FINAL PHASE I REPORT

STATEWIDE METHYL TERTIARY BUTYL ETHER RISK ANALYSIS FOR THE STATE OF NEW HAMPSHIRE

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LIST OF ACRONYMS

AGQS	Ambient Groundwater Quality Standard
ASTs	above ground storage tanks
ATV	all-terrain vehicle
BTEX	benzene, touluene, ethylbenzene, and xylene
CART	classification and regression trees
cy	cubic yards
DRED	Department of Resources and Economic Development
ELVs	end-of-life vehicles
EPA	U.S. Environmental Protection Agency
FHCs	fuel hydrocarbons
ft	feet
ft^2/day	square ft per day
GIS	Geographic Information System
GMZ	groundwater management zone
gpd	gallons per day
gpm	gallons per minute
GRANIT	Geographically Referenced Analysis and Information Transfer
GWHIs	Groundwater Hazard Inventory sites, also referred to as remediation sites
IRSPILL	Immediate response spill
LAST	leaking aboveground storage tank
LNAPL	light nonaqueous phase liquid
LUFT	leaking underground fuel tank
LUST	leaking underground storage tank
MCL	maximum contaminant level
MDEP	Maine Department of Environmental Protection
µg/L	microgram per liter
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
MNA	monitored natural attenuation
MOST	leaking motor oil storage tank
MtBE	methyl tertiary butyl ether
NEIWPCC	New England Interstate Water Pollution Control Commission
NH	New Hampshire

LIST OF ACRONYMS
(Concluded)

NHGS	New Hampshire Geological Survey
NHDES	New Hampshire Department of Environmental Services
NPDES	National Pollutant Discharge Elimination System
NTNC	non-transient non-community
NWWA	National Water Well Association
OPUFs	on premises use facility
ORC	Oxygen Release Compound
PCSs	Potential Contaminant Sites
ppb	parts per billion
ppm	parts per million
PWS	public water supply
PWSA	Public Water Supply Assessment
RCRA	Resource Conservation and Recovery Act
RFG	reformulated gasoline
RPCs	Regional Planning Commissions
SDWA	Safe Drinking Water Act
SPA	sanitary protective area
SWPAs	source water protection area
TAME	tertiary amyl methyl ether
TBA	tert butyl alcohol
UICs	underground injection control
UNH	University of New Hampshire
U.S.	United States
USGS	U.S. Geological Survey
USTs	Underground Storage Tanks
VOC	volatile organic compound
WESTON®	Weston Solutions, Inc.
WHPAs	wellhead protection areas
WMD	Waste Management Division
WSEB	Water Supply Engineering Bureau

EXECUTIVE SUMMARY

EXECUTIVE SUMMARY

Weston Solutions, Inc. was contracted by the New Hampshire Department of Environmental Services (NHDES) to perform a statewide methyl tertiary butyl ether (MtBE) risk analysis. NHDES defined the project as a multi-phase study to (1) assess the risk of MtBE contamination at public water supply (PWS) sources in the state; and (2) develop recommendations for risk reduction. This report represents the results of Phase I of the study, the MtBE risk analysis.

The Phase I study was designed to evaluate risks using two different approaches: an in-depth evaluation of a limited number of PWS sources (48 wells and 1 surface water source), and statistical analyses of available data for PWS wells throughout the state. A brief summary of the methodology and results of the detailed studies and the statewide statistical analyses are provided below.

The State has adopted a health-based drinking water standard for MtBE at 13 micrograms per liter (µg/L). Public water supplies evaluated as part of this study fell into three categories: water supplies with no detections of MtBE; water supplies with detections of MtBE, but no exceedances of the MtBE drinking water standard; and water supplies with concentrations of MtBE exceeding the drinking water standard of 13 µg/L. Remediation at contaminated sites and treatment of drinking water supplies is typically limited to those sites where the concentration of MtBE equals or exceeds 13 µg/L drinking water standard. Under state law, public funds may be spent on remediation and treatment if the health-based drinking water standard is exceeded. While remediation and treatment may be appropriate at lesser concentrations, New Hampshire law currently limits such expenditures of public funds to where the concentrations exceed the drinking water standard.

Detailed Studies

- The PWS sources selected for the detailed studies represented a variety of various locations within the State of New Hampshire, geographic and hydrogeologic settings, contaminant levels, well construction and well yield, and type of community served.
- Of the 49 PWS sources studied, 12 had maximum detected concentrations of MtBE greater than the maximum contaminant level (MCL) of 13 µg/L, 23 had MtBE detections of less than the MCL, and 14 had no detections of MtBE.

- Focused evaluations of nine surface water supply sources were performed to assess the impacts of motorized watercraft on surface water sources.

- Focused evaluations of six remediation sites near PWS wells were performed to assess the effectiveness of cleanup actions at remediation sites.

Statewide Statistical Analysis

- Data was collected from various sources throughout the state and combined into a comprehensive Geographic Information System and Access database, including:
  - PWS well characteristics (depth, yield, type, community served, etc.),
  - Distances between wells and nearest potential sources of MtBE,
  - Numbers and types of potential sources of MtBE in the wellhead protection areas (WHPAs),
  - Geologic and hydrogeologic settings, and
  - Analytical data (MtBE detections and concentrations).

- Transient, non-community water supply systems were not included in the Scope of Work for this study.

- Analytical data were available for a total of 1,482 PWS sources from the years 1993 through 2004, after deleting data for transient systems and wells with only blended water samples.

- Statistical modeling was conducted using two types of models/variable selection routines to predict two responses: (1) whether or not MtBE was detected in a well; and (2) the maximum level of MtBE measured in a well.

- The two variable selection routines used were classification and regression trees, and stepwise logistic and linear regression modeling.

- The statistical analysis was conducted on 187 parameters related to individual PWS sources or their geographic locations to determine if they were correlated with the presence of MtBE.

- 124 parameters were found to have some level of statistically significant effect on the prediction of MtBE in PWS sources.

Phase I Results

The results of the detailed studies were consistent with the results of the statewide statistical analysis. A number of the factors evaluated during the Phase I study were clearly associated with an increased risk of a PWS becoming contaminated with MtBE. These included:

- PWS wells serving Mobile Home Parks,
- PWS wells that shared the same nearest lineament as nearby remediation sites,
- PWS wells that were near remediation/leak/spill sites or had multiple remediation/leak/spill sites within their WHPA, and
- Surface water sources with high levels of motorized watercraft traffic.

A number of additional risk factors were identified that appeared to be related to increased risk, but the statistical correlation was not as strong. These included:

- PWS wells serving larger populations,
- PWS wells in proximity to junkyards,
- PWS wells in proximity to underground storage tanks (USTs)/above ground storage tanks or with multiple USTs within their WHPA,
- PWS wells that had petroleum use or storage in the sanitary protective area (75 to 400 feet radius), and
- PWS wells in proximity to vehicle maintenance activities.

Some hydrogeologic conditions and well construction factors were observed to cause a PWS well to be at higher risk of MtBE contamination. These included:

- Lower yielding PWS wells,
- PWS wells in low transmissivity aquifers (<2,000 square feet per day),
- Shallower PWS wells, and
- Gravel pack wells were more likely to have MtBE detections, but bedrock wells were more likely to have exceedances of the MtBE MCL.

The results of Phase I were not conclusive for some of the potential risk factors that were evaluated. These included:

- All-terrain vehicle/snowmobile trails, and
- Road runoff.

Focused Evaluations

The focused evaluations of nine surface water sources revealed a consistent pattern of seasonal MtBE contamination in lakes and ponds with motorized watercraft activities; however, all MtBE concentrations were below the MCL.

The focused evaluation of remediation sites indicated that although remedial activities at petroleum release sites appeared to be sufficient to protect nearby PWS sources from being impacted by traditional petroleum constituents (primarily benzene, toluene, ethyl benzene, and xylenes); these same activities were not adequate to protect the PWS source from becoming contaminated with MtBE.

Trend Analysis

An evaluation of statewide trends in MtBE contamination in PWS wells indicated that an increasing number of wells were contaminated with MtBE each year from 1993 to 2003, after which there was a minor decrease. New cases of MtBE detections ranged from 6 to 56 wells per year. An estimated 83 PWS wells with MtBE contamination were taken out of service between 1993 and 2003.

SECTION 1

INTRODUCTION

1. INTRODUCTION

Weston Solutions, Inc. (WESTON®) was contracted by the New Hampshire Department of Environmental Services (NHDES), as commissioned by the Oil Discharge and Disposal Cleanup Fund Disbursement Board, to perform a statewide methyl tertiary butyl ether (MtBE) risk analysis. NHDES defined the project as a multi-phase study to: (1) assess the risk of MtBE contamination at public water supply (PWS) wells in the state; and (2) develop recommendations for risk reduction. This report represents the results of Phase I of the study. These results will be used to develop risk reduction recommendations in Phase II of the study.

To complete Phase I of the study, WESTON developed a two pronged approach to assessing the risk of MtBE contamination in PWS wells. One portion of the study evaluated the susceptibility of PWS wells to MtBE contamination by performing detailed case studies on a limited number of individual wells, including an evaluation of the local hydrogeology, well construction and operation, and potential sources of MtBE contamination in the proximity of the wells. The other portion of the study involved performing a geo-statistical analysis of statewide data regarding PWS wells, hydrogeology, geo-political factors, and potential sources of MtBE. The two portions of the Phase I study were conducted concurrently to take advantage of any insights from one portion that could be used to focus the investigative efforts of the other portion of the study. The chief investigator for the detailed case studies was Ellen Moyer, PhD, P.E. of Greenvironment, LLC, a subcontractor to WESTON. The statistical analyses were performed by Ernst Linder, PhD and Elif Acer under a grant to the University of New Hampshire (UNH) Department of Mathematics and Statistics.

The initial tasks of the Phase I study involved performing a review of the literature and NHDES data available for use in the study. A summary of the sources of information reviewed and some of the pertinent information from our review is provided in Section 2. Based on our literature review, we developed a list of risk factors that were considered to be potential contributing factors to a well becoming contaminated with MtBE. Evaluation of these risk factors became the focus of the detailed case studies of individual wells, as well as the basis for selection of parameters for statistical analysis of statewide data. Identification of risk factors is discussed in Section 3. Section 4 describes the sources of data and the methodology used to construct the statewide database. The detailed studies of selected PWS wells are discussed in Section 5. Focused studies of surface water PWS sources and remediation sites in proximity to PWS wells are provided in Section 6 and 7, respectively. The statistical analysis of the data derived from the statewide database is discussed in Section 8. Overall conclusions of Phase I of the Statewide MtBE Risk Analysis are provided in Section 9.

SECTION 2

LITERATURE AND DATA REVIEW

2. LITERATURE AND DATA REVIEW

Before beginning the MtBE Risk Analysis, WESTON reviewed recently published literature regarding sources of MtBE, its prevalence in water supplies, typical pathways for migration, factors affecting its transport in the environment, and studies that attempted to identify water supply wells that were at the highest risk of becoming contaminated with MtBE. NHDES regulations and policies were reviewed to gain an understanding of the requirements for remediating sites where petroleum releases had been documented, and for maintaining and monitoring water supply sources. We also reviewed the various databases that are maintained by NHDES and other state and local agencies to identify data that were available for use in our statewide MtBE risk assessment. Section 4 contains details on the databases that were obtained, the sources and contents of these databases, and how they were incorporated into our study.

There is a large amount of information regarding MtBE in the literature. Rather than try to summarize all of the literature that we reviewed, this section of the report contains a brief summary of only the more pertinent information that shaped the design of our study. A complete listing of the documents that were obtained and reviewed for this study is provided in Appendix A. Below are highlights from the papers that provided the basis for selection of many of the risk factors evaluated in our study.

2.1 HISTORY OF MtBE IN NEW HAMPSHIRE

The gasoline additive MtBE has impacted the groundwater in the State of New Hampshire since its initial use as a substitute for tetraethyl lead, an octane booster phased out of gasoline in the late 1970's (Ayotte et al., 2005). However, significant impacts to the groundwater by MtBE began with the mandates of the Clean Air Acts Amendments of 1990, which required by law the use of reformulated gasoline (RFG) in certain areas of the country to help reduce emissions of carbon monoxide and volatile organic compounds (VOCs) to the environment and therefore result in a reduction in ozone formation. New Hampshire, though not required to use RFG, participated in the program because of the air pollution benefits it provided. Although the oxygen-containing additives to produce RFG may also include ethanol, ethyl tert-butyl ether, di-isopropyl ether, and tert-amyl methyl ether (TAME), MtBE was by far the primary additive utilized by most major oil companies to meet the oxygen requirements. Concentrations of MtBE in gasoline since RFG was adopted in New Hampshire (NH) have ranged from approximately 11% to 15% by volume (Johnson et al., 2000).

MtBE began being included in the VOC list at the state laboratory for New Hampshire in or around 1985, but private laboratories were not required to analyze for the compound until 1998. In addition, initial laboratory detection limits for the compound were generally higher, and therefore low levels were not often detected until 1991 when the standard detection limit for MtBE was decreased from 5 to 0.5 microgram per liter (µg/L).

The initial ambient groundwater quality standard (AGQS) of 100 µg/L was set by NH in 1990. At that time there were no federal regulatory standards for MtBE, and therefore, individual states were able to develop their own. In 1997 the AGQS for MtBE was reduced to 70 parts per billion (ppb). The current standard adopted by NH for the maximum contaminant level (MCL) is 13 µg/L and was adopted May 2000. Currently there is still no federal standard for MtBE in drinking water, although since 1997 there has been a Federal Health Advisory of less than 20 to 40 µg/L. As of 1 January 2007, MtBE will be banned in all petroleum products within the State of NH. The majority of gasoline service stations changed over from MtBE to different oxygenate additives in the spring of 2006.

2.2 PREVIOUS STATEWIDE STUDY OF NEW HAMPSHIRE PUBLIC WATER SUPPLY WELLS AND DOCUMENTED RELEASES

ENSR International and NHDES evaluated the relationship between detections of MtBE in NH PWS and documented releases of petroleum products (Moyer et al., 2002). The incidence of benzene, toluene, ethylbenzene, and xylenes (BTEX) in public water systems was also examined. At the time of the study, NH had a total of 1,147 community and non-transient non-community (NTNC) public water systems. These are the types of systems that are required to test regularly for VOCs. (Transient non-community systems, defined as a system, which serves at least 25 people, for at least 60 days per year, are not required to test for VOCs and were not included in this study.) As of 31 December 2000, the NH state laboratory database (representing approximately 65 to 70% of all compliance testing data) showed that MtBE had been detected in 239 or about 21% of NH community and NTNC water systems. Seventeen PWS in the database, or about 1.5% of community and NTNC water systems, had one or more samples with MtBE concentrations exceeding the NH MCL of 13 µg/L. Six public water systems had one or more samples with concentrations of benzene, a known human carcinogen, exceeding its MCL of 5 μg/L.

About 42% of the PWS in which MtBE had been detected had documented potential sources of gasoline, diesel, or fuel oil that could account for the MtBE detections, with 90% of these sources being leaking underground storage tanks (LUSTs) and the rest leaking aboveground storage tanks (LASTs) or junkyards. A potential link was considered to exist only if the potential source was located in the source water protection area (SWPA) of the public water system and reported 10 years or less prior to the first detection of MtBE in the public water system. Eight, or about 47%, of the PWS with sample concentration(s) of MtBE above the state MCL of 13 μg/L were associated with documented potential sources. Another 29% of the public water systems with MtBE concentration(s) above the current state MCL were associated with known petroleum product activity, mostly the presence of underground storage tanks (USTs) in the SWPA, although no releases were documented. Thus, three-quarters of the PWS with concentrations above the state MCL had petroleum storage and/or releases documented in the SWPA. Given the conservative assumptions that were made throughout this study, it is significant that this high a percentage of affected PWS had readily identifiable potential sources based purely on publicly available documents.

The study also suggested that watercraft may be possible sources of contamination of drinking water, not just lake water. Snowmobiles with their similarly inefficient engines may also be sources. Approximately 44% of the public water systems with detections of MtBE had no documented potential sources or any petroleum product activity within the SWPA. However, many of these systems had surface water bodies in their SWPA that could support motorized watercraft traffic.

In summary, considering the documented potential land-based sources and the possibility of some influence from surface water, a potential land- or surface-water-based source of MtBE could be identified for about 63% of the PWS with MtBE detections based on publicly available documents and Geographic Information System (GIS) information. More formal focused site investigations would be necessary to identify sources for the remaining 37% of the public water systems with MtBE detections, assuming the contamination is from point sources. Public water systems whose MtBE concentrations exceeded the state MCL were more likely to be situated near documented potential sources, the majority of those sources being LUSTs (Moyer et al., 2002).

2.3 NEW ENGLAND INTERSTATE WATER POLLUTION CONTROL COMMISSION SURVEY RESULTS FOR NEW HAMPSHIRE

In 2002, the New England Interstate Water Pollution Control Commission (NEIWPCC) received a grant from the United States (U.S.) Environmental Protection Agency (EPA) Office of Underground Storage Tanks to develop and conduct a survey of the states, the District of Columbia, and the U.S. territories to determine how MtBE and other oxygenate contamination is affecting state LUST programs and the cleanup of contaminated sites. The survey consisted primarily of multiple choice questions requesting general LUST site and oxygenate information. This survey was a follow-up to a survey conducted in 2000 by NEIWPCC that focused mostly on state experiences with MtBE at LUST sites. The following is a summary of the results for NH:

1. Cleanup standards for soil, groundwater, and drinking water were updated on 4 May 2000. The standard for soil was decreased from 2 parts per million (ppm) to 0.13 ppm, groundwater from 70 µg/L to 13 µg/L, and drinking water from 70 µg/L to 13 µg/L (primary) and 20 µg/L (secondary). The standards were effective 1 January 2001.

2. NH requires sampling and analysis of soil and groundwater for MtBE 80 to 100% of the time from LUSTs containing gasoline (but not heating oil, jet fuel, diesel, or other petroleum products).

3. Although there is potential for MtBE "diving plumes," NH does not investigate MtBE plumes differently from BTEX plumes. Only 11 states nationwide require 3-dimensional characterization of plumes, and less than half of all states take extra steps to make sure oxygenates do not migrate beyond standard monitoring parameters. To ensure oxygenates are not migrating beyond standard monitoring parameters, NH conducts extensive private well sampling when MtBE is found in drinking water wells.

4. In 2002, MtBE was detected in 60% of groundwater samples and 50% of soil samples collected in association with gasoline releases in NH.

5. NH has more than 20 sites where MtBE has been detected in soil or groundwater, but no source has been identified.

6. NH considers reopening previously closed sites where groundwater contamination exceeds the AGQS. More than seven sites have been reopened due to post-closure detection of oxygenates.

7. The average MtBE plume length in NH is 101 to 250 feet (ft).

8. The maximum observed MtBE plume length in NH is 1,000 to 5,000 ft.

9. NHDES and U.S. Geological Survey (USGS) conducted random sampling of drinking water wells in the state. Twenty five percent of wells tested have some level of MtBE. Approximately 30,000 to 40,000 public and private drinking water wells in NH are estimated to be contaminated by MtBE at some level.

10. Methyl tertiary butyl ether drives the cleanup at 10% of NH LUST sites. Of the 13 worst LUST sites, 3 were MtBE only.

11. As of the publication of the NEIWPCC study in 2002, NH had remediated to closure 11 to 50 sites with MtBE contamination.

12. Significant non-UST sources of MtBE contamination in NH have been linked to auto repair and wrecking companies, junkyards, residential dumping, auto accidents, and use of gasoline for brush pile burning.

2.4 STATE OF MAINE STUDY

The State of Maine produced a preliminary report in October 1998 on the statewide occurrence of MtBE in Maine's drinking water. The study was conducted by the Bureau of Health, the Maine Department of Environmental Protection and the Maine Geological Survey. Water samples were obtained from 951 randomly selected household wells and 793 regulated non-transient public water supplies. The results of their study for household wells and other private household water supplies are summarized below.

- Factors found *not* to be associated with MtBE detection include: type of well or water supply and proximity to gasoline storage tanks.

