended to provide a large margin of safety for noncarcinogenic effects and is in the range of margins typically provided for potential carcinogenic effects (USEPA 1997).

Additionally, the following draft Drinking Water Health Advisory Levels (HAL) for MTBE are being considered by USEPA (USEPA 1996):

$HAL_{lifetime}$ (Adult)	=	20 – 200 µg/L(ppb)
DWEL (Drinking Water Equivalent Level)	=	1000 µg/L
$HAL_{longterm}$	=	12,000 µg/L

The lifetime HAL is the concentration of a chemical in drinking water that is not expected to cause any adverse noncarcinogenic effects over a lifetime of exposure, with a margin of safety. The Drinking Water Equivalent Level (DWEL) is a lifetime exposure concentration protective of adverse, non-cancer health effects, that assumes all of the exposure to a contaminant is from a drinking water source. The long-term HAL is the concentration of a chemical in drinking water that is not expected to cause any adverse noncarcinogenic effects up to approximately seven years (10% of an individual's lifetime) of exposure, with a margin of safety.

The USEPA is in the process of revising the cancer guidelines. MTBE has tentatively been designated as a Group C – *possible* human carcinogen. If the Group C cancer designation is accepted as final, the $HAL_{lifetime}$ will be 20 µg/L (equivalent to ppb). The USEPA defines the carcinogenic potential of a Group C carcinogen as "limited evidence from animal studies and inadequate or no data for humans" (USEPA 1996). Toxicity studies have documented carcinogenic effects in rats and mice from exposure to MTBE by inhalation or oral dosage (Chun et al. 1992, Bird et al. 1997, Burleigh-Flayer et al. 1992, Belpoggi et al. 1995, 1997, 1998). Noncarcinogenic health effects have also been documented in animal studies (Bevan et al. 1997b, Tyl and Neeper-Bradley, 1989, Moser et al. 1998, Daughtrey et al. 1997).

The health effects of other oxygenates like diisopropyl ether (DIPE), ethyl tertiary-butyl ether (ETBE), tertiary-amyl methyl ether (TAME), and tertiary-butyl alcohol (TBA) have been less widely studied than MTBE. Health advisories for these chemicals have not been established. The carcinogenic effects of TAME and ETBE are unknown, but animal studies have shown neurotoxic and acute health effects (White et al. 1995, Daughtrey and Bird 1995, Dorman et al. 1997). Animal studies have shown some evidence of carcinogenic effects as well as reproductive and acute effects from TBA exposure (Cirvello et al. 1995, NTP 1995).

Overview of MTBE Policy in the U.S.

Concern over MTBE as a groundwater pollutant began when environmental monitoring and testing of water supply wells, coincidental with the high-volume use of MTBE, revealed contamination. Consequently many nationwide studies were launched to determine the impact of MTBE in groundwater and in drinking water supplies. California, New York, and Maine are among the more studied and progressive states.

In 1997, MTBE contamination caused the shutdown of several California wells including some which supply water to half of Santa Monica's residents and businesses. As a result of these incidences, California began testing public water supply systems for MTBE. Of the 3200 water supply sources tested, 1.2% were contaminated above 5 ug/L. As many as 10,000 groundwater sites throughout the State of California have been contaminated with MTBE (Keller, 1998). In an effort to address current and future MTBE pollution problems, California's recently adopted a Public Health Goal (PHG) of 13 μg/L for MTBE in drinking water and secondary standard of 5 μg/L based on taste and odor. Currently MTBE is added to almost all of the gasoline used in California as a means of meeting the requirements of the CAAA of 1990. The California Air Resources Board, however, recently approved rules that ban the use of MTBE as a gasoline additive after December 31, 2002.

New York's Department of Environmental Conservation is expected to lower the allowable concentrations of MTBE in groundwater and surface water from 50 μg/L to 10 μg/L (cleanup level). New York's Department of Environmental Health also will be changing their drinking water standard for MTBE to 10 μg/L.

In 1998 the State of Maine completed a survey of public and private wells for presence of MTBE. Water samples were collected from 793 public wells and 949 private wells. Low levels (between 0.2 and 35 ug/L) were detected in 16% of the public wells and in nearly 14 % of the private wells. MTBE was detected at levels greater than 35 ug/L (Maine's cleanup level) in 1.1% of the private wells tested (State of Maine 1998).

MTBE Standards for Other States

Most states have or are projected to establish by the end of 2000 MTBE groundwater cleanup levels (Figure 1) (Delta Environmental Consultants, 1999). However, 12 states, including Iowa, have indicated they are waiting for the USEPA to set a Maximum Contaminant Level (MCL) for drinking water. Leading the nation in establishing levels and applying stringent standards are California and New York. California's Public Health Goal (PHG) for drinking water is 13 μg/L and its enforceable secondary standard is 5 μg/L based on taste and odor. New York's Department of Environmental Conservation is expected to lower the allowable concentrations of MTBE in groundwater and surface water from 50 μg/L to10 μg/L. Wyoming's cleanup level is the least stringent at 200 μg/L. Some states have varying cleanup levels based on distance to receptors or risk-based evaluations. Many states base their cleanup level on whether groundwater use is potable or nonpotable, and cleanup levels can vary significantly depending on use. For example, Maine’s cleanup level is 70 ug/L for potable groundwater, and 50,000 μg/L for nonpotable groundwater. Hawaii’s cleanup level is 20 μg/L for potable groundwater, and 202,000 μg/L for nonpotable groundwater.

Only two of USEPA Region 7 states (Iowa, Kansas, Missouri, Nebraska) have set cleanup levels for MTBE at LUST sites. Cleanup levels in Missouri are 40 μg/L or 400 μg/L based on whether the groundwater use is considered potable or non-potable. Missouri has indicated their standards will likely change to 20 μg/L and 200 μg/L in January 2000. The cleanup level in Kansas is for potable water only (20 μg/L). A cleanup level has not been established for non-potable water. Iowa and Nebraska currently have not set MTBE cleanup levels.

A survey conducted by the University of Massachusetts indicates that fifteen states have established standards for MTBE is soil. Soil action levels (concentrations that trigger assessment and/or remediation) range from 0.05 mg/kg in Maine and New York to 60 mg/kg in Missouri (University of Massachusetts, 1998). Some states have varying soil cleanup levels based on distance to receptors, risk-based evaluations, or on what may leach into drinking water.