- The risk of required RFG use:

  - In areas of high population density (greater than 180 people per square mile), the risk of MtBE detection was 1.3 times higher in areas where RFG use is required compared to other areas.

  - In areas of low population density (less than 180 people per square mile), the risk of MtBE detection was 2.0 times higher in areas where RFG use is required compared to other areas.

- The risk of high population density:
  - In areas where RFG use is required, the risk of MtBE detection was 1.4 times higher in areas of high population density compared to other areas.
  - In areas where RFG use is not required, the risk of MtBE detection was 2.1 times higher in areas of high population density compared to other areas.

The results for public water supplies are as follows:

- Factors that were found not to be associated with MtBE detection included: type of well or water supply and proximity to gasoline storage tanks.
- Type of water use establishment was found to be associated with MtBE detection. Public water supplies that were businesses or mobile home parks were about twice as likely to have detectable levels of MtBE as compared with community water supplies and schools.
- Population density was a significant risk factor within areas where RFG use was required. However, unlike the private water data, population density was not a significant risk factor in areas where RFG is not required.
- The risk of required RFG use:
  - In areas of high population density, the risk of MtBE detection was 4.1 times higher in areas where RFG use is required compared to other areas.
  - In areas of low population density, the risk of MtBE detection was 1.7 times higher in areas where RFG use is required compared to other areas.
- The risk of population density:
  - In areas where RFG use is required, the risk of MtBE detection was 1.6 times higher in areas of high population density compared to other areas.
  - In areas where RFG use is not required, population density appeared to not be a risk factor.

2.5 U.S. GEOLOGICAL SURVEY STUDY OF MtBE AND COMMUNITY WATER SUPPLY WELLS

Johnson et al., (2000) summarized some of the history of the use of MtBE, its physical and chemical properties, its fate in the environment, and some suggestions for predicting the risk of a water supply well becoming contaminated with MtBE. Use of MtBE began in 1979, but with implementation of the Clean Air Act Amendments of 1990, the use of RFG to reduce emissions became common. MtBE differs from the other major toxic petroleum constituents (BTEX) in that it has a significantly higher solubility in groundwater and it is more resistant to biodegradation. This results in MtBE being more persistent and mobile in the environment.

Three primary mechanisms can reduce the concentration of MtBE and other contaminants in the environment before they reach a water supply well: dilution, dispersion, and degradation. However, per Johnson et al., it is degradation, followed by dilution that will control the concentrations of MtBE in a well, since little dispersion can be expected for a source that is within the capture zone of a well.

Degradation time is a function of source size and strength, groundwater flow rate, and pumping rate as well as the in situ biodegradation rate. Johnson et al., estimates that typically at least 10 years will be required for MtBE from a typical LUST to no longer be a threat to drinking water sources. (This assumes a 2-year half-life for MtBE and 5 to 6 half-lives to reduce the MtBE concentrations to tolerable levels.) To predict whether a well will be impacted by MtBE, Johnson et al., suggests modeling the 10-year capture zone area of the well and determining the areal density of significant sources in the vicinity of the well to estimate the number of sources that will on average contaminate the well at a concentration above tolerable levels. The probability of a well being impacted by MtBE can then be calculated as a function of the number of sources within the 10-year capture zone of the well.

Another factor which Johnson et al., considered important was the pumping stress factor. This was defined as the pumping rate of a well divided by the local aquifer yield. In other words, the volume of water that is pumped out of a well compared to the maximum volume that would normally flow through a wells capture zone under non-pumping conditions. Johnson et al.'s, reasoning was that for a fixed aquifer yield, the higher the pumping rate, the greater the probability that a contaminant plume would be drawn into the well. Under low pumping conditions, a plume may flow past the well (either above the screened interval of the well or next to the well) without impacting it. However, a high pumping stress factor could have the opposite effect, if the additional water pumped is insufficient to dilute the MtBE to non-detect levels.

2.6 UNIVERSITY OF CONNECTICUT AND U.S. GEOLOGICAL SURVEY STUDIES OF MtBE IN DIESEL, HEATING OIL, AND WASTE OIL

Robbins et al., (LUSTLine Bulletin 32, June 1999) presented evidence of the presence of MtBE in diesel and heating oil. The source of the MtBE in these fuels was unknown, but it was postulated that contamination of these two products with gasoline could have easily been the cause. Typically, the same pipelines, barges, and tank trucks are used for transporting gasoline, diesel, and heating oil. The presence of MtBE in these fuels was common and the concentrations of MtBE were sufficiently high to cause MtBE exceedances in water supply wells. USGS has documented the presence of environmentally significant concentrations of MtBE in waste oil (Baker et al., 2000).

2.7 U.S. GEOLOGICAL SURVEY STUDY OF MtBE IN STORMWATER

USGS conducted a study of MtBE in urban stormwater. Delzer et al., (1996) found that MtBE was the seventh most frequently detected VOC in urban stormwater, detected in 6.9% of the samples collected. Detected concentrations of MtBE ranged from 0.2 to 8.7 µg/L with a median of 1.5 µg/L.

2.8 UNIVERSITY OF NEW HAMPSHIRE STUDY OF MtBE IN PAUGUS BAY

A study of MtBE in Paugus Bay in Laconia, NH was conducted for NHDES by the Environmental Research Group at UNH. Kinner et al., (2003) looked at the temporal and spatial variability of MtBE in Paugus Bay to determine if the MtBE in Laconia drinking water supply was correlated to boating activities. Kinner et al., concluded that the contribution of MtBE from motor boats during late spring and summer was significant and was compounded by thermal stratification in the bay. Inputs of MtBE from stormwater discharge and atmospheric precipitation were insignificant. The severity of the impact of MtBE was attributed to MtBE being 42 times as soluble in water as in air and 2-stroke engines combusting only 70 to 75% of their fuel and exhausting the rest (uncombusted) into the water column. Additional discussion of the results of this study is provided in Section 6 of this report, Focused Evaluation of Surface Water Sources.

2.9 U.S. GEOLOGICAL SURVEY STUDY OF VOLATILE ORGANIC COMPOUNDS OCCURRENCE IN GROUNDWATER AND SURFACE WATER

USGS published a study in 2003 of the occurrence and temporal variability of MtBE and other VOCs in drinking water sources (both groundwater and surface water). Delzer and Ivahnenko observed a weak seasonal pattern in samples collected from reservoirs and lakes where gasoline oxygenates and other gasoline compounds were detected more frequently during spring and summer. This was presumed to be the result of increased use of motorized water craft during these seasons. MtBE was the most frequently detected VOC in this study.

2.10 UNIVERSITY OF CALIFORNIA AT DAVIS STUDY OF MtBE IN SURFACE WATER FROM WATERCRAFT

Reuter et al., published a study in 1998 to evaluate the relative contribution of motorized watercraft as a source of MtBE, seasonal distribution of MtBE, extent of MtBE transport from surface waters to deeper portions of lakes, loss rate of MtBE from the water column, and carry-over of MtBE between years.

Low concentrations of MtBE in lakes during spring months show that precipitation or highway runoff did not significantly contribute to MtBE content. Concentrations of MtBE in surface water increased in early to mid May.

There was a strong correlation between MtBE level and watercraft use throughout the study. The data were not sufficient to separate the relative contribution of various makes/models of watercraft. Although findings of this study may be applicable to other surface water bodies, other lakes/reservoirs have unique features that must be accounted for. These include: thermocline stability; volume; lake hydrodynamics; water-use schedules; depth of water intake system, etc. Simulation models are required for lake management and environmental planning. The paper discussed a 10-year ongoing study that involved collecting groundwater samples between 1993 and 2002 from urban and rural areas throughout the U.S.

2.11 U.S. GEOLOGICAL SURVEY STUDY OF MtBE AND GASOLINE OCCURRENCE IN GROUNDWATER

USGS recently issued a paper on the occurrence of MtBE and gasoline hydrocarbons in groundwater of the U.S. (Moran et al., 2005). They summarized three types of studies: major aquifer surveys, urban land-use studies, and agricultural land-use studies finding that the detection frequency of MtBE was highest in monitoring wells in urban areas and in public supply wells versus private water supply wells and groundwater underlying rural land use areas. Moran et al., also found the detection frequency of MtBE to be strongly associated with use of MtBE in gasoline and higher recharge rates.

Factors that were found by Moran et al., to be weakly associated with MtBE detection included the density of LUSTs, higher soil permeability, and aquifer consolidation. Interestingly, the probability of MtBE detection was not significantly related to the density of aboveground or underground gasoline storage tanks in the vicinity of the well. The probability of detecting MtBE was higher in aquifers of unconsolidated material as opposed to consolidated material (bedrock). Moran et al., also mentioned evaporative losses from tanks or pipelines, incomplete combustion in engines, urban stormwater runoff, and exhaust and leaks from motorized watercraft as non-point sources that could contribute to MtBE in the environment.

Only 13 groundwater samples from all study types, or 0.3%, had concentrations of MtBE that exceeded the lower limit of EPA's drinking water advisory of 20 to 40 µg/L. Samples with a detected concentration of MtBE are most intensively represented in the northeast region of the country. The overall detection frequency of MtBE was 7.6%, or 300 of a total of 3,964 samples. The overall detection frequency of one or more gasoline hydrocarbons (such as BTEX compounds) was 23.5%, or 931 of a total of 3,938 samples. TAME and diisopropyl ether were each detected in less than 1% of samples, and ethyl tert butyl ether was not detected.

Moran et al., point out that, due to fate and transport differences between MtBE and gasoline hydrocarbons, the occurrence of gasoline hydrocarbons together with MtBE should decrease as distance from a gasoline release increases. MtBE and gasoline hydrocarbons occurred together more frequently in samples with relatively high MtBE concentrations (>20 µg/L). The paper points out that an important aspect of the RFG program is the limitation of benzene in RFG to <1% by volume. Normally, gasoline contains between 1 and 1.5% by volume. So gasoline in areas of high MtBE use should contain less benzene relative to areas of low MtBE use, and detection frequencies and concentrations of benzene should be lower in areas of high MtBE use relative to areas of low MtBE use (Moran et al., 2005)

2.12 CALIFORNIA U.S. ENVIRONMENTAL PROTECTION AGENCY STUDY OF FUEL HYDROCARBONS AND OXYGENATES IN GROUNDWATER

A study of the impact of fuel hydrocarbons (FHC) and oxygenates on groundwater resources was published by Shih et al., in 2004. This study evaluated the potential for groundwater resource contamination by FHC and oxygenates by examining their occurrence, distribution, and spatial extent in groundwater beneath leaking underground fuel tank facilities in greater Los Angeles, California.

The study concluded that a large proportion of UST systems at gasoline stations leak, including upgraded double-wall systems. The number of leaks indicates that the problem is primarily in the design of the system, which arises from real estate limitations, fire defense considerations, and defense against accidents and vandalism. In the absence of completely new design and construction of the system that emphasizes detection, repair, and containment, an effective management strategy may involve placing greater emphasis on a UST program for ensuring adequate enforcement and compliance with existing UST regulations.

2.13 MOREAU SUMMARY OF TYPES OF UNDERGROUND STORAGE TANKS RELEASES

Marcel Moreau, an independent consultant who has worked exclusively in the field of liquid storage systems for over 20 years, contemplated the different ways that MtBE could be released to the environment from USTs in the June 1999 issue of the Maine Installer. In addition to the usual methods of spills, overfilling, and tank or piping holes, Moreau pointed out the potential for vapor releases, exacerbated by the widespread use of pressure/vacuum vents, which maintain positive pressure in the tanks.

2.14 U.S. GEOLOGICAL SURVEY STUDY OF ATMOSPHERIC DEPOSITION POTENTIAL FOR MtBE

In a 1998 USGS paper, Squillace et al., indicated that MtBE's high solubility in water and low Henry's Law Constant make it likely that atmospheric deposition of MtBE by precipitation is a conceivable pathway for MtBE to enter surface water or groundwater drinking water sources. Concentrations of MtBE in urban air appear to be on the order of 1 ppm by volume, resulting in an equilibrium concentration in precipitation of 1 µg/L or less.

2.15 U.S. ENVIRONMENTAL PROTECTION AGENCY AND NATIONAL WATER WELL ASSOCIATION AQUIFER VULNERABILITY MAPPING

EPA and the National Water Well Association developed a system to map potential aquifer vulnerability named "DRASTIC" (Florida Geographic Data Library Documentation, November 2002). The parameters they felt could be used to evaluate aquifer vulnerability were depth to groundwater, net recharge, aquifer media, soil media, topography, impact of vadose zone, and hydraulic conductivity. Maps defining these parameters are used to estimate the vulnerability of an aquifer to pollution introduced on the ground's surface.

2.16 U.S. GEOLOGICAL SURVEY LITERATURE REVIEW OF MtBE SOURCES IN DRINKING WATER

USGS conducted a review of literature for MtBE sources in drinking water in the U.S. in 2003. Delzer and Ivahnenko summarized their review of various studies. Collectively, the studies indicated that (1) MtBE occurred in public drinking water systems supplied by groundwater and surface water; (2) population density and reformulated gasoline use were significant factors for MtBE detection in water supplies; and (3) type of well, water supply, and proximity to gasoline storage tanks did not seem to be associated with MtBE detection.

2.17 U.S. GEOLOGICAL SURVEY STUDY OF MtBE IN PRIVATE AND PUBLIC WELLS IN ROCKINGHAM COUNTY, NEW HAMPSHIRE

Another recent study conducted by USGS (Ayotte et al., 2005) found that rates of MtBE detection in southeast NH were significantly higher than nationwide rates in the earlier study. Forty percent of samples from public wells and 21% of samples from private wells were found to have MtBE detections. Ayotte et al., found that MtBE concentrations correlated strongly with urban factors such as population density. MtBE was also correlated positively with greater well depth in public supply wells. The rate of MtBE occurrence was found to vary depending upon the category of public water system: community systems had the highest rate of occurrence at 53%, followed by transient non-community and NTNC at 35 and 27%, respectively.

2.18 U.S. GEOLOGICAL SURVEY STUDY OF MtBE OCCURRENCE IN THE NORTHEAST AND MID-ATLANTIC U.S.

USGS performed a study to estimate the likelihood of MtBE occurrence in drinking water supplied by groundwater sources in the northeast and mid-Atlantic regions of the U.S. Squillace and Moran (2000) found that a number of factors that describe the conditions in the vicinity of the well were related to the frequency of detection of MtBE. Three factors most effectively explained the occurrence of MtBE in a multivariate logistic regression model. These factors were: MtBE use in gasoline in the study area, the density of above ground storage tanks (ASTs) and USTs, and a soil erodability factor. The density of0* LUST, aquifer permeability, percentage of sand, depth to rock, groundwater use, water table depth, soil permeability, land surface slope, groundwater recharge, and well type (drinking or monitoring) were other factors that were tested, but which were not considered to be significant.

2.19 U.S. GEOLOGICAL SURVEY REPORT ON MONITORED NATURAL ATTENUATION OF MtBE

EPA recently issued a report "*Monitored Natural Attenuation of MtBE as a Risk Management Option at Leaking Underground Storage Tank Sites"* (Wilson et al., 2005), with particular attention to biodegradation processes. MtBE has been shown to biodegrade under aerobic, nitrate-reducing, sulfate-reducing, iron-reducing, and methanogenic conditions. However, there seems to be a wide variation from one site to another in the distribution and activity of native microorganisms that degrade MtBE. Tert butyl alcohol (TBA) is the first MtBE biodegradation product, and subsequent products can include formaldehyde, acetone, and 2-propanol. Anaerobic biodegradation of TBA has not been well documented. In many cases, TBA produced from MtBE biodegradation accumulates in the groundwater. The report gives guidance on evaluating and quantifying biodegradation as a part of Monitored Natural Attenuation (MNA). The report stresses the importance of not confusing attenuation over time in monitoring wells downgradient of the source with attenuation along the flow path of the aquifer.

SECTION 3

INDENTIFICATION OF POTENTIAL RISK FACTORS

3. IDENTIFICATION OF POTENTIAL RISK FACTORS

After literature review and completion of several of the detailed studies of PWS wells, the list of potential risk factors originally submitted in the proposal for this project was refined. The revised list of potential risk factors is shown on Table 3-1. The table indicates which risk factors could be evaluated in the detailed studies and/or in the statistical analyses. Data are either insufficient or inconsistent for evaluating several of the risk factors; these included aquifer stress, well age, and zoning.

Risk factors are organized into five general groups. Well characteristics and setting risk factors are related to the type of PWS facility, the geological setting, and well age and integrity. Well and sanitary protective area (SPA, also referred to as sanitary radius) operation and maintenance deals with factors over which the well owner/operator generally has control. MtBE point source risk factors include petroleum use, storage, and release point locations. MtBE non-point source risk factors include linear and areal features such as roads and surface water. Finally, land use risk factors deal with the nature and extent of human development near the well.

The risk factors in Table 3-1 were evaluated to the extent possible in Phase I of this project in the detailed studies and the statistical analyses. This work is described in the following sections of this report.

Table 3-1

Potential Risk Factors

Table 3-1
Potential Risk Factors

Potential Risk Factor	Detailed Studies	Statistical Analyses
Well Characteristics and Setting		
PWS type (e.g., Condo, School, etc.)	X	X
Well/aquifer type (e.g., bedrock or gravel packed well)	X	X
Well depth	X	X
Depth-to-bedrock	X	X
Depth-to-groundwater	X	X
Bedrock fractures	X	
Location in wetland or floodplain	X	X
Steepness of topography	X	X
Lineaments	X	X
Transmissivity	X	X
Safe yield	X	X
Well integrity (e.g., seal, stickup)	X	X
WHPA/SWPA area	X	X
Casing depth into bedrock		X
Aquifer stress (i.e., pumping rate vs. water availability)		
Age of well		
Well and SPA Operation and Maintenance		
Petroleum use, storage, or release in the SPA	X	X
Poor housekeeping in the SPA	X	X
Road runoff infiltrating SPA	X	
Operator inadequate certification	X	X
MtBE Point Sources		
Remediation sites, LASTs, LUSTs, UICs, OPUFs, spills	X	X
Nature and extent of site assessment and remediation	X	
Registered petroleum USTs and ASTs	X	X
Unregistered petroleum USTs and ASTs	X	
Official junkyards	X	X
Junked vehicles (unofficial junkyards)	X	
Vehicle repairs	X	X
Construction yards, car washes, highway garages	X	X
Homeowner improper petroleum use, storage, or disposal	X	
Septic systems	X	X
MtBE Non-Point Sources		
Roads and railroads	X	X
Infiltration of road runoff	X	
Official ATV/snowmobile trails	X	X
Unofficial ATV/snowmobile trails	X	
Surface water	X	X
Boat traffic, marinas, boat ramps	X	
Land Use		
Population density	X	X
Zoning		
Urban cover	X	X
Land use	X	
Location in RFG or non-RFG county	X	X
Inactive wells nearby	X	
Poor housekeeping in the WHPA/SWPA	X	

SECTION 4

CONSTRUCTION OF STATEWIDE DATABASE

4. CONSTRUCTION OF STATEWIDE DATABASE

WESTON performed a review of the types of data available in existing databases maintained by various state agencies to identify data that related to the risk factors discussed in Section 3 and that could be used for the MtBE Risk Analysis. The sources of the data and the types of data obtained are discussed in Subsection 4.1. Much of the data were available in GIS format, or tabulated with location coordinates. These data were compiled into a single comprehensive GIS database using the ESRI ArcGis suite of software. All of the tabulated data were compiled into a single comprehensive Microsoft Access database. Additional tabulated data relating to spatial characteristics of the wells and potential contaminant sources were generated by conducting spatial queries on the GIS database. The types of spatial queries that were conducted are discussed in Subsection 4.4. The tabular results of the spatial queries were loaded into the comprehensive Access database. The Access database was then queried to generate tables of data in Microsoft Excel format for statistical analyses. The data provided to UNH for the statistical analyses are discussed in Subsection 8.1.

4.1 DATA SOURCES

To obtain data for construction of the statewide database, WESTON spoke to various personnel at NHDES in the Waste Management Division (WMD) and the Water Supply Engineering Bureau (WSEB). The two primary sources of data used in the study that were obtained from NHDES were the Safe Drinking Water Act (SDWA) compliance testing analytical database managed by the WSEB (WSEB Analytical Database), and the OneStop GIS Database managed by the WMD (OneStop). The OneStop database was supplemented with additional GIS data from the Complex Systems Research Center at UNH (Complex Systems). The GIS database managed by Complex Systems is called GRANIT (Geographically Referenced Analysis and Information Transfer). GRANIT contains information regarding bedrock and surficial geology, lineaments, aquifer data, census data, wetlands, floodplains, Digital Elevation Models, and Digital Ortho Photos.

In addition to the databases listed above, many smaller, more specialized databases were obtained from various departments at NHDES, the Regional Planning Commissions (RPCs), and other state agencies such as the Department of Resources and Economic Development (DRED) and the New Hampshire Geological Survey (NHGS). Table 4-1 provides a summary of the databases obtained, the sources of the databases, and the types of data obtained from these sources. The data obtained from OneStop, GRANIT, RPCs, and DRED were provided in GIS format. All of the other databases were provided in tabular form, either in Microsoft Access or Excel format. Metadata for all of the data obtained from the various sources is provided in Appendix B. Most of the databases were obtained between November 2004 and January 2005. No further updates of the databases were obtained during the course of this study.

4.2 ANALYTICAL DATA

The WSEB of NHDES maintains a SDWA compliance testing analytical database (WSEB Analytical Database). The MtBE data in this database was the most essential element of the statistical analysis. For this reason, it is important to discuss the attributes and limitations of this data, and the decisions that were made to deal with these limitations.

The WSEB Analytical Database contains analytical data for “community”, “NTNC”, and “transient, non-community” PWS wells. We obtained VOC, MtBE, chloride, sodium, and nitrate data for all of these wells from the WSEB Analytical Database for our study. However, since the scope of work for this project did not include evaluation of “transient, non-community” PWS wells, the data for this category of wells were not used in our study.

4.2.1 Completeness of the Water Supply Engineering Bureau Analytical Database

Early records at NHDES document detections of MtBE occurring as early as 1987, which corresponds with the year in which the state laboratory began reporting and including MtBE in the VOC analysis. According to records at NHDES, as many as 64 new cases of MtBE detects occurred between the years 1987 and 1992. However, the WSEB Analytical Database provided to WESTON for use in this study did not include any detections of MtBE for the years 1987 through 1992. Tables 4-2 and 4-3 provide a summary of the number MtBE sample records and the number of unique wells or well blends that were entered into the WSEB Analytical Database each year from 1993 through 2004. Table 4-2 is a summary of the data collected from

Table 4-1
MtBE Risk Analysis
Sources of Data

Database	Source of Database	Types of Data Obtained	Data Format
Safe Drinking Water Act (SDWA) Compliance Testing Analytical Data	Water Supply Engineering Bureau - Laurie Cullerot	Analytical data, including MtBE, VOC, sodium, chloride, & nitrate concentrations.	Tabular
Public Water Supply System Well Construction Data	Water Supply Engineering Bureau - Laurie Cullerot	Well depth, permitted production volume, yield, safe yield.	Tabular
OneStop Database	Waste Management Division - George Hastings	Groundwater Hazard Inventory (aka remediation sties), Local Inventory of Potential Contaminant Sites, ASTs, USTs, Automobile Salvage Yards, Hazardous Waste Generators, NPDES Outfalls, Public Water Supply Wells, Wellhead Protection Areas, Water Well Inventory.	GIS
GRANIT GIS Database	UNH Complex Systems Research Center - Fay Rubin/Jennifer Lingeman	Surficial & Bedrock Geology, Lineaments, Terrain, Air Photos, Roads & Trails, Railroads, Soils, Surface Water, Pipelines, Watershed Boundaries, Aquifers, Population Density, Wetlands Inventory, Floodplains, Roads, Watersheds, Land Use	GIS
Well Completion Report Database	NH Water Well Board/NH Geological Survey - Rick Chorman/Derek Bennett	Well completion Report Data and approximate coordinates for approximately 33,000 public and private wells installed since 1984.	Tabular
Water Use Database	NH Geological Survey - Rick Chorman/Derek Bennett	Monthly water usage for registered water users (> 20,000 gallons per day).	Tabular
Underground Storage Tank Database	NHDES - Tom Beaulieu and George Hastings	Material stored, capacity, materials of construction, double containment, vapor recovery, date of installation.	Tabular
NHGS Statewide Monitoring Well Network	NH Geological Survey - Rick Chorman/Derek Bennett	Monthly water level measurements in 22 monitoring wells throughout the state.	Tabular
Public Water Supply Assessment Database	Water Supply Engineering Bureau - Paul Susca/Laurie Cullerot	Assessments of the vulnerability of PWS sources to contaminant sources.	Tabular
Sanitary Survey Database	Water Supply Engineering Bureau - Paul Susca/Laurie Cullerot	PWS system violations or deficiencies observed during NHDES site visits.	Tabular
Precipitation Data	National Oceanicgraphic and Atmospheric Administration	Daily precipitation data at weather stations throughout the state.	Tabular
Recreational Trail Maps	Department of Resources and Economic Development	Locations of Recreational Trails in the State	GIS
Zoning Maps	Regional Planning Commissions	Local Zoning Maps	GIS
Treatment Entities	Water Supply Engineering Bureau - Laurie Cullerot	Types of treatment processes used for public water supplies.	Tabular

Table 4-2
WSEB Analytical Database Sample and Well Counts
(Individual Wells Only)

Year	Number of Samples Collected*	Number of Wells Sampled	Number of Samples with MtBE Detections	Number of Wells with MtBE Detections	% of Samples with MtBE Detections	% of Wells with MtBE Detections	Mean MtBE Concentrations in Samples (ug/L)	Mean MtBE Concentrations in Wells (ug/L)
1993	761	716	22	20	3%	3%	0.33	0.33
1994	818	631	17	12	2%	2%	0.32	0.29
1995	672	549	17	14	3%	3%	0.30	0.30
1996	105	77	49	37	47%	48%	1.65	1.90
1997	144	107	83	61	58%	57%	1.23	1.18
1998	153	120	107	83	70%	69%	2.09	1.77
1999	1143	888	172	125	15%	14%	0.78	0.59
2000	904	715	197	124	22%	17%	0.99	0.66
2001	1063	692	284	121	27%	18%	1.03	0.61
2002	1250	758	411	140	33%	19%	1.20	0.65
2003	1342	775	441	151	33%	20%	1.28	0.64
2004	1240	726	380	145	31%	20%	1.32	0.72

* The large jump in the number of samples collected in 1999 was due to the requirement by the legislature that all community and non-community non-transient systems be sampled for MtBE in that year.

Table 4-3
WSEB Analytical Database Sample and Well Counts
(Includes Blended Samples)

Year	Number of Samples Collected*	Number of Wells/Blends Sampled	Number of Samples with MtBE Detections	Number of Wells/Blends with MtBE Detections	% of Samples with MtBE Detections	% of Wells/Blends with MtBE Detections	% of Samples that were Blends	Mean MtBE Concentrations in Samples (ug/L)	Mean MtBE Concentrations in Wells/Blends (ug/L)
1993	972	920	23	21	2.4%	2.3%	21.7%	0.34	0.34
1994	1061	826	20	15	1.9%	1.8%	22.9%	0.32	0.30
1995	897	749	23	19	2.6%	2.5%	25.1%	0.30	0.30
1996	354	257	71	53	20.1%	20.6%	70.3%	0.83	0.87
1997	366	291	103	79	28.1%	27.1%	60.7%	0.71	0.67
1998	381	306	137	108	36.0%	35.3%	59.8%	1.10	0.96
1999	1469	1158	219	162	14.9%	14.0%	22.2%	0.73	0.56
2000	1149	913	254	163	22.1%	17.9%	21.3%	1.04	0.66
2001	1355	897	370	160	27.3%	17.8%	21.5%	0.96	0.58
2002	1623	991	562	200	34.6%	20.2%	23.0%	1.13	0.63
2003	1707	997	602	212	35.3%	21.3%	21.4%	1.20	0.63
2004	1603	942	530	204	33.1%	21.7%	22.6%	1.26	0.70

* The large jump in the number of samples collected in 1999 was due to the requirement by the legislature that all community and non-community non-transient systems be sampled for MtBE in that year.

individual wells only. Table 4-3 is a summary of all data, including the records for the samples that were blends of water samples from two or more individual wells.

It should be noted that the WSEB Analytical Database did not include entries of non-detects, and did not list detection limits for non-detects. In order to proceed with the statistical analyses, WESTON created default non-detect values for each well for each sampling occasion for which WSEB had records indicating compliance sampling had been performed, but for which no detections (or non-detections) had been reported. We assumed a default detection limit of 0.5 µg/L for MtBE, since records of detection limits were not available for all of the analyses. This default detection limit was selected because it is the detection limit that has been reported by the NHDES Laboratory since 1991. Detection limits reported by private laboratories likely varied from the assumed 0.5 µg/L, but there was no efficient method of recreating these data.

A review of the number of MtBE sample records and the number of wells and well blends sampled during each of the years between 1993 and 2004 indicates a discrepancy in the data for the years 1996, 1997, and 1998. Either a significantly fewer number of wells were sampled for VOCs during these years or the database is not complete. The reduced number of samples collected during these years may have been a result of the WSEB VOC Waiver Program that NHDES initiated in 1993. The Waiver Program granted either a 3-year or a 6-year VOC sampling waiver to PWS systems that met certain criteria, one of which was no detections of contaminants for the previous 3 years. During the 3 years in question (1996 through 1998), the fraction of samples and wells with MtBE detects was much higher than during previous or later years. If clean wells were entered in the Waiver Program, and therefore not required to sample, this could have resulted in the fewer samples and higher detection frequencies observed. However, it is unclear why this was observed in 1996, 1997, and 1998, rather than in 1993 when the program began. Although NHDES maintains a database (Microsoft Excel spreadsheet) of PWS systems currently in the Waiver Program, there is no historical database to evaluate the number of PWS systems that were in the Waiver Program in the years 1996 through 1999. This information was maintained only in the individual PWS system files.

Prior to 1993, PWS systems were required to sample for VOCs once every 3 years. Starting in 1993, this frequency was increased to once every year, unless the PWS system was entered in the Waiver Program. However, if VOC contaminants are detected in a well, the frequency is further increased to once every quarter. In 1998, NHDES first required all private laboratories to analyze for and report MtBE. In 1999, legislation passed in the 1998 legislative session required all non-transient systems and all PWS systems in the Waiver Program to test for MtBE. These changes in the sampling and reporting requirements may also have impacted the frequency of MtBE analysis and detection observed in the WSEB Analytical Database.

4.2.2 Blended Samples

Examination of the WSEB Analytical Database indicated that a significant portion of the chemical analyses of water samples from multi-well PWS systems were performed on blended samples from two or more wells. The data from blended samples were not considered to be useful for purposes of statistical modeling because samples from contaminated wells may have been mixed with water from clean wells, making it unclear which wells were contaminated, and blended samples could not be correlated to a specific geographic location. The analytical data from blended samples was not included in the statistical modeling, since many of the risk factors being evaluated were related to the geographic location of the well and its proximity to various known or potential sources of MtBE.

To evaluate the impact of deleting the results of blended samples, the annual means for all of the wells were calculated with and without the blended sample data. To perform the calculations, one half of the assumed detection limit, or 0.25 µg/L, was used for the non-detect samples. The results of these calculations are provided in Tables 4-2 and 4-3. The annual means were very similar whether or not the blended samples were included. Therefore, we felt that deleting the blended samples was unlikely to bias the results of the statistical modeling.

Analytical records for a total of 4,230 individual PWS wells (2,890 PWS systems) were obtained from the WSEB Analytical Database. However, many of these were “TNC” wells that were not included in our study, or wells whose only samples were blends with other wells in the same system. The number of PWS wells in the WSEB Analytical Database remaining after screening out the transient wells and the blended samples was 1,482. This was the number of wells that were included in the statistical modeling. Out of the 1,482 wells included in the statistical modeling, a total of 325 wells had at least a single detection of MtBE as recorded in the WSEB Analytical Database.

4.2.3 Public Water Supply Water Treatment

The data in the analytical database include results for samples collected at PWS wellheads and also samples collected after PWS water treatment and/or water storage. We investigated the types and frequency of water treatment technologies employed at the PWSs to evaluate whether they would be likely to significantly reduce MtBE concentrations.

There were a total of 3,728 records of water treatment processes being used at 631 unique PWS (multiple processes are used at some PWS). Of the 3,728 records, only 544 cases (or 15% of the total of 3,728) were processes that could significantly reduce MtBE concentrations. These consisted of: 104 cases of activated carbon technologies, 219 cases of aeration technologies, 149 cases of ozonation or permanganate treatment, 14 cases of reverse osmosis treatment, and 58 cases of ultraviolet light treatment. The 544 cases of processes that could significantly reduce MtBE concentrations apply to 175 PWS, a small percentage of the total PWS.

The other remaining treatment processes included: pH adjustment, corrosion control, iron and manganese removal, disinfection, and particulate removal. These processes do not reduce MtBE concentrations to an appreciable extent. Because so much of the analytical data are post-treatment data and only 15% of the treatment systems would be expected to reduce MtBE concentrations, it was decided that a more complete picture would be provided by including the post-treatment data rather than excluding it.

4.3 GEOGRAPHIC INFORMATION SYSTEM DATABASE DEVELOPMENT

In general, all of the information in the Comprehensive GIS Database was already in GIS format as received, and was loaded in the GIS Database in the same form as it was received. Two exceptions to this were the bedrock elevation and bedrock groundwater static water surfaces, which were generated by WESTON from the water well completion data from the Water Well Board Database provided by NHGS. The well completion records for

33,290 wells that have location coordinates were obtained from NHGS. The depth to bedrock data were subtracted from the ground surface elevations to generate a bedrock elevation at each well location. These 33,290 bedrock elevations throughout the state were then used to generate a bedrock elevation surface in the GIS database. The same process was used to generate a static bedrock groundwater elevation surface using the static water levels reported for the 31,495 bedrock wells in the Water Well Board Database.

Figure 4-1 shows the locations of the 33,290 wells (data points) that were used to generate the bedrock and groundwater elevation surfaces. In the more populated areas of the state, the density of data points was high, whereas in the unpopulated areas, the data points are very limited. Since surfaces were interpolated between data points, the inferred bedrock and groundwater elevations for queries on locations in rural areas would not be expected to be very accurate. However, in high population density areas, better accuracy would be anticipated.

Another type of data that was created for the GIS Database was default wellhead protection areas (WHPAs) for NTNC wells that did not have WHPAs specified in OneStop. We selected a default WHPA radius of 1,500 ft to use for the NTNC wells. This is the default that would be used for community wells with production volumes of 7,200 to 14,400 gallons per day (gpd). The default WHPAs were used to conduct queries to identify which types and how many of each type of potential source were located within the WHPA of each well.

4.4 SPATIAL QUERIES

A series of four types of spatial queries were conducted on the Comprehensive GIS Database constructed by WESTON. The first type of query was performed to generate tabular data regarding the geographic and hydrogeologic setting at each PWS well location. These included such characteristics as population density, ground surface elevation, depth-to-bedrock, transmissivity, thickness of saturated overburden at well location, distance to nearest lineament, and whether or not the well was located in an RFG county, wetland, or floodplain, etc.

The second type of query was the “distance to nearest” query. The distance between the well and the nearest potential MtBE sources was performed for various categories of potential sources. The categories included the various types of “Groundwater Hazard Inventory” (GWHI) sites

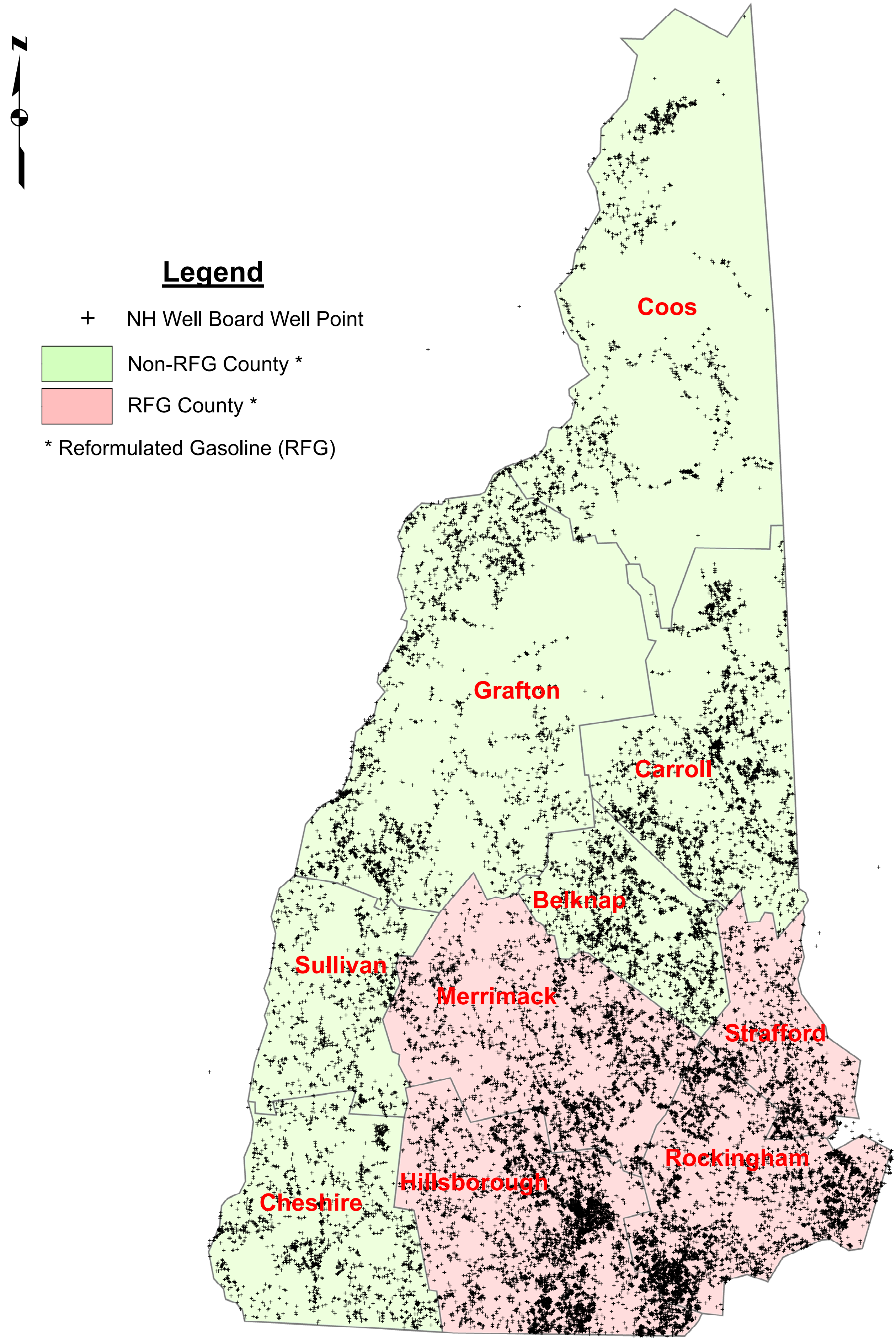

Figure 4-1
Wells with Construction Data & Coordinates in Water Well Board Database

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MANCHESTER, NEW HAMPSHIRE

NHDES

(also called “remediation sites”), the various types of “Potential Contaminantion Sites” (PCSs), Resource Conservation and Recovery Act (RCRA) sites, roads, trails, etc. NHDES defines the local inventory of PCSs to include any site where contaminants are known or very likely to be used in significant quantities, but where there are no known releases to the ground. The PCSs are identified by towns and municipalities in the state, and the inventory of these sites is only as complete as reported by the local entities. A review of the database indicated that the inventory of many of the PCS categories is incomplete.

The third type of GIS query was performed to identify which types and how many of each type of potential source were located within the WHPA of each well. The same types of potential sources were queried for presence in the WHPAs as were queried in the “distance to nearest” queries.