MTBE Regulation in Iowa

Iowa has joined the growing national concern over the potential for MTBE to contaminate groundwater. In 1999 the Iowa Legislature passed House File 772. Section 15, paragraph 4 “c” of this legislation requires testing for MTBE on soil and water samples collected at leaking underground storage tank (LUST) sites after July 1, 1999. The Environmental Protection Commission adopted rules to implement this law in June 1999. The rules were filed both emergency with implementation July 1, 1999 (the effective date of the law) and for notice of public comment. Chapter 135, "Technical Standards and Corrective Action Requirements of Owners and Operators of Underground Storage Tanks," Iowa Administrative Code was amended by adding new rule 135.19 (Appendix A).

The primary objective of this law is to determine MTBE presence and concentration in Iowa’s soil and groundwater. Based on the findings, the secondary objective is to determine whether the occurrence and levels are significant to warrant further regulatory action in order to protect public health and the environment.

Sampling Requirements

To facilitate implementation of the new rules, announcements and guidance documents were sent to affected parties, groundwater professionals, and Underground Storage Tank (UST) Certified Laboratories on June 24, 1999 (Appendix B), and on July 12, 1999 (Appendix C). Departmental guidance clarified parts of the rule and report submittal process by specifying the following:

- All stages of a LUST site investigation must include MTBE analyses (Tier 1, Tier 2, and Tier 3 assessments, annual site monitoring, and corrective action development).
- MTBE analysis must be performed regardless of type of petroleum substance under investigation (e.g., diesel releases).
- Analysis must be performed by laboratories certified under 567 – Chapter 83 of the Iowa Administrative Code (IAC). Samples must be prepared and analyzed by either (1) Gas Chromatograph/ Mass Spectrometry version of OA-1, "Method for Determination of Volatile Petroleum Hydrocarbons (gasoline)," revision 7/27/93, University Hygienic Laboratory, Iowa City, IA, or (2) US Environmental Protection Agency Method 8260B, SW-846, "Test Methods for Evaluating Solid Waste," Third Edition.
- Results are to be reported in both hard copy form and electronically in a spreadsheet format established by the department.

Data Analysis and Presentation

Data used in this study were collected from July 1, 1999, through December 17, 1999. Basic statistical analyses were performed on MTBE results for total groundwater samples and for total soil samples. Receptor water samples were not included with the groundwater data set. Receptor samples are those from plastic water lines, drinking water wells (private and municipal), non-drinking water wells, sewers, sumps, surface waters, as well as groundwater treatment system influent and effluent. (Under Iowa's UST RBCA program, receptors are enclosed spaces, buried conduits, plastic water lines, protected groundwater sources, drinking and nondrinking water wells, and surface water bodies which when affected by chemicals of concern may results in exposure to humans and aquatic life, explosive conditions or other adverse effects on health, safety and the environment. Chapter 567 IAC 135 outlines the requirements for evaluating these receptors and determining the risk a regulated substance (e.g., petroleum) may pose).

Average concentration, median concentration, maximum concentration, and concentration distributions were determined for soil and groundwater samples. The average or arithmetic mean is the sum of sample concentrations divided by the total number of samples. The median is middle value in a distribution where 50 percent of the observations (samples) are above the value and 50 percent are below the value. Concentration distribution ranges selected were based on significant reference concentrations (e.g., <15 μg/L – the MTBE quantitation limit laboratories must be capable of meeting as set by rule; 20 μg/L – the lower HAL, etc.) and then by orders of magnitude for the higher ranges.

In addition to sample totals, the department was interested in knowing the occurrence and maximum concentration of MTBE at LUST sites (e.g., how many LUST sites were contaminated with MTBE, how many LUST sites identified MTBE above the HAL, etc.). For each site, only the maximum soil and groundwater MTBE concentrations were considered. All other samples for a site were dropped from the data set. The average and median of the maximum MTBE concentrations for all LUST sites was calculated for both soil and groundwater. The distribution of MTBE maximum concentrations for LUST sites was also determined. Concentration distribution ranges selected were based on significant reference concentrations and then by orders of magnitude for the higher ranges as stated previously.

It should be noted that higher quantitation limits often result from a highly contaminated sample. A sample could contain a very large amount of MTBE, such that the volume or concentration exceeds the ability of the instrumentation to make a precise and accurate measurement. Thus, a dilution prior to analysis is required. A highly contaminated sample may also have interfering chemicals that mask the actual MTBE value. This contamination may be from a number of different hydrocarbons found in a petroleum-laden sample, not necessarily MTBE alone. *When calculating averages and medians for this project, a concentration equal to one half of the reported detection limit was assigned to samples with results reported as less-than values* (e.g., <200 μg/L was adjusted to 100 μg/L). Data distributions presented in this report are also based on adjusted values. Because a sample cannot reliably be quantified below the detection limit (it is unknown how much less than 200 μg/L the concentration is), this adjustment assigns a value midway between the highest and lowest assumed concentrations (e.g., 200 μg/L and 0 μg/L). This method of data adjustment is commonly used by the USEPA.

Results

As part of the standard site investigation procedures, a total of 3,257 samples were collected from 603 LUST sites across Iowa. This sampling yields an average of 5.4 samples per site. MTBE analyses were performed on samples of soil, groundwater, plastic water lines/tap, sewers, surface waters, non-drinking water wells, private drinking water wells, and municipal water wells (Table 2). Groundwater samples collected from monitoring wells during annual site monitoring events or RBCA investigations comprise the majority of the data. MTBE concentrations in soil and groundwater samples (prior to data adjustment) are presented in Tables 3 and 4, respectively. The data are sorted by city where the samples were collected, and the ten samples with the highest MTBE concentrations are highlighted.

MTBE results for water samples collected from receptors (e.g., plastic water lines, drinking water wells) are presented in Table 5. Of the 53 receptor samples, only five had a concentration greater than the laboratory's quantitation limit of 15μg/L. One receptor sample from a private drinking water well in northeast Iowa showed MTBE concentrations (23.7 μg/L) above USEPA's lower HAL (20 μg/L).

MTBE in Groundwater

Quality of data: A total of 2,569 groundwater samples were collected.

- 1,786 groundwater samples reported MTBE concentrations as less-than values (<x)
  - 1,456 of these reported levels as <15 µg/L or below (e.g., <2 µg/L).
  - 330 of these reported levels as “<”, but at some value above 15µg/L (e.g., <50 µg/L).