The fourth type of GIS query was performed to obtain data regarding the physical and hydrogeological setting of each of the potential MtBE sources. Data such as ground surface elevation, depth to bedrock, transmissivity, saturated thickness of overburden, distance to nearest lineament, etc. were queried.

Each of the four types of GIS queries generated tabulated data that was then loaded into the Comprehensive Access Database constructed for this project.

4.5 ACCESS DATABASE QUERIES

After the tabulated GIS query data were loaded into the Access database, queries were performed on the Access database to generate Microsoft Excel tables to provide to UNH for statistical analysis and to generate some data for overall observations regarding PWS characteristics data. The information provided to UNH is discussed further in Subsection 8.1. General observations regarding the type and quantity of PWS characteristics data available for this study are discussed in Subsection 4.6.

4.6 BREAKDOWN OF PUBLIC WATER SUPPLY CHARACTERISTICS DATA

Table 4-4 presents a breakdown of MtBE data by System Category and Type of Source. “Transient, Non-Community” wells and blended samples are not represented in this table. These

Table 4-4
MtBE Data by System Category and Well Type

System Category	Category Description	Number of PWS Sources	Number of PWS Sources w/ Analytical Data	Average Yield (gpm)	Average Well Depth (feet)	Average WHPA (Acres)	Average MTBE Concentration (ug/L)	MTBE Detection Frequency	Count of Sources with MtBE Detections	MtBE MCL Exceedance Frequency	Count of Sources at or above MCL (13 ug/L)
Category 1	Apartments	83	50	37	338	149	0.79	26%	13	4.0%	2
Category 2	Condominiums	289	125	36	388	195	0.43	11%	14	0.0%	0
Category 3	Large CWS	101	83	165	142	814	0.50	27%	22	1.2%	1
Category 4	Major CWS	182	149	391	129	1725	0.58	28%	41	2.0%	3
Category 5	Mobile Home Park	244	128	33	325	179	1.73	48%	61	5.5%	7
Category 6	Community of Single Family Residences	384	170	38	392	247	0.97	16%	28	2.9%	5
Category 7	Spring	0	0	N/A	N/A	N/A	N/A	N/A	0	N/A	N/A
Category 8	Service Station	0	0	N/A	N/A	N/A	N/A	N/A	0	N/A	N/A
Category 9	Comercial/Industrial	273	207	36	345	215	1.52	27%	56	3.9%	8
Category 10	Residence Homes, Senior Housing, Hospitals, Rehab Facilities, Medical Offices	41	29	29	450	174	0.60	34%	10	0.0%	0
Category 11	Functional Halls, Churches, Restaurants, Hotels, Inns, Camps, Rest Areas, Seasonal Residences, Recreational Facilities	1	1	10	720	162	0.25	0%	0	0.0%	0
Category 12	Schools, Daycares, Dormatories	355	312	25	322	138	0.75	13%	41	1.6%	5
Category 13	Other or Not Known	0	0	N/A	N/A	N/A	N/A	N/A	0	N/A	N/A
Category 14	Small CWS	104	46	29	289	360	0.65	24%	11	2.2%	1
Totals		2057	1300						297		32

Well Type	Category Description	Number of PWS Sources	Number of PWS Sources w/ Analytical Data	Average Yield (gpm)	Average Well Depth (feet)	Average WHPA (Acres)	Average MTBE Concentration (ug/L)	MTBE Detection Frequency	Count of Sources with MtBE Detections	MtBE MCL Exceedance Frequency	Count of Sources at or above MCL (13 ug/L)
ART	Artesian Well	13	4	10	343	122	0.25	0%	0	0.0%	0
BRW	Bedrock Well	1981	1088	32	373	237	1.07	21%	226	2.6%	28
DUG	Dug Well	97	37	44	17	162	1.22	22%	8	2.7%	1
GPW	Gravel Packed Well	308	217	329	61	1298	0.55	29%	64	1.8%	4
GRW	Gravel Well	35	15	79	87	480	0.78	27%	4	0.0%	0
INF	Infiltration Well	16	6	45	17	710	0.25	0%	0	0.0%	0
PTW	Point Well	42	13	80	28	228	0.47	23%	3	0.0%	0
SPR	Spring	41	20	69	101	554	0.36	20%	4	0.0%	0
Well Totals		2533	1400						309		33

Surface Water	Surface Water	86	41	NA	0	NA	0.26	2%	1	0.0%	0

Notes:

Average MtBE concentration was calculated by first averaging all samples for an individual source, then using the source average concentrations to calculate an average concentration for all sources in the category indicated. A value of 0.25 (half the detection limit) was used for non-detects.

MtBE detection frequency was calculated by dividing number of sources with MtBE detections in each category by total number of sources in each category for which analytical data was available in database.

MtBE MCL exceedance frequency was calculated by dividing the number of sources with MtBE at or above 13 ppb in each category by the total number of sources in each category for which analytical data was available in database.

Data is this table was obtained from the WSEB Analytical Database and represents only "community" and "non-transient, non-community" public water supply sources, and does not include blended samples.

WHPA = Well Head Protection Area

PWS sources are wells, springs, or surface water

PWS = Public Water Supply

CWS = Community Water Supply

data were derived from the WSEB databases that we received. Note that the WSEB database that contained the information on system categories and source types (WSEB Well Database) was a separate database from the WSEB Analytical Database. The "Number of Sources" column indicates the number of unique PWS identification numbers (a combination of the PWS system and source numbers) that were in the WSEB Well Database. The "Number of Sources w/Analytical Data" column lists the number of unique PWS identification numbers that were in the WSEB Well Database that also had at least one sample entry in the WSEB Analytical Database that was not a blended sample. The statistics provided in Table 4-4 are representative of the subset of wells for which this type of data was available.

Since a large number of PWS sources are not represented in the WSEB Analytical Database, we cannot be sure that these statistics are truly representative of all "Community" and "NTNC" PWS sources in the state. However, some general observations can be made regarding the frequency and severity of MtBE contamination in the various system categories and source types.

Wells supplying water to Mobile Home Parks clearly exhibited the highest frequency of MtBE detections of all of the system categories, with a 48% frequency of MtBE detections. They also exhibited the highest frequency of MCL exceedances for MtBE at 5.5%. Condominiums; Single Family Residences; and Schools, Daycares, and Dormatories exhibited the lowest frequencies of MtBE detections and exceedances.

It is more difficult to draw conclusions from the well/source type data. Bedrock and gravel packed wells are the two most common types of water supply sources in the state. Gravel packed wells appear to have a slightly higher MtBE detection frequency than bedrock wells (29% verses 21%). However, the MtBE exceedance frequency appears to be higher for the bedrock wells than the gravel packed wells (2.6% verses 1.8%). The small sample sizes of the other types of sources make it difficult to draw conclusions from these data.

SECTION 5

DETAILED STUDIES OF SELECTED PUBLIC WATER SUPPLY WELLS

5. DETAILED STUDIES OF SELECTED PUBLIC WATER SUPPLY WELLS

A total of 49 individual wells or surface water sources in 21 PWS systems were investigated in greater detail beyond that available in the databases assembled for this project and described in Section 4. This section summarizes the conduct and findings of these detailed studies. Detailed Study Reports are included in Appendix C.

5.1 DESCRIPTION OF INVESTIGATION METHODS

The following subsections contain a description of the objectives of the detailed studies, how PWS sources were selected for the study, the Scope of Work performed for each detailed study, and a general assessment of NHDES' methodology for delineation of the WHPAs and SWPAs.

5.1.1 Detailed Study Objectives

Objectives of the detailed studies were as follows:

1. Obtain additional pertinent information that is not available from the databases (e.g., housekeeping in SPA of well and well owner/operator opinions regarding risk factors).

2. Evaluate potential risk factors for the subset of 49 wells based on review of both the database information and the additional information gained in the detailed studies.

3. Support the statewide statistical analyses by:

    a. Better understanding the information in the databases (e.g., whether all types of potential MtBE sources are captured in the databases).

    b. Evaluating the completeness of the information in the databases (e.g., whether there are additional all-terrain vehicle (ATV) trails that are not captured in the database).

    c. Evaluating the accuracy of the information in the databases (e.g., whether MtBE concentrations in laboratory reports match the database).

5.1.2 Selection of Public Water Supply Sources for Detailed Studies

Public water supply sources for the detailed studies were selected from the WSEB database. Although all PWS wells evaluated in the detailed studies were represented in the WSEB database, not all of them were included in the statistical analyses. Some of the detailed study wells were only sampled as blends, and therefore could not be used for the statistical analyses. The PWS sources selected covered a broad range of characteristics in the following areas:

1. MtBE concentrations: above the MCL, detectable but below the MCL, not detected.
2. Geographic coverage: throughout the state and in both RFG and non-RFG areas.
3. PWS source type: bedrock well, gravel pack well, point well, gravel well, surface water source.
4. PWS type: major, large, and small community water systems; industrial; commercial; condominium; mobile home park; school; single family residential.
5. Safe yield: from 5 to 11,806 gallons per minute (gpm).
6. Well depth: from 18 to 1,420 ft.
7. Surface water: present or not present in the WHPA/SWPA.
8. Potential MtBE sources such as ASTs or USTs: present or not present in the WHPA/SWPA.

Preliminary information on the latter two criteria was obtained from GIS maps prepared for a prior study (Moyer et al., 2002). This was augmented with additional information from OneStop and the project databases.

Wells with no detections of MtBE were selected to serve as controls for the study. Some of the non-detect wells are from the same PWS systems as other MtBE-contaminated wells selected for the study. Additional wells with no MtBE detections were selected because they were in proximity to LUST sites and would appear to be at a high risk. It was notably difficult to find wells without detections of MtBE that had LUST sites within 2,000 ft; this search identified only seven such wells in the state. Table 5-1 summarizes the wells selected for the detailed studies and the selection criteria, and Figure 5-1 shows the well locations.

Table 5-1
Wells Selected for Detailed Studies and Selection Criteria

EPA Well ID#	PWS Name	Town	County	RFG County?	PWS Type	PWS Type	Well Type	Well Depth (feet)	Safe Yield (gpm)	Surface Water in WHPA	ASTs, USTs, Spills, or Junkyards in WHPA
Wells with MTBE Exceedances of MCL (12)											
0773010-002	Kings Towne MHP	Epsom	Merrimack	yes	C	MHP	BRW	277	62	no	yes
0811010-003	Farmington WD	Farmington	Stafford	yes	C	MCWS	GPW	50	225	yes	yes
1994010-004	Franklin Pierce College	Rindge	Cheshire	no	C	School	BRW	550	20	yes	yes
1861010-003	Pembroke Water Works	Pembroke	Merrimack	yes	C	MCWS	GPW	82	450	yes	yes
2194010-007	Coos County Farm	Stewartstown	Coos	no	C	SCWS	GPW	140	80	yes	yes
2194010-008	Coos County Farm	Stewartstown	Coos	no	C	SCWS	GPW	140	80	yes	yes
1522010-001	Patrician Shores	Meredith	Belknap	no	C	Single-family	BRW	325	20	yes	no
0203030-001	Northbrook MHP	Belmont	Belknap	no	C	MHP	BRW	180	7	no	yes
1973030-001	PEU/Green Hills Estates	Raymond	Rockingham	yes	C	MHP	PTW	18	42	no	yes
1973030-002	PEU/Green Hills Estates	Raymond	Rockingham	yes	C	MHP	PTW	18	42	no	yes
1973030-003	PEU/Green Hills Estates	Raymond	Rockingham	yes	C	MHP	GPW	29	30	no	yes
1973030-004	PEU/Green Hills Estates	Raymond	Rockingham	yes	C	MHP	GPW	18	30	no	yes
Average	**>MCL 13 ppb**			71% RFG		67% Overburden		**152**	**91**	43% yes	92% yes
Median	**>MCL 13 ppb**							**111**	**42**		
Wells with MTBE Detected but at or Below MCL (23)											
0773010-003	Kings Towne MHP	Epsom	Merrimack	yes	C	MHP	BRW	104	65	no	yes
1861010-002	Pembroke Water Works	Pembroke	Merrimack	yes	C	MCWS	GPW	82	625	yes	yes
1861010-004	Pembroke Water Works	Pembroke	Merrimack	yes	C	MCWS	GPW	51	250	yes	no
1861010-006	Pembroke Water Works	Pembroke	Merrimack	yes	C	MCWS	GPW	60	400	yes	yes
1994010-005	Franklin Pierce College	Rindge	Cheshire	no	C	School	BRW	1,010	52	yes	yes
1471010-003	City of Manchester	Manchester	Hillsborough	yes	C	MCWS	Surface	NA	11,806	yes	yes
2296010-002	Labsphere Corp.	Sutton	Merrimack	yes	NTNC	Industrial	BRW	600	12	no	no
0862020-001	Pine Landing Condo Assn	Freedom	Carroll	no	C	Condo	BRW	800	8	yes	no
0862020-002	Pine Landing Condo Assn	Freedom	Carroll	no	C	Condo	GPW	44	60	yes	no
1522010-002	Patrician Shores	Meredith	Belknap	no	C	Single-family†	BRW	550	7	yes	no
2195020-001	Stewartstown Comm. School	Stewartstown	Coos	no	NTNC	School	BRW	360	30	no	yes
1591010-001	Monroe Water Dept.	Monroe	Grafton	no	C	SCWS	GRW	48	21	no	yes
1591010-002	Monroe Water Dept.	Monroe	Grafton	no	C	SCWS	GRW	50	24	no	yes
2301020-001	West Swanzey Water Co.	Swanzey	Cheshire	no	C	LCWS	GPW	76	300	yes	yes
2301020-002	West Swanzey Water Co.	Swanzey	Cheshire	no	C	LCWS	GPW	77	350	yes	yes
1746020-001	Latva Machine Inc.	Newport	Sullivan	no	NTNC	Commercial	BRW	300		yes	yes
0203030-002	Northbrook MHP	Belmont	Belknap	no	C	MHP	BRW	500	7	no	yes
0053010-003	Pine Needles MHP	Alstead	Cheshire	no	C	MHP	BRW	720	5	no	no
1141020-004	Emerald Lake	Hillsborough	Hillsborough	no	C	SCWS	BRW	403	50	yes	no
1141020-006	Emerald Lake	Hillsborough	Hillsborough	no	C	SCWS	BRW	500	15	yes	no
1141020-007	Emerald Lake	Hillsborough	Hillsborough	no	C	SCWS	BRW	230	21	yes	no
1141020-008	Emerald Lake	Hillsborough	Hillsborough	no	C	SCWS	BRW	206	30	yes	no
1141020-009	Emerald Lake	Hillsborough	Hillsborough	no	C	SCWS	BRW	560	40	yes	no
Average	**< MCL 13 ppb**			26% RFG		36% overburden		**333**	**644**	70% yes	52% yes
Median	**< MCL 13 ppb**							**265**	**35**		
Wells with no MTBE Detected (14)											
0811010-004	Farmington WD	Farmington	Stafford	yes	C	MCWS	GPW	28	225	no	yes
0811010-005	Farmington WD	Farmington	Stafford	yes	C	MCWS	GPW	23	190	no	yes
1861010-007	Pembroke Water Works	Pembroke	Merrimack	yes	C	MCWS	GPW	75	309	yes	no
1994010-006	Franklin Pierce College	Rindge	Cheshire	no	C	School	BRW	1,420	24	yes	yes
1994010-008	Franklin Pierce College	Rindge	Cheshire	no	C	School	BRW	1,100	25	yes	yes
1994010-009	Franklin Pierce College	Rindge	Cheshire	no	C	School	BRW	480	35	yes	yes
0382010-001	Rosebrook Water Co.	Carroll	Coos	no	C	LCWS	GPW	43	322	yes	yes
0382010-002	Rosebrook Water Co.	Carroll	Coos	no	C	LCWS	GPW	52	450	yes	yes
1141020-001	Emerald Lake	Hillsborough	Hillsborough	no	C	SCWS	BRW	306	25	yes	no
0365010-003	Henry Moore School	Candia	Rockingham	yes	NTNC	School	BRW	350	40	no	yes
0053010-001	Pine Needles MHP	Alstead	Cheshire	no	C	MHP	BRW	500	9	no	no
0053010-002	Pine Needles MHP	Alstead	Cheshire	no	C	MHP	BRW	608	10	no	no
0895010-002	Gilmanton Elem. School	Gilmanton	Belknap	no	NTNC	School	BRW	425	12	yes	yes
2316020-001	State Police/Registry	Tamworth	Carroll	no	NTNC	Workplace	BRW	140	40	no	yes
Average	**ND**			29% RFG		36% Overburden		**396**	**123**	57% yes	71% yes
Median								**328**	**38**		
										57%	**71%**
Overall Average				38% RFG		43% Overburden		**307**	**360**	61% yes	67% yes
Overall Median								**193**	**40**		
										61%	**67%**
Minimum								18	5		
Maximum								1,420	11,806		

Notes:

BRW - Bedrock Well
GPW - Gravel Packed Well
PTW - Point Well
SCWS - Small Community Water Supply
LCWS - Large Community Water Supply
MHP - Mobile Home Park
MCWS - Major Community Water Supply
† = Single Family Indicates a Community of Single-family
C - Community Water System
NTNC - Non Transient, Non-Community

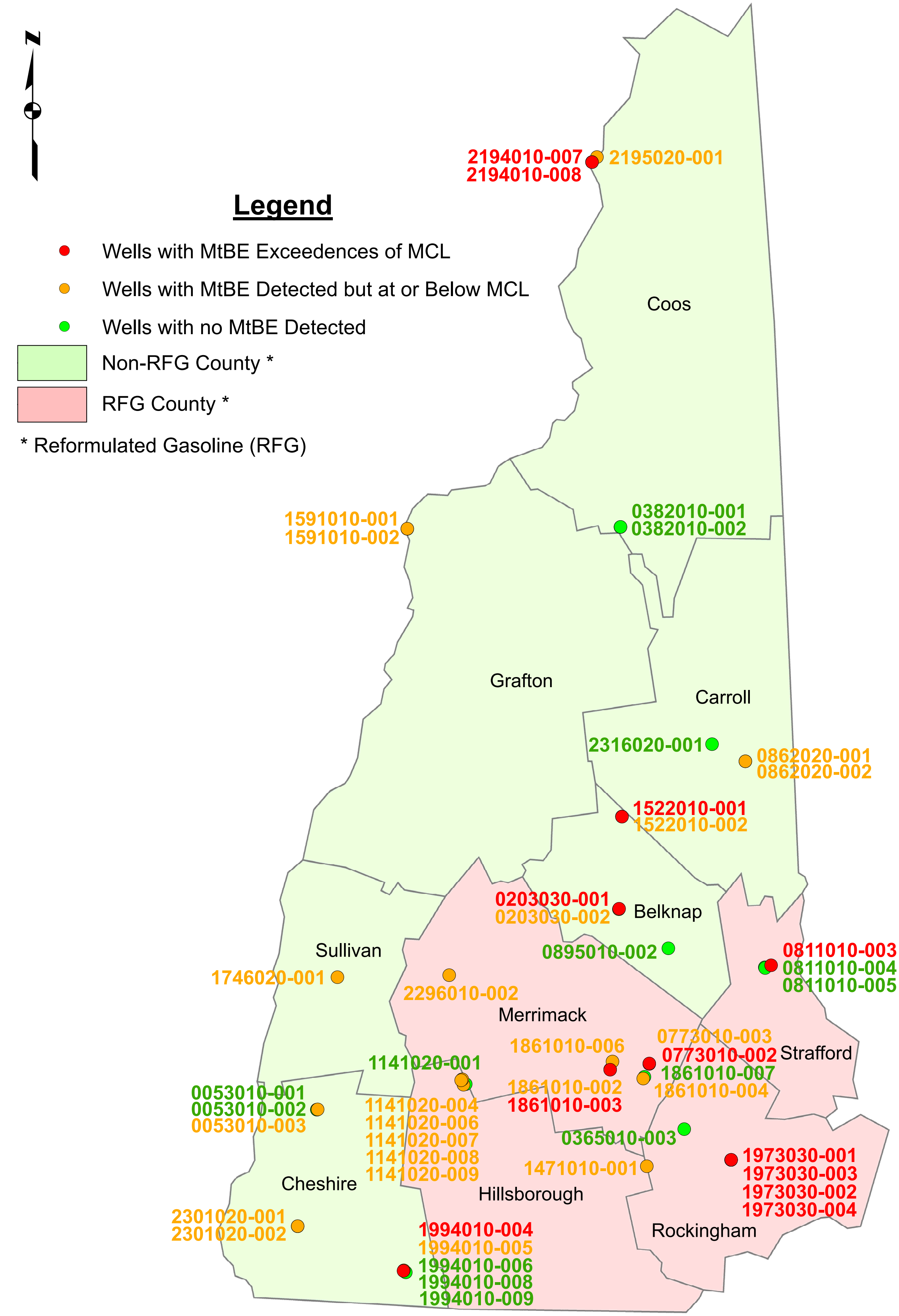


Figure 5-1
Detailed Study Locations

WESTON SOLUTIONS
MANCHESTER, NEW HAMPSHIRE

NHDES

5.1.3 Detailed Study Scope of Work

The detailed studies involved collecting readily available information from a variety of sources. This included the following:

1. Searching the project databases for all available information – about the well construction and operation, hydrogeology, analytical data, NHDES sanitary survey and Public Water Supply Assessment (PWSA) Survey results, potential MtBE sources (remediation sites, LUSTs, LASTs, USTs, ASTs, spills, on premises use facilities (OPUFs), underground injection control sites (UICs), and junkyards), ATV trails, and roads.

2. Reviewing NHDES PWS files containing correspondence and information on new source assessments and approvals, pumping tests, local hydrogeology, WHPA delineation, permits to operate, well construction and operation, NHDES PWSAs and sanitary surveys, laboratory analytical results, sampling waivers, and violations.

3. Reviewing NHDES OneStop information and paper files on potential MtBE sources.

4. Preparing and reviewing GIS maps. An example of the set of maps produced for each detailed study is provided in Figures 5-2a through d.

   The maps included the following features:

   a. Location map showing wells, WHPA/SWPAs, roads, surface water features, potential MtBE source identification numbers, hazardous waste generators, wetlands, watershed boundaries, ATV trails, and lineaments.

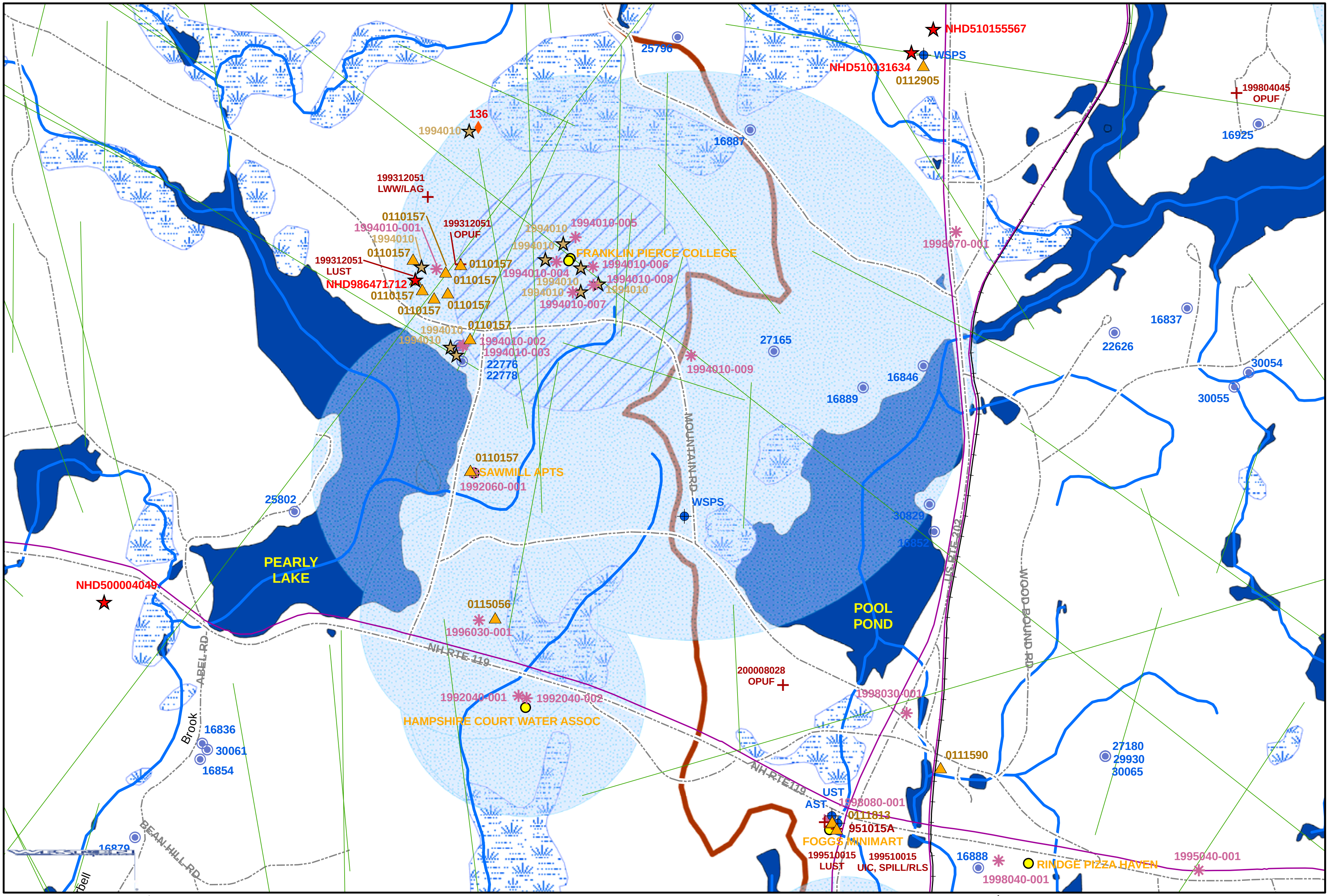
   b. Topography and groundwater elevation contours.

   c. Aerial photography.

   d. Transmissivity (for wells in areas where aquifer mapping was available).

5. Obtaining and reviewing assessors maps and, in some cases, ownership information covering the WHPA/SWPA from the Town Hall.

6. Visiting the location to inspect (and photograph) the well, the SPA (see below), and the WHPA/SWPA for visual evidence of potential MtBE sources, topography, geology, and boat/ATV/snowmobile/vehicle traffic.



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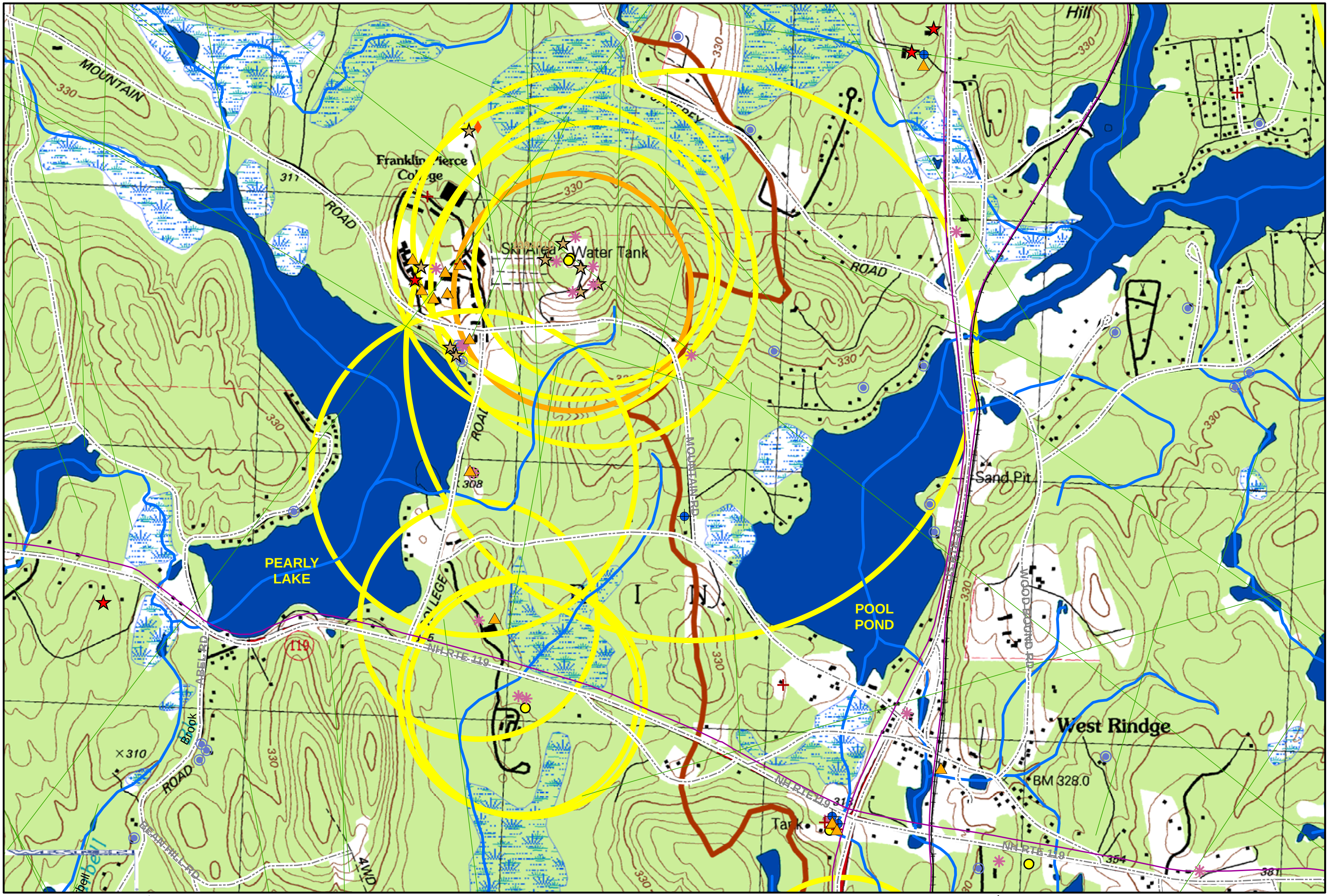
N, W, E, S

630 315 0 630
Feet

Legend

- Public Water Supply Wells
- Underground Storage Tanks
- Water Well Inventory
- PWS Pump House
- GW Hazards Inventory
- Registered Water Use
- NPDES Outfall
- Aboveground Storage Tanks
- Local PCS Inventory
- Hazardous Waste Generator
- Roads
- Surface Water
- Lineament
- Additional Trails
- Lake/Pond
- Wetland
- HUC12 Watershed Boundary
- Well Head Protection Area (WHPA) - Active
- Well Head Protection Area (WHPA) - Inactive

Figure 5-2a
Map 1 - PWS Vicinity with Feature Identification Numbers
Franklin Pierce College
1994010-004/005/006/008/009
New Hampshire DES MtBE Study



Legend

- Public Water Supply Wells
- Underground Storage Tanks
- Water Well Inventory
- PWS Pump House
- GW Hazards Inventory
- Registered Water Use
- NPDES Outfall
- Aboveground Storage Tanks
- Local PCS Inventory
- Hazardous Waste Generator
- Roads
- Surface Water
- Lineament
- Additional Trails
- Lake/Pond
- Wetland
- HUC12 Watershed Boundary
- Well Head Protection Area (WHPA) - Active
- Well Head Protection Area (WHPA) - Inactive
- * Topography in Feet
- Water Table Elevation Contour (feet)

Figure 5-2b
Map 2 - Topography and Groundwater Elevation Contours
Franklin Pierce College
1994010-004/005/006/008/009
New Hampshire DES MtBE Study

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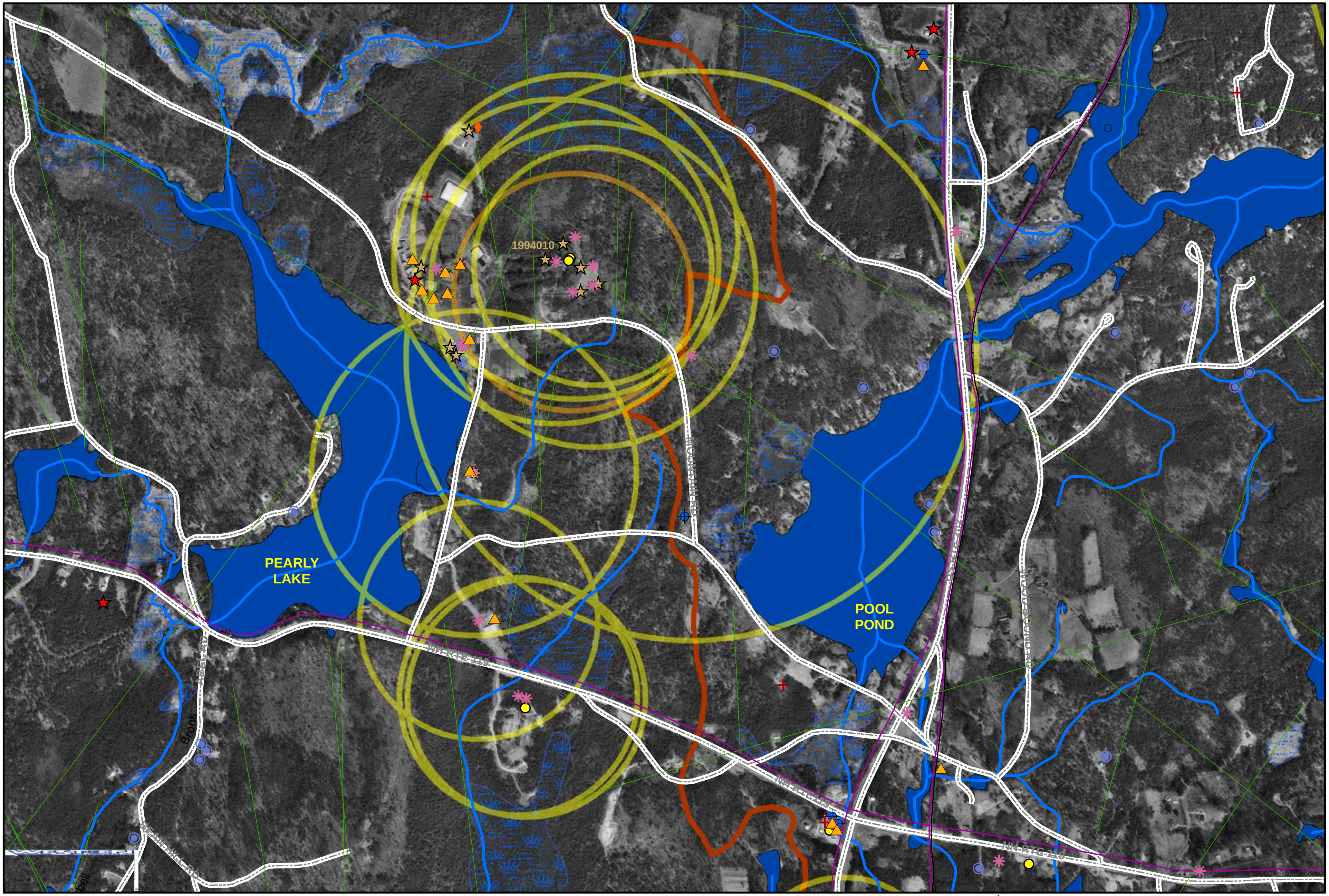


N
W E
S

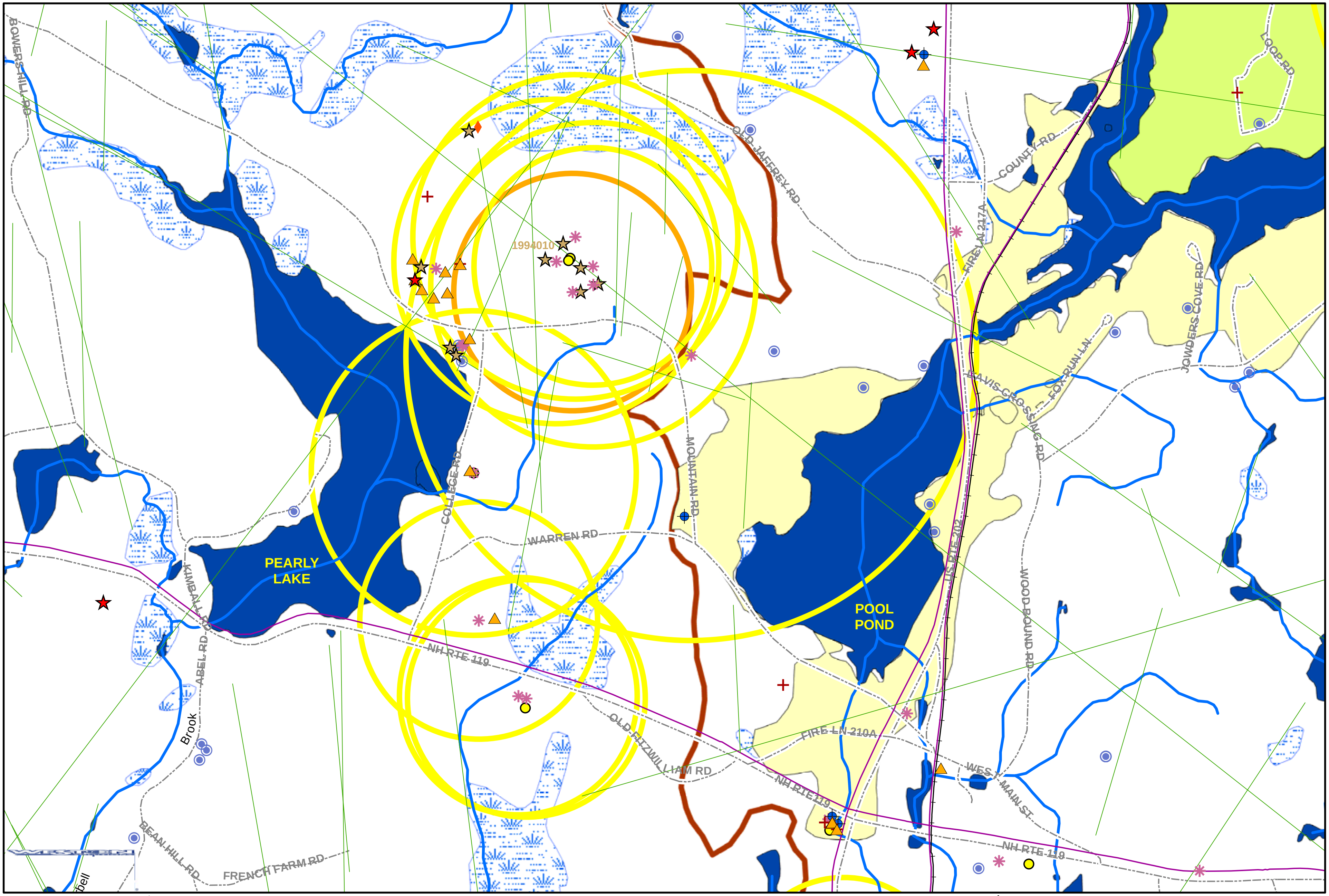
630 315 0 630
Feet

Legend

- Public Water Supply Wells
- Underground Storage Tanks
- Water Well Inventory
- PWS Pump House
- GW Hazards Inventory
- Registered Water Use
- NPDES Outfall
- Aboveground Storage Tanks
- Local PCS Inventory
- Hazardous Waste Generator
- Roads
- Surface Water
- Lineament
- Additional Trails
- Lake/Pond
- Wetland
- HUC12 Watershed Boundary
- Well Head Protection Area (WHPA) - Active
- Well Head Protection Area (WHPA) - Inactive

Figure 5-2c
Map 3 - Aerial Photography
Franklin Pierce College
1994010-004/005/006/008/009

New Hampshire DES MtBE Study



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N
W E
S

630 315 0 630
Feet

Legend

- Public Water Supply Wells
- Underground Storage Tanks
- Water Well Inventory
- PWS Pump House
- GW Hazards Inventory
- Registered Water Use
- NPDES Outfall
- Aboveground Storage Tanks
- Local PCS Inventory
- Hazardous Waste Generator
- Roads
- Surface Water
- Lineament
- Additional Trails
- Lake/Pond
- Wetland
- HUC12 Watershed Boundary
- Well Head Protection Area (WHPA) - Active
- Well Head Protection Area (WHPA) - Inactive
- Water Table Elevation Contour (feet)

Tranmissivity Range (squared feet/day)

- 0-2000
- 2000-4000
- 4000-8000
- > 8000

Figure 5-2d
Map 4 - Transmissivity
Franklin Pierce College
1994010-004/005/006/008/009

New Hampshire DES MtBE Study

7. Interviewing the well owner/operator on a variety of subjects such as well installation and operation, water treatment, sample collection points and methods, traffic in the area, water conservation and public education efforts, historical conditions in the WHPA, and ideas regarding potential risk factors.