- 783 groundwater samples positively identified MTBE (no “<” qualifier)
  - 573 of the positive samples were equal to or greater than 15 µg/L.
  - 210 positively identified MTBE, but at levels below 15 µg/L.

Total Groundwater Samples

Approximately 32% of the groundwater samples analyzed reported MTBE levels above 15 µg/L. Nearly 29% of groundwater samples analyzed showed MTBE levels above the USEPA’s lower HAL of 20 µg/L (Figure 2). The highest groundwater concentration reported was 99,400 µg/L. This sample was considered anomalous and not included in the data analysis. The next highest groundwater concentration reported was 42,500 µg/L. The average MTBE concentration for all groundwater samples which equaled or exceeded 15 µg/L was 613 µg/L, with a median of 81 µg/L. Utilizing all samples, including those reporting results less than 15 µg/L, the average MTBE concentration for groundwater was 200 µg/L, with a median of 5 µg/L.

Groundwater Maximums per LUST Site

Groundwater samples were collected at 523 sites from 248 Iowa cities. As can be expected, more sites were sampled in the more populous cities: Des Moines (41 sites), Davenport (19), Cedar Rapids (16), Sioux City (15). In breaking down the number of LUST sites where groundwater was tested for MTBE, it was determined that 26% were located in DNR Region 5 (Figure 3).

To determine the occurrence of MTBE in groundwater on a LUST site basis, the maximum concentration was selected from each site and all other groundwater data for that site were ignored. Figure 4 shows the MTBE distribution in groundwater based on maximum concentrations at each LUST site. The average concentration of the MTBE maximums for the 523 sites was then determined. The average concentration for groundwater samples that equaled or exceeded 15 µg/L was 967 µg/L, with a median of 119 µg/L. Utilizing all groundwater maximum samples including those with reported results less than 15 µg/L, the average concentration was 574 µg/L, with a median of 40.9 µg/L. MTBE was detected above the quantitation level of 15 µg/L at approximately 59% of the LUST sites, and above the USEPA’s lower HAL of 20 µg/L at approximately 55% of the LUST sites.

MTBE in Soil

Quality of data: A total of 635 soil samples were collected.

- 562 soil samples reported MTBE concentrations as less-than values (<x)
  234 of these reported levels as <0.015 mg/kg or below (e.g., <0.002 mg/kg).
  328 of these reported levels as "<", at some value above 0.015 mg/kg (e.g., <50 mg/kg).

- 73 soil samples positively identified MTBE (no "<" qualifier)
  72 of the positive samples were equal to or greater than 0.015 mg/kg.
  1 sample positively identified MTBE, but at levels below 0.015 mg/kg.

Total Soil Samples
Of the 635 soil samples tested, approximately 60% reported MTBE levels above the quantitation limit of 0.015 mg/kg (Figure 5). Approximately 22% reported MTBE levels above 10 mg/kg. The highest MTBE concentration was reported as less than 5,000 mg/kg for three soil samples. The next highest concentration was quantified as 2,460 mg/kg. The average concentration of MTBE in all soil samples which equaled or exceeded 0.015 mg/kg was 122.5 mg/kg, with a median of 5 mg/kg. Utilizing all soil samples, including those reporting results less than 0.015 mg/kg, the average MTBE concentration was 72.9 mg/kg, with a median of 0.18 mg/kg.

Soil Maximums per LUST Site
Soil samples were collected at 179 sites from 100 Iowa cities. The results parallel those of groundwater with more sites being sampled in the more populous cities: Des Moines (15 sites), Ottumwa (8), Ames and Davenport (7), Cedar Rapids and Sioux City (5). A breakdown by state region of the LUST sites which tested soil for MTBE was determined (Figure 6). Soil samples were collected from more LUST sites in DNR Region 5 than any other region of the state (27%).

To determine the occurrence of MTBE in soil on a LUST site basis, the maximum concentration from each site was selected and all other soil data for a site were ignored. Figure 7 shows the MTBE concentration distribution in soil based on maximums at each LUST site sampled. The average of the MTBE maximums for the 179 sites was then determined. The average concentration for soil samples that equaled or exceeded 0.015 mg/kg was 225 mg/kg, with a median of 0.27 mg/kg. Utilizing all soil maximums, including samples with reported results less than 0.015 mg/kg, the average concentration was 138 mg/kg, with a median of 0.18 mg/kg. MTBE was detected above the quantitation level of 0.015 mg/kg at approximately 62% of the LUST sites sampled.

Other Oxygenates

Laboratories performing MTBE analyses are also required to run standards for other possible compounds like diisopropyl ether (DIPE), ethyl-tertiary butyl ether (ETBE), tertiary-amyl methyl ether (TAME), and tertiary-butyl alcohol (TBA) to be certain of their identification should they be detected. Laboratories are not required to quantify these chemicals, but in some cases concentrations were reported. (Table 6). DIPE, ETBE, TAME, and TBA were detected in less than 0.1% of the soil samples tested. DIPE, ETBE, TAME, and TBA were detected in less than 1.3% of the groundwater samples tested. These other oxygenates were not detected in drinking water well, plastic water line, sewer, or sump samples.

MTBE in Public Water Supplies (PWS)

Bedrock Public Water Supply (PWS) Sampling Project

In the spring of 1999, the Iowa Comprehensive Petroleum Underground Storage Tank Fund Board (ICPUSTB) and the Iowa Department of Natural Resources (IDNR) contracted with the University of Iowa's Hygienic Laboratory (UHL) to conduct analyses of water samples from public water supply (PWS) wells located in Iowa's vulnerable bedrock regions. The purpose of this project is to determine whether petroleum releases in vulnerable bedrock are impacting water supplies. The concern is certain bedrock types, particularly fractured systems, may act as preferential pathways for contaminants to reach groundwater used as drinking water sources. As part of the Risk-Based Corrective Action (RBCA) process, any municipal water supply well located within one mile of a LUST site which is in a vulnerable bedrock region must be sampled for chemicals of concern. In Iowa there are approximately 550 wells (240 PWSs) which meet these criteria (Appendix D).