8. Interviewing representatives of the local fire and health departments for information regarding spills, accidents, traffic, and ideas regarding potential risk factors.

9. Summarizing the above information on a "data summary" Microsoft Excel table and preparing a brief narrative describing the PWS, analytical data, site visit, and summary of potential risk factors.

10. In some of the first studies to be conducted, a WESTON geologist also evaluated NHDES documentation on the delineation of the WHPA/SWPA. The purpose of this was to evaluate whether the WHPA/SWPA appears to be a reasonable area to investigate with regard to potential MtBE sources. In all the cases reviewed, the WHPA/SWPA delineation appeared reasonable (as described below) so, in an effort to use budget most effectively, this evaluation was not carried out for subsequent detailed studies.

11. All of the above detailed study reports were reviewed and the results were compiled and summarized.

The SPA is a circle around a PWS well whose radius is 75 to 400 ft, depending primarily on the well pumping rate. (For "community" wells, the minimum radius is 150 ft; for "NTNC" wells, the minimum radius is 75 ft.) The corresponding area of the SPA ranges from 0.4 to 11.5 acres. The SPA is required to be dedicated to the PWS well; no other activities or uses are allowed in the SPA other than those necessary to operate and maintain the well, unless granted a waiver by NHDES or unless the well was installed before 1992 when the requirements came into effect. Regardless of the legal technicalities, during a sanitary survey, NHDES will inspect the SPA and ask that efforts be made to keep the SPA in as natural a state as possible. For several of the detailed study wells, an official sanitary radius was not found during the file review but an estimated radius was provided by NHDES based on estimated water use, safe yield, and/or number of people at the facility served by the well.

5.1.4 Assessment of Wellhead Protection Area/Source Water Protection Area Delineation

For a subset of wells in the study, evaluations of the WHPA/SWPA boundaries were conducted to assess the appropriateness of how the boundaries were delineated. The purpose of this evaluation was to determine whether the WHPA/SWPA was the appropriate area to investigate around a well for potential MtBE sources that could potentially impact the well.

The WHPA/SWPA boundaries for the overburden/gravel packed PWS wells were delineated using the "Wellhead Protection Area Delineation Guidance" forms. These forms use the Uniform Flow Equation to calculate the downgradient (x) and side gradient (y) boundaries of the WHPA/SWPA for an overburden well. The variables used for each variation of this equation include maximum pumping rate (Q), aquifer transmissivity (T), and average hydraulic gradient (i).

In each instance, the calculations and variables used in the equations to solve for the (x) and (y) values were appropriate, even when varying pumping rates or transmissivity ranges were taken into account. For example, the downgradient boundary of the WHPA/SWPA for Well 003 at the Farmington Water District was calculated using a maximum pumping rate of 270 gpm; however, Well 003 was reportedly pumped at rates of between 300 and 350 gpm while in service. The downgradient boundary was also calculated using a T value of 2,000 square ft per day (ft^2/day), as reported on a USGS aquifer map of the area. Regardless of these discrepancies, the value of the flow boundary downgradient of the well (400 ft) remained valid. Using a Q value of 270 gpm and a T value of 2,000 ft^2/day, the downgradient segment was calculated by the Uniform Flow Equation to be 275 ft. For conservative purposes, this value was rounded up to 400 ft to coincide with the upper range of the sanitary protective radius (75 - 400 ft). By substituting the reported maximum pumping rate of 350 gpm, the x value would be 356 ft (still less than 400). Furthermore, the transmissivity of the aquifer may be as high as 4,000 ft^2/day, as reported in the OneStop database. Because the T value appears in the denominator of the Uniform Flow Equation, substituting higher T values into the equation would only reduce the resulting x value.

The higher value for the maximum pumping rate would impact the calculation of the side-gradient boundaries, as that calculation is performed by multiplying the x value by 2Π. Using a maximum pumping rate of 350 gpm would result in a side-gradient boundary segment of approximately 2,300 ft (1,150 ft in each direction), which is slightly higher than the 1,728-ft value calculated on the WHPA/SWPA delineation form. However, the final WHPA/SWPA for Well 003 was modified to take into account topography and other minor surface water divides, so the overall difference was not significant for this location. In addition, if the higher transmissivity values reported in the area were used in the calculation, the resulting y values would be lower anyway.

The overburden PWS wells included in the evaluation included those for the Farmington Water District, Coos County Farm, Pennichuck East Utility Company/Green Hills Estates, Pine Landing Condo Association, Monroe Water Department, and West Swanzey Water Company. For these locations, the information obtained in the delineation forms was evaluated along with site-specific hydrogeological conditions of the area and used to render a decision regarding the validity of the WHPA/SWPA boundaries. Since each evaluation showed that the WHPA/SWPA boundaries appeared to be reasonable as delineated in the state's delineation worksheets, it was determined that repeated evaluations of the remaining WHPA/SWPAs were not necessary.

The WHPA/SWPA boundaries for several bedrock PWS wells were also evaluated, including those for the Kings Towne Mobile Home Park, Patrician Shores, Pine Landing Condo Association, and Latva Machine properties. For these prescribed boundaries, the WHPA/SWPAs are represented as fixed radii, based on the concept that as the wells are pumped the water table is drawn down around the well. A cone-shaped zone is then created where the water level has dropped. This cone of depression is essentially circular in shape in areas where the hydraulic gradient is small, where there are no major sources of recharge such as ponds, canals, or rivers, or where no barriers to flow such as the sides of valleys, dikes, or other low-permeability zones exist. This is analogous to the "calculated fixed radius method", which is recommended for systems located in confined and unconfined aquifers where the aquifers have small hydraulic gradients. For the bedrock wells evaluated in the study, the radii were considered appropriate based on individual assessments of the hydrogeological and pumping conditions present at each location.

In several detailed studies, potential connections between surface water and groundwater were identified by reviewing topographic maps, observing conditions in the field, and interviewing town officials and well owner/operators. Franklin Pierce College is one example (see Figures 5-2a through d). Two potential sources, a former junkyard at

Van Dyke Construction and a gas station/bulk oil facility ("Fogg's Corner") were outside of the WHPA/SWPA, but potentially connected to it by surface water. Van Dyke Construction (UST Site No. 0112905 located to the northeast) is on the edge of a wetland that is partially in the WHPA, and surface water from Fogg's Corner (LUST Site No. 199510015 located to the southeast) drains via a stream to Pool Pond, which is in the WHPA/SWPA. Pearly Pond, on the western side of the figure, is also partially in the WHPA/SWPA.

5.2 DETAILED STUDY RESULTS

This section provides a summary of the results of the detailed studies of the 49 PWS sources evaluated.

5.2.1 Caveats Regarding the Detailed Study Results

Results of the detailed studies are summarized in Tables 5-2 through 5-6 and discussed below. A number of important caveats need to be kept in mind when reviewing the results of the detailed studies:

- First, the number of detailed studies (49) is not large enough to be statistically significant.
- The detailed studies were performed by a total of seven individuals, and investigators varied somewhat in their technical backgrounds, approaches, and areas of interest. A certain amount of subjectivity in assessing the relative importance of specific potential risk factors was inevitable. An effort was made to standardize methods as much as possible, but some differences were unavoidable.
- There were differences in the level of information available for the studies. Some wells had more available information than others.
- The level of information available was rarely sufficient to confirm a direct connection between a particular MtBE source and a nearby contaminated well. In most cases, there were several candidate sources, and it was impossible to determine which one(s) were the actual cause(s) of the contamination.
- Most contaminated wells exhibited several characteristics that were considered potential risk factors, but clearly not every potential risk factor exhibited by a well was directly related to MtBE contamination in that well. For instance, if the actual source of contamination in a well was a nearby LUST, other potential risk factors

Table 5-2
PWS Well Properties

EPA Well ID#	PWS Name	Town	County	RFG County?	PWS Type	PWS Type	Well Type	Well Depth (feet)	Safe Yield (gpm)	Population Density (people/sq. mi)	WHPA/S WPA Size (acres)	Max. MtBE Concentrations	Date of Max. MtBE Concentrations
Wells with MTBE Exceedances of MCL (12)													
0773010-002	Kings Towne MHP	Epsom	Merrimack	yes	C	MHP	BRW	277	62	1,034	122	39 ppb	1 June 2004
0811010-003	Farmington WD	Farmington	Stafford	yes	C	MCWS	GPW	50	225	335	166	16 ppb	11 Feb. 2003
1994010-004	Franklin Pierce College	Rindge	Cheshire	no	C	School	BRW	550	20	99	303	29 ppb	9 May 2005
1861010-003	Pembroke Water Works	Pembroke	Merrimack	yes	C	MCWS	GPW	82	450	139	1081	14 ppb	29 April 1999
2194010-007	Coos County Farm	Stewartstown	Coos	no	C	SCWS	GPW	140	80	90	362	27 ppb*	27 Oct. 1993
2194010-008	Coos County Farm	Stewartstown	Coos	no	C	SCWS	GPW	140	80	90	362	27 ppb*	27 Oct. 1993
1522010-001	Patrician Shores	Meredith	Belknap	no	C	Single-family†	BRW	325	20	852	122	14 ppb	11 July 1997
0203030-001	Northbrook MHP	Belmont	Belknap	no	C	MHP	BRW	180	7		122	14 ppb	5 Feb. 2003
1973030-001	PEU/Green Hills Estates	Raymond	Rockingham	yes	C	MHP	PTW	18	42	457	428	50 ppb	9 August 2000
1973030-002	PEU/Green Hills Estates	Raymond	Rockingham	yes	C	MHP	PTW	18	42	757	428	44 ppb	9 August 2000
1973030-003	PEU/Green Hills Estates	Raymond	Rockingham	yes	C	MHP	GPW	29	30	757	428	58 ppb	20 June 2000
1973030-004	PEU/Green Hills Estates	Raymond	Rockingham	yes	C	MHP	GPW	18	30	757	428	33 ppb	9 August 2000
Average	**>MCL 13 ppb**			71% RFG				**152**	**91**	**488**	**363**	**30 ppb**	
Median	**>MCL 13 ppb**							**111**	**42**	**457**	**362**	**28 ppb**	
Wells with MTBE Detected but at or Below MCL (23)													
0773010-003	Kings Towne MHP	Epsom	Merrimack	yes	C	MHP	BRW	104	65	1,034	162	7.1 ppb	1 June 2004
1861010-002	Pembroke Water Works	Pembroke	Merrimack	yes	C	MCWS	GPW	82	625	139	1081	2.9 ppb	13 March 2003
1861010-004	Pembroke Water Works	Pembroke	Merrimack	yes	C	MCWS	GPW	51	250	28	763	2.9 ppb	13 March 2003
1861010-006	Pembroke Water Works	Pembroke	Merrimack	yes	C	MCWS	GPW	60	400	139	1564	0.66 ppb	29 April 1999
1994010-005	Franklin Pierce College	Rindge	Cheshire	no	C	School	BRW	1,010	52	99	303	10 ppb	5 Aug. 2004
1471010-003	City of Manchester	Manchester	Hillsborough	yes	C	MCWS	Surface	NA	11,806			2.7 ppb	15 Aug. 1997
2296010-002	Labsphere Corp.	Sutton	Merrimack	yes	NTNC	Industrial	BRW	600	12	44	122	13 ppb	27 Sept. 1999
0862020-001	Pine Landing Condo Assn	Freedom	Carroll	no	C	Condo	BRW	800	8	84	112	2.5 ppb*	9 May 1996
0862020-002	Pine Landing Condo Assn	Freedom	Carroll	no	C	Condo	GPW	44	60	84	112	2.5 ppb*	9 May 1996
1522010-002	Patrician Shores	Meredith	Belknap	no	C	Single-family†	BRW	550	7	83	122	2.2 ppb	21 Sept. 1995
2195020-001	Stewartstown Comm. School	Stewartstown	Coos	no	NTNC	School	BRW	360	30	30	303	1.7 ppb	26 March 1999
1591010-001	Monroe Water Dept.	Monroe	Grafton	no	C	SCWS	GRW	48	21	145	545	0.76 ppb	8 Feb. 2000
1591010-002	Monroe Water Dept.	Monroe	Grafton	no	C	SCWS	GRW	50	24	145	545	2.7 ppb	8 Feb. 2001
2301020-001	West Swanzey Water Co.	Swanzey	Cheshire	no	C	LCWS	GPW	76	300	930	444	3.8 ppb*	30 Sept. 2003
2301020-002	West Swanzey Water Co.	Swanzey	Cheshire	no	C	LCWS	GPW	77	350	930	444	3.8 ppb*	30 Sept. 2003
1746020-001	Latva Machine Inc.	Newport	Sullivan	no	NTNC	Commercial	BRW	300		35	122	2.6 ppb	11 Feb. 1999
0203030-002	Northbrook MHP	Belmont	Belknap	no	C	MHP	BRW	500	7		122	9.9 ppb	26 Feb. 2004
0053010-003	Pine Needles MHP	Alstead	Cheshire	no	C	MHP	BRW	720	5	58	122	10.8 ppb	19 Dec. 2002
1141020-004	Emerald Lake	Hillsborough	Hillsborough	no	C	SCWS	BRW	403	50	1,280	162	1.1 ppb	9 Oct. 2001
1141020-006	Emerald Lake	Hillsborough	Hillsborough	no	C	SCWS	BRW	500	15	42	162	5.4 ppb	19 Oct. 1999
1141020-007	Emerald Lake	Hillsborough	Hillsborough	no	C	SCWS	BRW	230	21	42	935	2.3 ppb*	2 Jan. 2002
1141020-008	Emerald Lake	Hillsborough	Hillsborough	no	C	SCWS	BRW	206	30	42	935	2.3 ppb*	2 Jan. 2002
1141020-009	Emerald Lake	Hillsborough	Hillsborough	no	C	SCWS	BRW	560	40	42	935	2.3 ppb*	2 Jan. 2002
Average	**< MCL 13 ppb**			26% RFG				**333**	**644**	**260**	**460**	**4.2 ppb**	
Median	**< MCL 13 ppb**							**265**	**35**	**84**	**303**	**2.7 ppb**	
Wells with no MTBE Detected (14)													
0811010-004	Farmington WD	Farmington	Stafford	yes	C	MCWS	GPW	28	225	301	347	ND	NA
0811010-005	Farmington WD	Farmington	Stafford	yes	C	MCWS	GPW	23	190	301	347	ND	NA
1861010-007	Pembroke Water Works	Pembroke	Merrimack	yes	C	MCWS	GPW	75	309	28	763	ND	NA
1994010-006	Franklin Pierce College	Rindge	Cheshire	no	C	School	BRW	1,420	24	99	162	ND	NA
1994010-008	Franklin Pierce College	Rindge	Cheshire	no	C	School	BRW	1,100	25	99	303	ND	NA
1994010-009	Franklin Pierce College	Rindge	Cheshire	no	C	School	BRW	480	35	99	935	ND	NA
0382010-001	Rosebrook Water Co.	Carroll	Coos	no	C	LCWS	GPW	43	322	12	783	ND	NA
0382010-002	Rosebrook Water Co.	Carroll	Coos	no	C	LCWS	GPW	52	450	12	783	ND	NA
1141020-001	Emerald Lake	Hillsborough	Hillsborough	no	C	SCWS	BRW	306	25	339	303	ND	NA
0365010-003	Henry Moore School	Candia	Rockingham	yes	NTNC	School	BRW	350	40	203	162	ND	NA
0053010-001	Pine Needles MHP	Alstead	Cheshire	no	C	MHP	BRW	500	9	14	122	ND	NA
0053010-002	Pine Needles MHP	Alstead	Cheshire	no	C	MHP	BRW	608	10	14	122	ND	NA
0895010-002	Gilmanton Elem. School	Gilmanton	Belknap	no	NTNC	School	BRW	425	12	16	160	ND	NA
2316020-001	State Police/Registry	Tamworth	Carroll	no	NTNC	Workplace	BRW	140	40	90	122	ND	NA
Average	**ND**			29% RFG				**396**	**123**	**116**	**387**		
Median	**ND**							**328**	**38**	**95**	**303**		
Overall Average				38% RFG				**307**	**360**	**275**	**415**		
Overall Median								**193**	**40**	**99**	**303**		
Minimum								18	5		112		
Maximum								1,420	11,806		1,564		

Notes: * = MtBE concentration from blended well samples.
BRW - Bedrock Well
GPW - Gravel Packed Well
PTW - Point Well
SCWS - Small Community Water Supply
LCWS - Large Community Water Supply
MHP - Mobile Home Park
MCWS - Major Community Water Supply
† = Single Family Indicates a Community of Single-family