UHL instructed water supply operators to collect samples from each well and prior to any treatment. Initially samples were analyzed for benzene, toluene, ethylbenzene, and xylenes (BTEX) using Iowa Method OA-1, and for total extractable hydrocarbons (TEH) using Iowa Method OA-2. When Chapter 135 was amended July 1, 1999, to include MTBE analysis at LUST sites, UHL began analyzing the bedrock-PWS samples for MTBE using the Gas Chromatograph/ Mass Spectrometry version of Iowa Method OA-1.

Bedrock PWS Sampling Project Results

During the initial sampling event conducted in the second and third quarters of 1999, 530 water samples were obtained from 235 public water supplies. MTBE was not detected above the quantitation limit (15 µg/L) in any of the PWS samples. During the fourth quarter 1999 sampling event, 518 samples were analyzed with no MTBE concentrations detected above the quantitation limit (15 µg/L) in any of the samples. MTBE was identified below the quantitation limit for eight samples. These samples were collected from the following water supply wells: Ackley (well 3), Independence (well 6 and well 7), LeClaire (well 1), Maquoketa (well 3 and well 4), Montour (well 2) and Wyoming (well 2).

Currently, the results from the Bedrock PWS Sampling Project are available for review in hardcopy form at the DNR Records Center, Wallace State Office Building, Des Moines. Individual PWS records are filed under LUST Bedrock by Public Water Supply (e.g., LUST Bedrock PWS - Albion). A summary of results for all PWS's sampled is filed under "LUST Bedrock PWS – Summary. These records are also available on the UST web page: http://www.state.ia.us/epd/ust/lqust.htm.

Other Known PWS Impacts

Although not part of the bedrock sampling project, MTBE was detected at low levels in water samples collected from municipal water supply systems for the cities of Ida Grove (Ida County), Galva (Ida County), and Alvord (Lyon County). These water supplies are located in DNR Region 3 in northwest Iowa. MTBE has been detected at low levels in Ida Grove's drinking water supply each quarter since 1997. The highest level reported was 12.0 μg/L for a sample collected September 24, 1998 from Well #3 after treatment, but before blending with water from other source wells. The most recent sample (11/29/1999) showed 6.3 μg/L. A concentration of 18 μg/L was detected in one sample collected from Galva's drinking water supply system on April 5, 1996. MTBE concentrations of 63 μg/L, 17 μg/L, and 15 μg/L were detected in Alvord's drinking water supply in January, August, and October of 1994, respectively. Both Galva and Alvord have abandoned their water supply wells and are utilizing another regional rural water source, due in part to MTBE contamination.

Conclusions

MTBE has been identified in approximately 32% of the groundwater samples tested. Nearly 29% of the groundwater samples exceeded USEPA's recommended lower HAL of 20 μg/L. However, of the LUST sites sampled, approximately 55% of the sites detected levels which may present a public health concern (i.e., above the lower HAL). MTBE has been detected in approximately 60% of the soil samples tested, and at approximately 62% of the LUST sites testing for MTBE. The frequency of MTBE detected in soil is surprising. Given its physical and chemical properties, and that fact that most of the releases under investigation have reached surficial aquifers, a higher frequency of MTBE groundwater contamination would be expected. Although MTBE was detected at low levels in private and municipal wells in Iowa, the number of documented incidences raises concerns about the likelihood of future impacts.

Because ozone and carbon monoxide levels in Iowa's air have not exceeded standards set by the USEPA, the use of RFG is not mandated in Iowa. Petroleum Marketers of Iowa (PMI) reports MTBE is not currently used or sold in the state. MTBE found in Iowa's soil and groundwater today is most likely the result of releases that occurred in the late 1970's and 1980s when its use as an octane enhancer in the state was more common. In an effort to ensure that MTBE does not cause harm to public health or the environment, House File 772 also contains a provision stating that "as of 2/1/2000 no retail dealer shall offer for sale in this state a motor vehicle fuel that contains more than 2% MTBE..". With the enforcement of this law, future contamination of Iowa's soil and groundwater can be minimized. However, existing MTBE contamination must be addressed.

Careful consideration should be given to implementing a significant change in Iowa's regulations regarding the assessment of leaking underground storage tanks through introducing MTBE as a chemical of concern. Based on the findings of this project, the department recommends regulating MTBE as a chemical of concern under the current risk-based corrective action program. This would entail determining which exposure pathways should be considered and establishing MTBE target levels specific to those pathways. If MTBE is regulated, the department recommends sites previously classified as No Action Required not be reopened unless a public health or environmental risk can be traced to a particular site.

For immediate consideration, the department recommends the following when implementing regulations:

- Testing for MTBE during standard LUST site investigations should continue. Possible exceptions may be warranted when 1) the release under investigation is determined to be a semi-volatile petroleum substance (e.g., diesel, waste oil); and 2) after an initial assessment of a release, it is determined that MTBE is not present in the subsurface.
- Considering the second exception above, testing for MTBE during tank closure activities should be performed.
- Further investigation of those sites where extremely high levels of MTBE have been identified should be conducted. The department should determine the potential for exposure to the public through drinking water supplies (e.g., determine whether the MTBE plume has been defined and the location of drinking water wells in relation to the MTBE contamination).

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Appendix A

ENVIRONMENTAL PROTECTION COMMISSION[567]

Adopted and Filed Emergency

Pursuant to the authority of Iowa Code section 455B.474, the Environmental Protection Commission proposes to amend Chapter 135, "Technical Standards and Corrective Action Requirements of Owners and Operators of Underground Storage Tanks," Iowa Administrative Code by adding new rule 135.19.

This amendment establishes requirements for analyzing for methyl tertiary-butyl ether (MTBE) in soil and water samples collected as part of investigations and corrective action at underground storage tank sites with petroleum contamination. This change is needed to implement 1999 Iowa Acts, House File 772 which becomes effective July 1, 1999.

1999 Iowa Acts, House File 772, Section 15, paragraph 4"c" requires; "At sites where groundwater or soil monitoring is required, pursuant to section 455B.474, subsection 1, paragraph "d", "f", or "h", the department of natural resources shall require that monitoring include testing for the presence of methyl tertiary-butyl ether from the locations where other sample analyses are required. The department shall provide regular updates to the interim committee established in paragraph "b" as required by the interim committee. The department shall report the findings and recommendations of the testing to the general assembly prior to the 2000 Session of the Seventy-eighth General Assembly." The provision is effective July 1, 1999.

In compliance with Iowa Code section 17A.4(2), the commission finds that notice and public participation are impractical because of the requirements of H.F. 772 and the immediate need to implement the new provision in order to provide the information to the interim committee and report findings and recommendations to the 2000 Session of the Seventy-eighth General Assembly. This additional sampling procedure does not require any additional field work than would otherwise be required. Analytical costs could double based on a limited survey of private laboratories. The additional MTBE analytical work may exceed the capacity of some private laboratories.

In compliance with Iowa Code section 17A.5(2)"b"(1), the Commission finds that the normal effective date of the amendment should be waived and this amendment should be effective July 1, 1999, which is the effective date of H.F. 772, section 15(4)"c".

This amendment is also published herein under Notice of Intended Action as **ARC** to allow for public comment. This emergency filing permits the commission to implement the new provision of the law.

This amendment is intended to implement 1999 Iowa Acts, House File 772.

This rule may have an impact on small businesses as provided in Iowa Code section 17A.31.

This amendment becomes effective July 1, 1999.

Amend Chapter 135 by adding the following new rule 135.19 as follows:

567--135.19 (455B) Analyzing for methyl tertiary-butyl ether (MTBE) in soil and groundwater samples.

135.19(1) *General.* The objective of analyzing for MTBE is to determine its presence in soil and water samples collected as part of investigation and remediation of contamination at underground storage tank facilities.

135.19(2) *Required MTBE testing.* Soil and water samples must be analyzed for MTBE when collected for risk-based corrective action as required in rules 135.8(455B) through 135.12(455B). This includes but is not limited to:

a. Risk-based corrective action (RBCA) evaluations required for Tier 1, Tier 2, and Tier 3 assessments and Corrective Action Design Reports.

b. Site monitoring.

c. Site remediation monitoring.

135.19(3) *MTBE testing not required.* Soil and water samples for the following actions are not required to be analyzed for MTBE:

a. Closure sampling under rule 135.15 unless Tier 1 or Tier 2 sampling is being performed.

b. Site checks under subrule 135.7(3) unless Tier 1 or Tier 2 sampling is being performed.

135.19(4) *Reporting* The analytical data must be submitted in a format prescribed by the department.

135.19(5) *Analytical methods for methyl tertiary-butyl ether (MTBE).* When having soil or water analyzed for MTBE from contamination caused by petroleum or hazardous substances, owners and operators of UST systems must use a laboratory certified under 567--Chapter 83 for petroleum analyses. In addition they must ensure all soil and water samples are properly preserved and shipped within 72 hours of collection to a laboratory certified under 567---Chapter 83 for petroleum analyses.

a. Sample preparation and analysis shall be by:

(1) GC/MS version of OA-1, "Method for Determination of Volatile Petroleum Hydrocarbons (gasoline)," revision 7/27/93, University Hygienic Laboratory, Iowa City, IA, or;

(2) US Environmental Protection Agency Method 8260B, SW-846, "Test Methods for Evaluating Solid Waste," Third Edition.

b. Laboratories performing the analyses must run standards for MTBE on a routine basis, and standards for other possible compounds like ethyl-tertiary butyl ether (ETBE), tertiary-amyl methyl ether (TAME), diisopropyl ether (DIPE), and tertiary-butyl alcohol (TBA) to be certain of their identification should they be detected.

c. Laboratories must run a method detection limit study and an initial demonstration of capability for MTBE. These must be kept on file.

d. The minimum detection level for MTBE in soil is 15 ug/kg. The minimum detection level for MTBE in water is 15 ug/l.

Appendix B

Memorandum

DATE: June 24, 1999

TO: LUST Site Owners, Groundwater Professionals, UST Certified Environmental Labs, and Other Interested Parties

FROM: James R. Humeston, Supervisor

RE: **New Requirement To Analyze For Methyl Tertiary-Butyl Ether (MTBE)**

The 1999 Iowa legislature passed 1999 Iowa Acts, House File 772 that contains a provision in Section 15, paragraph 4"c" requiring testing for MTBE on soil and water samples collected at LUST sites after July 1, 1999. The Environmental Protection Commission adopted rules to implement the law at their June 21, 1999 meeting. The rules were filed both emergency with implementation July 1, 1999, the effective date of the law, and for notice of public comment.

The rules were adopted emergency because of the immediate need to implement the new provision. The department is required to provide the information on the MTBE sampling to a legislative interim committee and report findings and recommendations to the 2000 Session of the Seventy-eighth General Assembly.

Enclosed is a copy of the rules filed emergency. You may send written comments on the rules until Tuesday, August 3, 1999 to James R. Humeston at the above address.

In order to assure reliable and accurate analytical results, the rules require MTBE analysis be conducted by Gas Chromatography/Mass Spectrometry (GC/MS) using the GC/MS version of OA-1 , "Method for Determination of Volatile Petroleum Hydrocarbons (gasoline)," revision 7/27/93, or US Environmental Protection Agency Method 8260B, SW-846, "Test Methods for Evaluating Solid waste," Third Edition. Using gas chromatography by itself as the analytical method results in false positives or negatives to be reported due to interference.

Any laboratory used for analysis of MTBE must have UST laboratory certification in Iowa. The certified laboratory is not required to have analyte certification for MTBE at this time. The requirements in the rule must be followed.

If you have any questions concerning this memo or on the attached rule proposal, please contact Paul Nelson at 515/281-8779 or by email at pnelson@max.state.ia.us.

Appendix C

TANK MEMO

TO: ***Groundwater Professionals*** ***July 9, 1999***

FROM: ***Iowa Department of Natural Resources*** ***Volume 3, Issue 3***
Underground Storage Tank Section
Wallace Building, Des Moines, IA 50319

[redacted]

General Guidance for MTBE Monitoring and Reporting

The Environmental Protection Commission adopted rules on June 21, 1999, to implement an amendment to Chapter 135 which requires soil and water samples collected at LUST sites be tested for methyl tertiary-butyl ether (MTBE). This requirement is **effective July 1, 1999**. These rules can be found on the UST web page (http://www.state.ia.us/epd/ust/gwprof/gwbb.htm) or a hard copy may be obtained from DNR by telephoning 515/ 281-6010.

Applicability: Soil and water samples collected for LUST investigations must be tested for the presence of MTBE. This applies to Tier 1, Tier 2, Tier 3 assessments, site monitoring (pre- and post-RBCA), CADR development and implementation (including pilot testing, excavation samples, etc.), and remediation monitoring (influent and effluent water samples). MTBE analysis does not need to be conducted on samples collected in association with tank closures or site checks unless the site check samples are used in Tier 1 or Tier 2 evaluations.