Table 5-3
Nearby Potential Sources

EPA Well ID#	PWS Name	Distance to Nearest Rem. Site (feet)	# Rem. Sites, LUST, LAST, UIC, Spills, OPUF in SPA	# Rem. Sites, LUST, LAST, UIC, Spills, OPUF in WHPA/SWPA	Distance to Nearest UST/AST (feet)	# USTs/ASTs in SPA	# USTs/ASTs in WHPA/SWPA	Distance to Nearest Junkyard (feet)	Distance to Nearest Road (feet)	Distance to Nearest ATV/SM Trail (feet)	Distance to Surface Water (feet)
Wells with MTBE Exceedances of MCL (12)											
0773010-002	Kings Towne MHP	1,200	1	5	700	1	100	19,634	147	3,939	700
0811010-003	Farmington WD	420	0	1	500	0	10	18,767	750	8,645	750
1994010-004	Franklin Pierce College	1,211	0	3	1,000	0	35	4,000	810	38,259	1,900
1861010-003	Pembroke Water Works	170	0	6	2,010	0	31	8,322	179	75	200
2194010-007	Coos County Farm	2,400	0	1	1,067	0	10	153,350	1,160	3,974	113
2194010-008	Coos County Farm	2,400	0	1	1,067	0	10	153,350	1,120	3,974	113
1522010-001	Patrician Shores	3,440	0	0	3,510	0	5	15,202	200	4,000	400
0203030-001	Northbrook MHP	351	0	1	1,337	0	1		243	6,327	3,000
1973030-001	PEU/Green Hills Estates	1,123	0	0	200	2	150	17,200	41	12,400	549
1973030-002	PEU/Green Hills Estates	1,130	0	0	200	2	150	17,200	71	12,400	549
1973030-003	PEU/Green Hills Estates	1,130	0	0	200	2	150	17,200	71	12,400	549
1973030-004	PEU/Green Hills Estates	1,130	0	0	200	2	150	17,200	76	12,400	549
Average	**>MCL 13 ppb**	**1,342**	**0.08**	**1.5**	**999**	**0.75**	**67**	**40,130**	**406**	**9,899**	**781**
Median	**>MCL 13 ppb**	**1,130**	**0.00**	**1.0**	**850**	**0.00**	**33**	**17,200**	**190**	**7,486**	**549**
Wells with MTBE Detected but at or Below MCL (23)											
0773010-003	Kings Towne MHP	1,200	0	5	700	0	100	19,808	156	3,893	700
1861010-002	Pembroke Water Works	170	0	6	1,964	0	31	8,242	225	75	100
1861010-004	Pembroke Water Works	136	0	0	4,113	0	50	24,966	1,080	75	25
1861010-006	Pembroke Water Works	1,257	0	3	2,341	0	31	10,582	1,070	75	190
1994010-005	Franklin Pierce College	1,491	0	3	1,000	0	35	4,000	1,092	38,383	2,300
1471010-003	City of Manchester	873	0	4	435		18	11,004	1,299	3,317	0
2296010-002	Labsphere Corp.	2,600	0	0	3,400	0	0	15,202	403	500	2,320
0862020-001	Pine Landing Condo Assn	1,150	0	1	4,081	0		19,838	230	7,736	496
0862020-002	Pine Landing Condo Assn	1,150	0	1	4,081	0		19,838	230	7,733	496
1522010-002	Patrician Shores	3,385	0	0	3,510	0	5	15,202	200	4,000	400
2195020-001	Stewartstown Comm. School	847	0	2	20	2	54	153,350	780	1,000	1,090
1591010-001	Monroe Water Dept.	2,400	0	0	428	1	9	66,101	380	450	1,281
1591010-002	Monroe Water Dept.	2,400	0	0	428	1	9	66,101	380	450	1,281
2301020-001	West Swanzey Water Co.	3,800	0	1	1,310	0		2,502	245	5	64
2301020-002	West Swanzey Water Co.	3,800	0	1	1,265	0		2,502	198	5	119
1746020-001	Latva Machine Inc.	120	1	1	120	2	2	4,025	85	1,091	624
0203030-002	Northbrook MHP	727	0	1	1,399	0	1	1,300	677	5,947	3,000
0053010-003	Pine Needles MHP	9,722	0	0	500	0	12	19,382	75	3,575	4,000
1141020-004	Emerald Lake	2,463	0	0	25	0	12	11,769	71	947	150
1141020-006	Emerald Lake	5,502	0	0	25	0	12	15,512	46	476	3,730
1141020-007	Emerald Lake	5,400	0	0	25	0	12	15,512	31	46	3,860
1141020-008	Emerald Lake	5,400	0	0	25	0	12	15,512	121	138	3,860
1141020-009	Emerald Lake	5,400	0	0	25	0	12	15,512	251	271	3,860
Average	**< MCL**	**2,669**	**0.04**	**1.3**	**1,357**	**0.27**	**22**	**23,381**	**405**	**3,486**	**1,476**
Median	**< MCL**	**2,400**	**0.00**	**1.0**	**700**	**0.00**	**12**	**15,512**	**230**	**500**	**700**
Wells with no MTBE Detected (14)											
0811010-004	Farmington WD	1,511	0	0	1,102	0	4	13,913	1,000	100	800
0811010-005	Farmington WD	1,872	0	0	1,604	0	4	13,920	800	50	1,000
1861010-007	Pembroke Water Works	136	0	0	5,542	0	50	26,276	941	75	500
1994010-006	Franklin Pierce College	1,672	0	3	1,000	0	35	4,000	682	38,715	2,100
1994010-008	Franklin Pierce College	1,698	0	3	1,000	0	35	4,000	454	38,798	2,000
1994010-009	Franklin Pierce College	3,134	0	3	1,000	0	35	4,000	208		2,000
0382010-001	Rosebrook Water Co.	696	0	2	696	0	19	52,446	655	1,096	150
0382010-002	Rosebrook Water Co.	643	0	2	643	0	19	52,505	502	976	150
1141020-001	Emerald Lake	1,103	0	1	8,509	0	7	12,101	15	2,615	250
0365010-003	Henry Moore School	578	0	4	470	0	24	3,380	500	6,340	260
0053010-001	Pine Needles MHP	9,722	0	0	500	0	12	19,382	660	3,575	4,000
0053010-002	Pine Needles MHP	9,722	0	0	500	0	12	19,382	550	3,575	4,000
0895010-002	Gilmanton Elem. School	225	0	1	400	0	2	23,950	465	4,640	1,420
2316020-001	State Police/Registry	374	0	2	180	1	7	8,481	200	41	350
Average	**ND**	**2,363**	**0.00**	**1.5**	**1,653**	**0.07**	**19**	**18,410**	**545**	**7,738**	**1,356**
Median	**ND**	**1,307**	**0.00**	**1.5**	**848**	**0.00**	**16**	**13,917**	**526**	**2,615**	**900**
Overall Average		**2,257**	**0.04**	**1.4**	**1,354**	**0.33**	**32**	**26,062**	**445**	**6,272**	**1,271**
Overall Median		**1211**	**0.00**	**1.0**	**700**	**0.00**	**12**	**15512**	**251**	**3446**	**624**
Minimum		120	0	0	20	0	0	1,300	15	5	0
Maximum		9,722	1	6	8,509	2	150	153,350	1,299	12,400	4,000
Total			2	68		16	1,484				

Table 5-4
Other Current or Historical
Potential Risk Factors

EPA Well ID#	PWS Name	Road in SPA?	Inactive Potentially Unabandoned Well in WHPA/SWPA?	Well Seal OK?	Certified Operator?	Within 200' of Lineament?	Stickup OK?
Wells with MTBE Exceedances of MCL (12)							
0773010-002	Kings Towne MHP	1	1	1	1	0	1
0811010-003	Farmington WD	1	1	1	0	1	0
1994010-004	Franklin Pierce College	0	1	0	1	1	0
1861010-003	Pembroke Water Works	1	0	0	0	0	0
2194010-007	Coos County Farm	0	0	0	0	0	0
2194010-008	Coos County Farm	0	0	0	0	0	0
1522010-001	Patrician Shores	1	0	1	0	0	0
0203030-001	Northbrook MHP	0	0	0	0	0	0
1973030-001	PEU/Green Hills Estates	1	0	0	0	0	0
1973030-002	PEU/Green Hills Estates	1	0	0	0	0	0
1973030-003	PEU/Green Hills Estates	1	0	1	0	0	1
1973030-004	PEU/Green Hills Estates	1	0	1	0	0	1
Average	**>MCL 13 ppb**	**0.67**	**0.25**	**0.42**	**0.17**	**0.17**	**0.25**
Median	**>MCL 13 ppb**	**1.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Wells with MTBE Detected but at or Below MCL (23)							
0773010-003	Kings Towne MHP	1	1	1	1	0	1
1861010-002	Pembroke Water Works	1	0	0	0	0	0
1861010-004	Pembroke Water Works	0	0	0	0	1	0
1861010-006	Pembroke Water Works	0	0	0	0	0	0
1994010-005	Franklin Pierce College	0	1	1	1	0	0
1471010-003	City of Manchester	1	0	0	0	0	0
2296010-002	Labsphere Corp.	0	1	0	0	0	0
0862020-001	Pine Landing Condo Assn	0	0	0	0	0	0
0862020-002	Pine Landing Condo Assn	0	0	0	0	0	0
1522010-002	Patrician Shores	1	0	0	0	0	0
2195020-001	Stewartstown Comm. School	1	0	0	0	0	0
1591010-001	Monroe Water Dept.	0	0	0	1	0	0
1591010-002	Monroe Water Dept.	0	0	0	1	0	0
2301020-001	West Swanzey Water Co.	1	1	0	0	0	0
2301020-002	West Swanzey Water Co.	1	1	0	0	0	0
1746020-001	Latva Machine Inc.	1	0	1	1	0	1
0203030-002	Northbrook MHP	0	0	0	0	0	0
0053010-003	Pine Needles MHP	1	0	1	1	1	1
1141020-004	Emerald Lake	1	1	1	0	1	0
1141020-006	Emerald Lake	1	1	1	0	0	0
1141020-007	Emerald Lake	1	1	1	0	0	0
1141020-008	Emerald Lake	1	1	1	0	0	0
1141020-009	Emerald Lake	0	1	1	0	0	0
Average	**< MCL 13 ppb**	**0.57**	**0.43**	**0.39**	**0.26**	**0.13**	**0.13**
Median	**< MCL 13 ppb**	**1.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Wells with no MTBE Detected (14)							
0811010-004	Farmington WD	0	0	0	0	0	0
0811010-005	Farmington WD	0	0	0	0	0	0
1861010-007	Pembroke Water Works	0	0	0	0	1	0
1994010-006	Franklin Pierce College	0	1	0	0	1	0
1994010-008	Franklin Pierce College	0	1	0	0	1	0
1994010-009	Franklin Pierce College	0	1	0	0	1	0
0382010-001	Rosebrook Water Co.	0	0	0	1	0	1
0382010-002	Rosebrook Water Co.	0	0	0	0	0	0
1141020-001	Emerald Lake	1	1	1	0	0	0
0365010-003	Henry Moore School	0	1	0	0	0	0
0053010-001	Pine Needles MHP	0	0	1	1	1	1
0053010-002	Pine Needles MHP	0	0	1	1	1	1
0895010-002	Gilmanton Elem. School	0	1	0	0	0	1
2316020-001	State Police/Registry	0	0	0		0	0
Average	**ND**	**0.07**	**0.43**	**0.21**	**0.23**	**0.43**	**0.29**
Median	**ND**	**0.00**	**0.72**	**0.00**	**0.00**	**0.00**	**0.00**
Overall Average		**0.45**	**0.39**	**0.35**	**0.23**	**0.22**	**0.20**
Overall Median		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
		0 = no 1 = yes	0 = no 1 = yes	0 = yes 1 = no	0 = yes 1 = no	0 = no 1 = yes	0 = yes 1 = no

Table 5-5
NHDES Public Water Source Assessment Rankings

EPA Well ID#	PWS Name	Septic Systems	Highways/Railroads	SR Susceptibility	Known Contam. Sources	Urban Cover	Potential Contam. Sources	Well Integrity	Total	Predicts MtBE?	Prediction Correct?
Wells with MTBE Exceedances of MCL (12)											
0773010-002	Kings Towne MHP	2	2	1	1	2	0	0	8	yes	yes
0811010-003	Farmington WD	2	2	0	2	1	1	0	8	yes	yes
1994010-004	Franklin Pierce College	2	0	0	1	0	0	0	3	no	no
1861010-003	Pembroke Water Works	2	2	0	0	0	1	0	5	yes	yes
2194010-007	Coos County Farm	0	2	0	1	0	0	0	3	no	no
2194010-008	Coos County Farm	0	2	0	1	0	0	0	3	no	no
1522010-001	Patrician Shores	2	2	1	0	0	0	0	5	yes	yes
0203030-001	Northbrook MHP	1	1	1	0	2	0	0	5	yes	yes
1973030-001	PEU/Green Hills Estates										
1973030-002	PEU/Green Hills Estates										
1973030-003	PEU/Green Hills Estates										
1973030-004	PEU/Green Hills Estates										
Average	**>MCL 13 ppb**	**1.38**	**1.63**	**0.38**	**0.75**	**0.63**	**0.25**	**0.00**	**5.00**	**56% yes**	**56% yes**
Median	**>MCL 13 ppb**	**2.00**	**2.00**	**0.00**	**1.00**	**0.00**	**0.00**	**0.00**	**5.00**		
Wells with MTBE Detected but at or Below MCL (23)											
0773010-003	Kings Towne MHP	2	2	1	1	2	0	0	8	yes	yes
1861010-002	Pembroke Water Works	2	2	0	1	0	1	0	6	yes	yes
1861010-004	Pembroke Water Works	2	2	0	0	0	0	0	4	yes	yes
1861010-006	Pembroke Water Works	2	1	0	0	0	1	0	4	yes	yes
1994010-005	Franklin Pierce College	0	0	0	1	0	0	0	1	no	no
1471010-003	City of Manchester	1	2		0	0	2	0	5	yes	yes
2296010-002	Labsphere Corp.	2	2	1	1	0	1	0	7	yes	yes
0862020-001	Pine Landing Condo Assn	1	0	1	0	2	0	0	4	yes	yes
0862020-002	Pine Landing Condo Assn	1	0	1	0	2	0	0	4	yes	yes
1522010-002	Patrician Shores	2	2	1	0	0	0	0	5	yes	yes
2195020-001	Stewartstown Comm. School	2	2	0	0	1	1	0	6	yes	yes
1591010-001	Monroe Water Dept.	2	2	2	0	1	1	0	8	yes	yes
1591010-002	Monroe Water Dept.	2	2	2	0	1	1	0	8	yes	yes
2301020-001	West Swanzey Water Co.	2	1	0	1	2	0	0	6	yes	yes
2301020-002	West Swanzey Water Co.	2	1	0	1	2	0	0	6	yes	yes
1746020-001	Latva Machine Inc.	1	2	1	0	0	1	0	5	yes	yes
0203030-002	Northbrook MHP	1	1	0	0	0	0	0	2	no	no
0053010-003	Pine Needles MHP	1	0	1	0	0	0	0	2	no	no
1141020-004	Emerald Lake	2	0	2	0	0	0	0	4	yes	yes
1141020-006	Emerald Lake	1	0	1	0	0	0	0	2	no	no
1141020-007	Emerald Lake	1	0	0	0	0	0	0	1	no	no
1141020-008	Emerald Lake	1	0	0	0	0	0	0	1	no	no
1141020-009	Emerald Lake	1	0	0	0	0	0	0	1	no	no
Average	**< MCL 13 ppb**	**1.48**	**1.04**	**0.64**	**0.26**	**0.57**	**0.39**	**0.00**	**4.35**	**70% yes**	**70% yes**
Median	**< MCL 13 ppb**	**2.00**	**1.00**	**0.50**	**0.00**	**0.00**	**0.00**	**0.00**	**4.00**		
Wells with no MTBE Detected (14)											
0811010-004	Farmington WD	2	2	0	0	1	0	0	5	yes	no
0811010-005	Farmington WD	2	0	0	0	0	0	0	2	no	yes
1861010-007	Pembroke Water Works	2	1	0	0	0	0	0	3	no	yes
1994010-006	Franklin Pierce College	0	0	0	1	0	0	0	1	no	yes
1994010-008	Franklin Pierce College	0	0	0	1	0	0	0	1	no	yes
1994010-009	Franklin Pierce College	0	0	0	1	0	0	0	1	no	yes
0382010-001	Rosebrook Water Co.	0	2	1	2	0	1	0	6	yes	no
0382010-002	Rosebrook Water Co.	0	2	1	2	0	1	0	6	yes	no
1141020-001	Emerald Lake	2	0	2	0	0	0	0	4	yes	no
0365010-003	Henry Moore School	1	2	1	2	0	1	0	7	yes	no
0053010-001	Pine Needles MHP	1	0	1	0	0	0	0	2	no	yes
0053010-002	Pine Needles MHP	1	0	1	0	0	0	0	2	no	yes
0895010-002	Gilmanton Elem. School	2	2	2	0	0	1	0	7	yes	no
2316020-001	State Police/Registry										
Average	**ND**	**1.00**	**0.85**	**0.69**	**0.69**	**0.08**	**0.31**	**0.00**	**3.62**	**46% yes**	**54% yes**
Median	**ND**	**1.00**	**0.00**	**1.00**	**0.00**	**0.00**	**0.00**	**0.00**	**3.00**		
Overall Average		**1.32**	**1.13**	**0.59**	**0.50**	**0.44**	**0.33**	**0.00**	**4.30**	**61% yes**	**64% yes**
Overall Median		**1.50**	**1.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**4.00**		

0 = low; 1 = medium; 2 = high

A total ranking of 4 or greater was used to predict MtBE detection.

Table 5-6
Detailed Study Opinions
Regarding Potential Risk Factors

EPA Well ID#	PWS Name	Road Runnoff a Risk?	USTs/ASTs a Risk?	Rem. Sites a Risk?	Petroleum Storage or Use in SPA?	Poor Housekeeping in WHPA a Risk?	ELVs a Risk?	ATVs/SMs a Risk?	Boat Traffic a Risk?	Vehicle Repairs a Risk?	Compromised Well Integrity a Risk?	Total	Predicts MtBE?	Prediction Correct?
Wells with MTBE Exceedances of MCL (12)														
0773010-002	Kings Towne MHP	1	1	1	1	1	0	0	0	0	1	6	yes	yes
0811010-003	Farmington WD	1	1	1	0	1	1	0	0	1	1	7	yes	yes
1994010-004	Franklin Pierce College	1	1	1	0	0	1	0	1	0	0	5	yes	yes
1861010-003	Pembroke Water Works	1	1	1	0	1	0	1	0	1	0	6	yes	yes
2194010-007	Coos County Farm	1	1	1	1	0	0	0	0	0	0	4	yes	yes
2194010-008	Coos County Farm	1	1	1	1	0	0	0	0	0	0	4	yes	yes
1522010-001	Patrician Shores	1	1	0	0	0	0	0	1	0	1	4	yes	yes
0203030-001	Northbrook MHP	0	0	1	1	1	1	0	0	0	0	4	yes	yes
1973030-001	PEU/Green Hills Estates	1	1	0	1	1	1	1	0	1	0	7	yes	yes
1973030-002	PEU/Green Hills Estates	1	1	0	1	1	1	1	0	1	0	7	yes	yes
1973030-003	PEU/Green Hills Estates	1	1	0	1	1	1	1	0	1	0	7	yes	yes
1973030-004	PEU/Green Hills Estates	1	1	0	1	1	1	1	0	1	0	7	yes	yes
Average	**>MCL 13 ppb**	**0.92**	**0.92**	**0.58**	**0.67**	**0.67**	**0.58**	**0.42**	**0.17**	**0.50**	**0.25**	**5.67**	**100% yes**	**100% yes**
Median	**>MCL 13 ppb**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**0.00**	**0.00**	**0.50**	**0.00**	**6.00**		
Wells with MTBE Detected but at or Below MCL (23)														
0773010-003	Kings Towne MHP	1	1	1	0	1	0	0	0	0	1	5	yes	yes
1861010-002	Pembroke Water Works	1	1	1	0	1	0	1	0	1	0	6	yes	yes
1861010-004	Pembroke Water Works	1	0	0	0	1	0	1	0	0	0	3	no	no
1861010-006	Pembroke Water Works	1	1	1	0	0	0	1	0	1	0	5	yes	yes
1994010-005	Franklin Pierce College	1	1	1	0	0	1	0	1	0	0	5	yes	yes
1471010-003	City of Manchester	1	0	1	0	0	0	0	1	0	0	3	no	no
2296010-002	Labsphere Corp.	0	0	1	1	0	0	0	0	0	0	2	no	no
0862020-001	Pine Landing Condo Assn	1	1	0	0	0	0	0	1	0	0	3	no	no
0862020-002	Pine Landing Condo Assn	1	1	0	0	0	0	0	1	0	0	3	no	no
1522010-002	Patrician Shores	1	0	0	0	0	0	0	1	0	0	2	no	no
2195020-001	Stewartstown Comm. School	1	1	1	1	1	0	0	0	0	0	5	yes	yes
1591010-001	Monroe Water Dept.	1	1	0	1	0	0	0	0	0	0	3	no	no
1591010-002	Monroe Water Dept.	1	1	0	1	0	0	0	0	0	0	3	no	no
2301020-001	West Swanzey Water Co.	1	0	0	0	1	1	1	0	1	0	5	yes	yes
2301020-002	West Swanzey Water Co.	1	0	0	0	1	1	1	0	1	0	5	yes	yes
1746020-001	Latva Machine Inc.	1	1	1	1	1	0	0	0	1	0	6	yes	yes
0203030-002	Northbrook MHP	0	0	1	1	1	1	0	0	0	0	4	yes	yes
0053010-003	Pine Needles MHP	1	1	0	1	1	1	0	0	1	1	7	yes	yes
1141020-004	Emerald Lake	1	0	0	1	0	0	1	1	0	1	5	yes	yes
1141020-006	Emerald Lake	1	0	0	1	0	0	1	1	0	1	5	yes	yes
1141020-007	Emerald Lake	1	0	0	1	0	0	1	1	0	1	5	yes	yes
1141020-008	Emerald Lake	1	0	0	1	0	0	1	1	0	1	5	yes	yes
1141020-009	Emerald Lake	1	0	0	1	0	0	1	1	0	1	5	yes	yes
Average	**< MCL 13 ppb**	**0.91**	**0.48**	**0.39**	**0.52**	**0.39**	**0.22**	**0.43**	**0.43**	**0.26**	**0.30**	**4.35**	**65% yes**	**65% yes**
Median	**< MCL 13 ppb**			**0.00**	**1.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**5.00**		
Wells with no MTBE Detected (14)														
0811010-004	Farmington WD	1	1	0	0	0	0	1	0	0	0	3	no	yes
0811010-005	Farmington WD	1	1	0	0	0	0	1	0	0	0	3	no	yes
1861010-007	Pembroke Water Works	1	0	0	0	1	0	1	0	0	0	3	no	yes
1994010-006	Franklin Pierce College	1	1	1	0	0	1	0	1	0	0	5	yes	no
1994010-008	Franklin Pierce College	1	1	1	0	0	1	0	1	0	0	5	yes	no
1994010-009	Franklin Pierce College	1	1	1	0	0	1	0	1	0	0	5	yes	no
0382010-001	Rosebrook Water Co.	1	1	1	1	1	1	0	0	0	0	6	yes	no
0382010-002	Rosebrook Water Co.	1	1	1	1	0	1	0	0	0	0	5	yes	no
1141020-001	Emerald Lake	1	0	1	0	0	0	0	1	0	1	4	yes	no
0365010-003	Henry Moore School	1	1	1	0	0	0	0	0	0	0	3	no	yes
0053010-001	Pine Needles MHP	0	1	0	1	1	1	0	0	1	1	6	yes	no
0053010-002	Pine Needles MHP	0	1	0	1	1	1	0	0	1	1	6	yes	no
0895010-002	Gilmanton Elem. School	1	0	1	0	0	0	0	0	0	0	2	no	yes
2316020-001	State Police/Registry	1	1	1	0	0	0	1	0	0	0	4	yes	no
Average	**ND**	**0.86**	**0.79**	**0.64**	**0.29**	**0.29**	**0.50**	**0.29**	**0.29**	**0.14**	**0.21**	**4.29**	**65% yes**	**45% yes**
Median	**ND**	**1.00**	**1.00**	**1.00**	**0.00**	**0.00**	**0.50**	**0.00**	**0.00**	**0.00**	**0.00**	**4.50**		
Overall Average		**0.90**	**0.67**	**0.51**	**0.49**	**0.43**	**0.39**	**0.39**	**0.33**	**0.29**	**0.27**	**4.65**	**73% yes**	**65% yes**
Overall Median		**1.00**	**1.00**	**1.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**5.00**		

0 = not considered a risk; 1 = yes, considered a risk
A total ranking of 4 or greater was used to predict if MtBE was detected

such as roads in the SPA, an inadequate sanitary seal, or a shallow well depth may have also been observed. In such a case, the shallow well depth may have been a factor, but the proximity to roads or inadequate sanitary seal may have been insignificant. However, when attempting to evaluate potential risk factors in Section 5, all four of these factors could appear to be associated with the MtBE contamination because they were present and there was no objective data to weight one factor more highly than another.