MTBE analyses must be performed regardless of what type of petroleum release is under investigation (gasoline, diesel, fuel oil, waste oil, motor oil, hydraulic fluid, jet fuel, kerosene, mineral spirits).

Laboratory Analysis: MTBE sample analysis must be performed by a laboratory certified under 567—Chapter 83. A list of Iowa Certified Laboratories may be obtained from DNR by calling 515/281-6010, or from the University Hygienic Laboratory's web page: http://www.uhl.uiowa.edu/Services/LabCertification/f_certified_all_form.html. Soil and water samples must be properly preserved and shipped to a certified lab within 72 hours of collection. Groundwater professionals must comply with the selected laboratory's requirements and procedures regarding shipping and handling, use of trip blanks, chain-of-custody forms, etc.

Laboratories must use one of the following methods for sample preparation and analysis of MTBE:

- Gas Chromatography/Mass Spectrometry (GC/MS) version of OA-1, "Method for Determination of Volatile Petroleum Hydrocarbons (gasoline)," revision 7/27/93, University Hygienic Laboratory, Iowa City, IA; **or**
- US Environmental Protection Agency Method 8260B, SW-846, "Test Methods for Evaluating Solid Waste," Third Edition.

Laboratories performing the analyses are required to run standards for MTBE on a routine basis, and standards for other possible compounds like ethyl-tertiary butyl ether (ETBE), tertiary-amyl methyl ether (TAME), diisopropyl ether (DIPE), and tertiary-butyl alcohol (TBA) to be certain of their identification should they be detected. When these chemicals are detected, their presence will be noted in a comment on the lab data sheet - they will not be quantified. Laboratories must be able to achieve a minimum detection level of 15 ug/kg for MTBE in soil, and 15 ug/L for MTBE in water.

Reporting: MTBE monitoring results must be reported to the department on a Microsoft Excel 5.0 Spreadsheet using the format and heading order as presented in the attached example document called "MTBE Sampling

Results" (no exceptions). The MTBE spreadsheet form may be downloaded from the UST web page: http://www.state.ia.us/epd/ust/lqust.htm.

The "Monitoring Event" column should be completed with the stage of the RBCA process in which the samples were collected (e.g., Tier 1, Tier 2, SMR, pre-RBCA SMR, CADR Remediation sampling). Sample locations should be clearly identified. If the sample location is not a monitoring well or borehole, the Sample ID should be descriptive enough to tell the origin of the sample (e.g., Municipal Well #1, influent to carbon treatment system, etc.) Sampling dates must be entered in the mm/dd/yyyy format. Provide ground surface and sample depth elevations in feet above sea level (ASL) measured to the nearest 0.1 foot and static water level in feet ASL measured to the nearest 0.01 foot. MTBE results from treatment system samples are to be tabulated in the MTBE-Groundwater column (influent, effluent). Additionally, if ethyl-tertiary butyl ether (ETBE), tertiary-amyl methyl ether (TAME), diisopropyl ether (DIPE), or tertiary-butyl alcohol (TBA) is identified in the sample, this should be reported in the "Comments" column. Concentrations must be reported in units of mg/kg for soil samples and ug/L for water samples. If there are no results for a particular sample, the column must be left blank (e.g., a water sample was collected from MW-13, but no soil sample was collected, leave the column "MTBE Soil" blank). If the concentration reported is less than the quantitation limit, indicate the quantitation value preceded by the less than symbol (<). MTBE data collected prior to July 1, 1999 do not need to be submitted.

A diskette containing the spreadsheet file along with a hardcopy of the MTBE Excel spreadsheet must accompany any LUST report submitted to the department (Tier 1, SMR, pre-RBCA SMR, CADR, etc.) with the exception of monthly free product recovery reports. The MTBE Excel file may be copied to the same disk which is submitted with a Tier 1 report, Tier 2 SCR, or version 2.2 SMR (forthcoming). The Excel file name should contain the LUST number for the site (e.g., M8LTA26.XLS). A separate disk must be submitted for each LUST site (i.e., multiple files for multiple LUST sites should not be submitted on one disk, nor should multiple LUST sites be compiled into one spreadsheet file).

Copies of chromatograms and associated quantitation reports for the above testing **do not need to be submitted** to the department, but must be made available upon request. The laboratory data sheets which summarize the sample results (sample and site identification, detection limits, collection / analysis dates, who collected / analyzed the samples, etc.) must be provided when the disk is submitted. Ensure the laboratory data sheets contain the site name, address and LUST number.

[redacted]

Update on Water Supply Sampling in Vulnerable Bedrock Regions

The project to sample water supplies in vulnerable bedrock regions is underway, and some results have been reported by University Hygienic Laboratory. In addition to BTEX and TEH, MTBE analysis is being conducted. Currently, the information is available for review in hardcopy form at the DNR Records Center, Wallace State Office Building, Des Moines. The records are filed under LUST Bedrock by Public Water Supply (an example file name: LUST Bedrock PWS - Albion). A list of public water supplies in bedrock regions which have been sampled will be kept at the Records Center. You will soon be able to access these records on the UST web page (http://www.state.ia.us/epd/ust/lqust.htm). The information will be updated as laboratory results are obtained.

Appendix D. Public Water Supply Wells in the LUST Bedrock Sampling Project

ACKLEY
- WELL 2
- WELL 3
- WELL 7

AKRON
- WELL 4
- WELL 5
- WELL 6

ALBION
- WELL 1
- WELL 2
- WELL 3

ALBURNETT
- WELL 1
- WELL 2

ALDEN
- WELL 2
- WELL 3

ALGONA
- WELL 1
- WELL 2
- WELL 5
- WELL 6
- WELL 7

AMANA
- WELL 3
- WELL 5
- WELL 6

ANAMOSA
- WELL 1
- WELL 2
- WELL 4

ANAMOSA-DNR
- WELL 1

ANDREW
- WELL 1
- WELL 2

APLINGTON
- WELL 2
- WELL 3

ARLINGTON
- WELL 3
- WELL 4

ASBURY
- WELL 1
- WELL 2

ATKINS
- WELL 1
- WELL 2

ATLANTIC
- WELL 10
- WELL 11
- WELL 12
- WELL 6
- WELL 7
- WELL 8
- WELL 9

AUBURN
- WELL 4
- WELL 5

BALDWIN
- WELL 1
- WELL 2

BANCROFT
- WELL 2
- WELL 3

BAYARD
- WELL 1
- WELL 2

BENNETT
- WELL 1

BETTENDORF
- WELL 1

BODE
- WELL 1
- WELL 2

BRIGHTON
- WELL 2

BRITT
- WELL 1
- WELL 2

BUFFALO
- WELL 1
- WELL 2

BURLINGTON
- WELL 1
- WELL 1
- WELL 2
- WELL 3

CALAMUS
- WELL 1

CALMAR
- WELL 2
- WELL 3

CASCADE
- WELL 4
- WELL 5

CEDAR FALLS
- WELL 10
- WELL 11
- WELL 3
- WELL 6
- WELL 7
- WELL 8

Appendix D. Public Water Supply Wells in the LUST Bedrock Sampling Project

CEDAR RAPIDS
- CEDAR R
- WELL E1
- WELL E10
- WELL E11
- WELL E12
- WELL E13
- WELL E14
- WELL E15
- WELL E16
- WELL E17
- WELL E18
- WELL E19
- WELL E2
- WELL E20
- WELL E3
- WELL E4
- WELL E5
- WELL E6
- WELL SEM
- WELL W1
- WELL W11
- WELL W2
- WELL W3
- WELL W4
- WELL W5
- WELL W6
- WELL W7
- WELL W8
- WELL W9

CENTRAL CITY
- WELL 2
- WELL 3

CHARLES CITY
- WELL 4
- WELL 5
- WELL 7

CHARLOTTE
- WELL 2
- WELL 3

CLARENCE
- WELL 2
- WELL 3
- WELL 4

CLEAR LAKE
- WELL 1
- WELL 2

CLINTON
- WELL 10
- WELL 11
- WELL 3
- WELL 6
- WELL 7
- WELL 8
- WELL 9

COGGON
- WELL 1
- WELL 2

COLESBURG
- WELL 2
- WELL 4

COLUMBUS JUNCTION
- WELL 4
- WELL 5

CONRAD
- WELL 3
- WELL 4

COON RAPIDS
- WELL 1
- WELL 5

CORALVILLE
- WELL 1
- WELL 10
- WELL 2
- WELL 6
- WELL 7
- WELL 8

CRESCO
- WELL 3

DAKOTA CITY
- WELL 2
- WELL 3

DECORAH
- WELL 1
- WELL 2
- WELL 3
- WELL 5
- WELL 6
- WELL 7

DELHI
- WELL 1
- WELL 2

DELMAR
- WELL 1

DEWITT
- WELL 3
- WELL 5
- WELL 6

DOW CITY
- WELL 3

DOWS
- WELL 4
- WELL 5

DUBUQUE
- WELL 1
- WELL 2

DUNLAP
- WELL 1
- WELL 2
- WELL 3

DYERSVILLE
- WELL 2
- WELL 4

EAGLE GROVE
- WELL 3
- WELL 4
- WELL 5

EARLVILLE
- WELL 1
- WELL 2

Appendix D. Public Water Supply Wells in the LUST Bedrock Sampling Project

EAST AMANA
- WELL 2

EDDYVILLE
- WELL 1

EDGEWOOD
- WELL 1
- WELL 2
- WELL 3

ELDRIDGE
- WELL 2
- WELL 3

ELKADER
- WELL 2
- WELL 3

ELMA
- WELL 1

ELY
- WELL 1

EPWORTH
- WELL 2
- WELL 3
- WELL 4

EVANSDALE
- WELL 1
- WELL 3
- WELL 4
- WELL 5

FAIRBANK
- WELL 3
- WELL 4

FARLEY
- WELL 1
- WELL 2
- WELL 3

FARMERSBURG
- WELL 1

FARMINGTON
- WELL 1
- WELL 2

FAYETTE
- WELL 2
- WELL 3

FERTILE
- WELL 1

FLOYD
- WELL 1
- WELL 2

FORT ATKINSON
- WELL 1

FORT DODGE
- WELL 12
- WELL 14
- WELL 15
- WELL 16
- WELL 17
- WELL 8
- WELL 9

FREEPORT
- WELL 1

GARNAVILLO
- WELL 1
- WELL 2

GARNER
- WELL 1
- WELL 2

GARRISON
- WELL 3

GILMORE CITY
- WELL 2
- WELL 3

GLIDDEN
- WELL 5
- WELL 6
- WELL 7

GOODELL
- WELL 1
- WELL 2

GRAFTON
- WELL 1
- WELL 2

GRAND MOUND
- WELL 1
- WELL 2

GREENE
- WELL 1
- WELL 2

GRISWOLD
- WELL 3
- WELL 4
- WELL 5

GUTHRIE CENTER
- WELL 1
- WELL 2
- WELL 3
- WELL 4
- WELL 5

GUTTENBERG
- WELL 1
- WELL 2

HANLONTOWN
- WELL 1

HAWARDEN
- WELL 1
- WELL 2
- WELL 3
- WELL 4
- WELL 5
- WELL 6
- WELL 7
- WELL 8
- WELL 9

HAWKEYE
- WELL 3
- WELL 4

HAZLETON
- WELL 1
- WELL 3

Appendix D. Public Water Supply Wells in the LUST Bedrock Sampling Project

HIAWATHA
- WELL 4
- WELL 5

HOPKINTON
- WELL 2
- WELL 3
- WELL 4

HUDSON
- WELL 5

HUMBOLDT
- SPRING 1
- WELL 1

INDEPENDENCE
- WELL 3
- WELL 4
- WELL 6
- WELL 7

IOWA CITY
- IOWA R
- U OF I WAT
- WELL 1

IOWA FALLS
- WELL ER1
- WELL ER2
- WELL ER3
- WELL PS1
- WELL PS2
- WELL PS3

IRETON
- WELL D-1
- WELL D-2
- WELL S-1
- WELL S-2

JANESVILLE
- WELL 3

JESUP
- WELL 2
- WELL 3
- WELL 4

KELLOGG
- WELL 1
- WELL 2
- WELL 3

KENSETT
- WELL 1
- WELL 2

KEOKUK
- MISS R

KLEMME
- WELL 1
- WELL 2

LA MOTTE
- WELL 1
- WELL 2

LA PORTE CITY
- WELL 2
- WELL 3
- WELL 4

LAKE CITY
- WELL 3
- WELL 4

LAKEVIEW KNOLL
- WELL 1

LAMONT
- WELL 1
- WELL 2

LANSING
- WELL 1
- WELL 2

LECLAIRE
- WELL 1
- WELL 2
- WELL 4

LEDYARD
- WELL 1
- WELL 2

LEMARS
- WELL 6
- WELL 7

LIME SPRINGS
- WELL 1
- WELL 2

LISBON
- WELL 1
- WELL 2
- WELL 3

LIVERMORE
- WELL 2
- WELL 3
- WELL 4

LONG GROVE
- WELL 1

LOST NATION
- WELL 1
- WELL 2

LOW MOOR
- WELL 1
- WELL 2

MANCHESTER
- WELL 4
- WELL 5
- WELL 6
- WELL 7
- WELL 8

MANLY
- WELL 2
- WELL 4

MAQUOKETA
- WELL 3
- WELL 4
- WELL 5
- WELL 6

MARBLE ROCK
- WELL 1

Appendix D. Public Water Supply Wells in the LUST Bedrock Sampling Project

MARION
- WELL 1
- WELL 2
- WELL 3
- WELL 4
- WELL 5

MARQUETTE
- WELL 2
- WELL 3

MARSHALLTOWN
- WELL 14
- WELL 6
- WELL 7
- WELL 8
- WELL 9

MARTELLE
- WELL 1
- WELL 2

MASON CITY
- WELL 10
- WELL 12
- WELL 14
- WELL 16
- WELL 7
- WELL 8
- WELL 9
- WELL A3

MCGREGOR
- WELL 6

MECHANICSVILLE
- WELL 2
- WELL 3

MEDIAPOLIS
- WELL 1
- WELL 3
- WELL 4
- WELL 5
- WELL 6

MERRILL
- WELL 4

MIDDLE AMANA
- WELL 8

MILES
- WELL 1
- WELL 2

MONONA
- WELL 2
- WELL 3

MONTICELLO
- WELL 2
- WELL 3
- WELL 4

MONTOUR
- WELL 1
- WELL 2

MONTROSE
- WELL 1
- WELL 2

MORNING SUN
- WELL 1
- WELL 2

MOUNT PLEASANT
- WELL 4

MOUNT VERNON
- WELL 2
- WELL 3
- WELL 4
- WELL 5
- WELL 6

NASHUA
- WELL 2
- WELL 3
- WELL 4

NEW HARTFORD
- WELL 1
- WELL 2

NORA SPRINGS
- WELL 2
- WELL 3

NORTH LIBERTY
- WELL 1
- WELL 2

NORTHWOOD
- WELL NOR
- WELL SOU

OELWEIN
- WELL 42
- WELL 59
- WELL 80

OLIN
- WELL 1
- WELL 2

OSAGE
- WELL 2
- WELL 4
- WELL 5

OTTUMWA
- BLACK L
- DES M R
- N LAGOON
- S LAGOON

PARKERSBURG
- WELL 1
- WELL 2

Appendix D. Public Water Supply Wells in the LUST Bedrock Sampling Project

PEOSTA
- WELL 1

PERRY
- WELL 12
- WELL 13
- WELL 14
- WELL 18
- WELL 19
- WELL 20
- WELL 21
- WELL 9

POSTVILLE
- WELL 3
- WELL 4
- WELL 5

POWESHIEK WATER ASSO
- WELL 1
- WELL 2
- WELL 3
- WELL 4

PRESTON
- WELL 1
- WELL 2

PRINCETON
- WELL 1

PROTIVIN
- WELL 1
- WELL 2

RED OAK
- WELL 1

RENWICK
- WELL 1
- WELL 2

RIDGEWAY
- WELL 1
- WELL 2

RIVER HEIGHTS
- WELL 1
- WELL 2
- WELL 3

ROCKFORD
- WELL 1
- WELL 2

ROLAND
- WELL 1
- WELL 2

ROLFE
- WELL 1
- WELL 2

ROWAN
- WELL 1

RUDD
- WELL 1
- WELL 2

SALEM
- WELL 3
- WELL 4

SHEFFIELD
- WELL 1
- WELL 2
- WELL 4

SHELL ROCK
- WELL 1
- WELL 2

SHELLSBURG
- WELL 1

SOLON
- WELL 2
- WELL 3

SPRINGVILLE
- WELL 1

ST ANSGAR
- WELL 1
- WELL 2

STACYVILLE
- WELL 1

STOCKTON
- WELL 1
- WELL 2

STORY CITY
- WELL 1
- WELL 2
- WELL 3

STRAWBERRY POINT
- WELL 3
- WELL 4

TAMA
- WELL 3
- WELL 4
- WELL 5

THORNTON
- WELL 1
- WELL 2

TIFFIN
- WELL 1
- WELL 2
- WELL 3

UNION
- WELL 1
- WELL 3

VINCENT
- WELL 1
- WELL 2

VINTON
- WELL 3
- WELL 4

WALCOTT
- WELL 2
- WELL 3

Appendix D. Public Water Supply Wells in the LUST Bedrock Sampling Project

WATERLOO
- WELL 10
- WELL 11
- WELL 12
- WELL 13
- WELL 15
- WELL 17
- WELL 18
- WELL 19
- WELL 22
- WELL 7
- WELL 9

WAUCOMA
- WELL 1

WAUKON
- WELL 2
- WELL 3
- WELL 4

WAVERLY
- WELL 5
- WELL 6
- WELL 7

WAYLAND
- WELL 1
- WELL 2

WEBSTER CITY
- WELL 6

WELLMAN
- WELL 1
- WELL 2

WEST BEND
- WELL 1
- WELL 3
- WELL 5

WEST BURLINGTON
- WELL 4

WEST FIELD
- WELL 3

WEST LIBERTY
- WELL 2
- WELL 3
- WELL 4

WEST UNION
- WELL 3
- WELL 4
- WELL 6

WHEATLAND
- WELL 2

WINFIELD
- WELL 1
- WELL 2

WINTHROP
- WELL 1
- WELL 2
- WELL 3

WOODBINE
- WELL 1
- WELL 2
- WELL 3

WORTHINGTON
- WELL 1

WYOMING
- WELL 1
- WELL 2