- A confounding factor is that wells that have so far not been contaminated may still be at risk and become contaminated in the future.

- Many of the factors are interrelated or colocated, which is a complication for both the detailed studies and the statistical analyses. For example, population density is related to distance to nearest AST or UST and a multitude of other risk factors.

- Since wells are listed individually, conditions at PWS systems with multiple wells are more frequently represented in the data pool than conditions at PWS systems with single wells. This may have had the effect of giving greater weight to the conditions at multiple well systems.

- The wells were selected to cover a range of characteristics, which invariably skewed the analysis. The wells selected for the detailed studies therefore do not represent a random sampling of PWS wells in the state.

- The wells were grouped into three categories: wells with exceedances of the MCL (hereafter abbreviated as "wells with exceedances"); wells with detectable concentrations of MtBE but no exceedances of the MCL (hereafter called "wells with detects"); and wells with no detected MtBE concentrations (hereafter called "clean wells"). Because of the small sample size, because the wells selected do not necessarily represent a random sampling of the population, and because the data from wells within each category were averaged for evaluation, it is possible for data from one or two wells in each category to skew the averages and provide potentially misleading results.

- Often, if not always, multiple risk factors are present when a well becomes contaminated with MtBE. For example, in order for MtBE to enter a well, at least two conditions must be present: (1) a source of MtBE must be released into the environment; and (2) a pathway must exist for the MtBE to travel to the well. The presence of a LUST in close proximity to a well does not result in contamination in the well if it is downgradient of the well and no pathway exists between the LUST and the well. Also, road runoff may contain MtBE and flow past the wellhead, but if the well seal and casing are properly installed and the runoff does not infiltrate the ground, the well will not be impacted. It is often difficult to assess all of the multiple factors that influence a well's susceptibility to contamination.

As a result of the above limitations, the results of the detailed studies should be considered qualitative in nature. Still, interesting findings emerged, some of which could not be gleaned from statistical analyses. The detailed studies complement the statistical analyses that are on the one hand more objective, but on the other hand, less in depth. The statistical analyses provide the breadth, and the detailed studies provide the depth, for this evaluation of MtBE in PWS wells/sources.

Tables 5-2 through 5-6 summarize information gathered and opinions rendered relative to the detailed studies. Table 5-2 summarizes basic information for each of the investigated wells. Table 5-3 summarizes information on the nearby potential sources. Table 5-4 summarizes information on additional potential risk factors. If the risk factor was present, it was assigned a value of 1; if absent, it was assigned a value of 0. Table 5-5 summarizes results of selected NHDES PWSA rankings. The PWSAs evaluated risks to wells from many types of contamination. Seven of the 13 criteria that were deemed potentially most relevant to MtBE contamination were selected and are presented left to right in order of overall ranking for the group of 49 wells as a whole. High, medium, and low rankings were converted to values of 2, 1, and 0, respectively, so that averages could be computed (PWSA rankings were not available for Pennichuck East Utility Company/Green Hills Estates). Table 5-6 summarizes WESTON's opinions as to the presence or absence of potential risk factors for each of the detailed studies. If a risk factor was thought applicable to a well, a value of 1 was assigned; if not, a value of 0 was assigned. They are arranged left to right in order of overall prevalence for the group of 49 wells as a whole.

5.2.2 Public Water Supply Well/Surface Water Source Properties

The PWS well properties include location, well type, PWS type, well depth, safe yield, population density, and WHPA/SWPA size. Overall, 35% of the wells were in RFG counties. The wells with exceedances were more predominantly in RFG counties; 58% of the wells with exceedances were in RFG counties. Of the clean wells, only 29% were located within RFG counties.

Higher MtBE concentrations appeared to be associated with shallower well depths. The average depth of the wells with exceedances was 152 ft, versus 333 and 396 ft for the wells with detects and clean wells, respectively. The overall average depth was 307 ft. The median values for the three groups of wells followed a similar pattern; the median depth of the wells with exceedances was 111 ft, versus 265 and 328 ft for the wells with detects and clean wells, respectively. The overall median depth was less, 193 ft (three very deep wells at Franklin Pierce College had skewed the average depth to the higher value of 307 ft). These results differed from the findings of the Rockingham County study (Ayotte et al., 2005); USGS found that MtBE concentrations correlated positively with well depth for PWS wells.

One factor that may partially account for the different findings is that 82% of the public wells sampled in the Rockingham County study were bedrock wells, as opposed to only 56% in this statewide study.

Of the wells selected, the shallower, more contaminated wells tended to be overburden wells, including 67% of the wells with exceedances, 36% of the wells with detects, and 36% of the clean wells. Overall, 21 of the 49 wells selected (or 44% of the total, not counting the one surface source) were overburden wells.

The wells with exceedances also tended to have lower pumping rates, 91 gpm on average. The average pumping rate for the wells with detects was skewed by the very high flow rate of Manchester Water Works; if this value is excluded, the average pumping rate for wells with detects is 137 gpm rather than 644 gpm. Clean wells had an average pumping rate of 123 gpm. The wells with detects and the clean wells had average pumping rates that were at least 35% higher than the wells with exceedances. The median pumping rates for the three groups of wells did not follow this pattern. The median pumping rates for the three groups of wells were similar to one another, and the wells with exceedances had the highest median pumping rate, 42 gpm, compared with 35 gpm for the wells with detects and 38 gpm for the clean wells. This correlation differs slightly from the Rockingham County study, which found an inverse relationship between MtBE concentrations and the safe yield of the water supply. However, the data correlation in the Rockingham County study was not statistically significant.

Average population density in the vicinity of the well was greatest for the wells with exceedances (488 people per square mile), intermediate for wells with detects (260 people per square mile), and least for clean wells (116 people per square mile). The overall average was

275 people per square mile. Median population density was also greatest for wells with exceedances; the median was 457 people per square mile as opposed to the much lower values of 84 and 95 people per square mile for the wells with detects and clean wells, respectively, and an overall median of 99 people per square mile. These results suggest that population density is a potential risk factor. USGS' Rockingham County study (Ayotte et al., 2005) also found that MtBE concentrations correlated strongly with population density.

The WHPA/SWPA size was generally similar for the three categories of wells, on average 363, 460, and 387 acres, respectively (with an overall average of 415 acres). Medians were also generally similar, at 362, 303, and 303 acres (with an overall median of 303 acres). This is fortunate because Table 5-3 includes information on numbers of potential sources in the WHPA/SWPAs. Having similar WHPA/SWPA sizes makes these data more comparable. WHPA/SWPA areas ranged from 112 to 1,564 acres.

Table 5-2 also includes the maximum MtBE concentration detected at each well and the date of the maximum detection. Maximum MtBE concentrations ranged from non-detect to 58 µg/L. The data of maximum detection ranged from 27 October 1993 to 9 May 2005.

5.2.3 Nearby Potential Point Sources

Tables 5-3 and 5-5 include information on potential MtBE sources near the wells. These include remediation sites, USTs and ASTs, junkyards and end-of-life vehicles (ELVs), known and potential contamination sources, and septic systems.

Remediation Sites

The distance to the nearest remediation site ranged from 120 to 9,722 ft. The wells with exceedances had an average distance of 1,342 ft, whereas the wells with detects and clean wells had average distances of 2,669 and 2,363 ft, respectively. Median distances were 1,130, 2,400, and 1,307 ft, respectively. The overall median was 1,211 ft. The data suggest that distance to the nearest remediation site may be a risk factor for MCL exceedances.

Remediation sites in the SPA were rare. There was one occurrence at a well with exceedances, at Kings Towne Mobile Home Park, and one at a well with detects, at Latva Machine. The former was a diesel LAST and the latter was a fuel oil LUST. In both cases, contaminated soil was removed but groundwater apparently was neither assessed nor remediated.

The number of remediation sites in the WHPA/SWPA ranged from 0 to 6, and the average number was similar for the three groups of wells, 1.5, 1.3, and 1.5, respectively. Medians were also similar, 1.0, 1.0, and 1.5, respectively, with an overall median value of 1.0. In this group, we included LASTs, LUSTs, UICs related to floor drains, spills, OPUFs, and Remediation Sites. (We did not include "H_2O" or "Ether" sites, nor did we include UICs for well pumping tests.)

Documented spills occurring in the WHPA/SWPA were less numerous and were typically addressed quickly. The issue of small spills that would not typically be reported to NHDES could in some cases be significant. For example, the Rindge Fire Chief estimates that 10 gallons of gasoline per year are released from vehicles at Franklin Pierce College. These are small releases on the order of 1 gallon each that are reported to the local fire department and do not include releases from car accidents or unreported releases.

There were a total of 68 remediation sites in the WHPA/SWPAs of the 49 wells. With the exception of removal of 20,000 gallons of groundwater during an UST removal at Rosebrook Water Company (see below), review of the detailed study reports did not identify cases of groundwater remediation at any of the 68 remediation sites. Furthermore, in many cases, groundwater was not sampled to determine if it had been impacted. This seemed particularly true of OPUF sites. A few examples of remediation sites in the WHPAs/SWPAs are summarized below; none are in SPAs. Detailed information on the PWS wells discussed can be found in the Detailed Study Reports provided in Appendix C. Remediation approaches and impacts are discussed further in the Section 7 of this report.

- At a gas station site near Rosebrook Water Company, a gasoline LUST was removed in 1998 that was approximately 1,000 ft from the PWS wells and in their WHPA/SWPA. Fifteen cubic yards (cy) of soil and 20,000 gallons of groundwater were removed along with the UST. Contaminated soil remained, and there was a sheen on groundwater. MtBE concentrations in groundwater up to 2,090 µg/L have been detected in nearby monitoring wells, and MtBE exceedances in groundwater extend off-site. MtBE concentrations exceeding the MCL have been detected in a monitoring well approximately 250 ft from the PWS wells; however, it is not certain that this and other nearby detections are a result of the LUST rather than petroleum storage in the SPA. It has been estimated that 85 gallons of gasoline remain in soils at the LUST site. Pilot testing of soil vapor extraction and groundwater pump and treat is anticipated to begin soon. A groundwater management zone (GMZ) has been established but it appears that the extent of contamination has not been fully delineated; the GMZ ends at the property line. It should be noted, however, that as of the time of our investigation, MtBE has not been detected in the nearby PWS well, even though it is located approximately 1,000 ft from the remediation site and in the WHPA/SWPA. One possible explanation is that MtBE-contaminated groundwater is being diluted by the large volume of clean water that is being extracted from the PWS wells. This remediation site is discussed in more detail in Section 7.

- At Franklin Pierce College, a fuel oil UST was closed in place. MtBE was detected at 2 µg/L in a composite groundwater sample. Four soil samples were non-detect for MtBE [<160 micrograms per kilogram] and groundwater samples from five monitoring wells were non-detect for MtBE in three rounds of sampling (<2 µg/L). The consultant concluded that the extent of soil and groundwater contamination was not fully delineated and recommended further delineation. However, a *"No Further Action" Letter* was issued in 2003. This LUST site is in the WHPA/SWPA of MtBE-contaminated PWS wells located approximately 1,000 ft away.

- At Kings Towne Mobile Home Park, fuel oil was formerly stored in individual 330-gallon USTs for each of 131 homes. The USTs were removed in 1997, and fuel oil is currently stored in ASTs. Twelve of the 131 USTs had documented releases ("OPUFs"); some had holes as large as 1 inch in diameter. Approximately 1/3 of the OPUFs in the mobile home park were in the WHPA/SWPA. Soil (41 cy) was excavated until organic vapor meter readings were less than 50 ppm, or groundwater was encountered. Excavation did not extend underneath homes. Monitoring wells were placed in six of the tank pits, and groundwater samples from two of the wells had MtBE concentrations of 39 and 291 µg/L. These results indicate that fuel oil releases can result in measurable MtBE concentrations in groundwater. Continued monitoring indicated that MtBE appeared in groundwater at a third location in late 1997 (at concentrations of 14 and 20 µg/L). Bedrock groundwater was not investigated, and it is not known if the USTs impacted Wells 002 or 003. Overburden groundwater contours prepared by the remediation contractor indicate that overburden groundwater in the vicinity of the OPUFs generally flows toward the river and away from the PWS wells; however, a connection between the overburden aquifer and the bedrock wells cannot be ruled out. The first MtBE detection at the PWS wells was in December 1996, which is consistent with the discovery of the LUSTs in 1997. Cleanup levels used for the remediation were an AGQS of 100 µg/L for MtBE and a Generic Soil Cleanup Standard of 3 milligrams per kilogram (mg/kg) for MtBE. Additional contaminated soil (22.4 tons) was removed from one of the two recommended locations in 2000, and soils were below RCMS-1 soil standards, which for MtBE was 0.13 mg/kg. MtBE concentrations greater than the MCL have persisted in the wells through 2004.

- Near Kings Towne Mobile Home Park, an estimated 150 gallons of Number 2 fuel oil was released in 1992 from a copper line as a result of suspected vandalism. It contaminated a neighbor's 10-foot-deep dug well less than 15 ft away. Depth to groundwater was only 3 ft and a sheen was present. A water sample had 4 µg/L of MtBE; this was the only detection of MtBE. Approximately 100 tons of soil were removed at the property. The owner agreed to remove additional contaminated soil but not excavate below the water table. Laboratory results in 1993 for samples from three monitoring wells (the deepest being 9.4-foot deep) showed that MtBE was not detected. This spill was 1,000 to 1,500 ft from the PWS wells, and in the WHPA/SWPA.

- In Pembroke, there have been at least six UICs or LUSTs remediated in the WHPAs of Wells 002, 003, and 006. All six sites involved soil excavation but none included groundwater remediation. Although several included groundwater monitoring, the extent of the plume was not always fully delineated. Thus, it is unclear if the extent of remediation was necessarily adequate to address groundwater impacts. In at least one case (Harley Davidson), MtBE was detected in coarse-grained soil samples but groundwater was apparently not investigated. Wells 002, 003, and 006 have all had detections of MtBE and Well 003 has had exceedences of the MCL.

Referring to Table 5-6, the presence of nearby remediation (GWHI) sites were identified as a potential risk factor for 51% of the wells overall. The sites included LASTs, LUSTs, remediation sites, UICs, OPUFs, and in a few cases, spills in or near the WHPA. This was the third most prevalent potential risk factor identified overall. In general, potential contaminant sources that are strongly associated with MtBE contamination would be expected to be observed more frequently near wells with exceedances, less frequently for wells with detects, and rarely for clean wells (called "the expected pattern" hereafter). However, this simple concept is complicated by factors such as local hydrogeology and groundwater flow gradients, which may prevent contaminants from migrating toward the well. Therefore, it is not altogether surprising that ratings for GWHI sites did not follow the expected pattern; the averages were 0.58, 0.39, and 0.64 for wells with exceedances, wells with detections, and clean wells, respectively.

Underground Storage Tanks and Aboveground Storage Tanks

We included all USTs and ASTs in this category, whether registered or unregistered, and without regard to the product stored. Many ASTs and USTs are small residential tanks for heating oil. Many ASTs are outdoors and exposed to the elements, and some do not have a solid footing.

Referring to Table 5-3, proximity to USTs and ASTs appeared to be associated with MtBE contamination. The distance to the nearest UST or AST ranged from 20 to 8,509 ft. The wells with exceedances had an average distance of 999 ft, the wells with detects had an average distance of 1,357 ft, and the clean wells had an average distance of 1,653 ft. The average nearest distance was 1,354 ft. The corresponding median distances of 850, 700, and 848 ft; however, did not bear this out; the medians were generally similar for all three groups.

There were 16 instances of USTs and ASTs located in the SPA in the group of 49 wells studied, and this appears to be a probable risk factor. Wells with exceedances had an average of 0.75 USTs and ASTs, compared with 0.27 for wells with detects and 0.07 for clean wells. (Medians were all zero.)

The number of USTs and ASTs in the WHPA/SWPA ranged from 0 to 150, with an average of 32 per WHPA/SWPA. This appears to be a likely risk factor, especially with regard to MCL exceedances. Wells with exceedances had an average of 67, compared with 22 for wells with detects and 19 for clean wells. The pattern was generally similar for the corresponding median values of 33, 12, and 16, with an overall median of 12. The total number of USTs and ASTs estimated to be in the WHPA/SWPAs of the 49 wells was 1,484.

Referring to Table 5-6, USTs and/or ASTs were identified as a potential risk factor for 68% of the wells overall. These were registered or unregistered tanks, and they contained gasoline or other petroleum products. The averages in Table 5-6 did not follow the expected pattern (0.92, 0.48, and 0.79 for wells with exceedances, wells with detections, and clean wells, respectively), but USTs or ASTs were present within the WHPA/SWPA for all but one of the wells with exceedances. (Medians were 1, 0, and 1, with an overall median of 1.)

Junkyards and End-of-Life Vehicles

Referring to Table 5-3, the distance to the nearest junkyard ranged from 1,300 to 153,350 ft. The average distances were 40,130 ft for wells with exceedances, 23,381 ft for wells with detects, and 18,410 ft for clean wells (Median distances were lower, but followed a similar trend; medians were 17,200, 15,512, and 13,917 ft, respectively, with an overall median of 15,512.) Most distances are too far for junkyards to be expected to impact the wells. There were only

10 cases of a junkyard being located less than a mile from the well. During the course of our detailed studies, several automobile salvage yards were observed that did not appear in the OneStop database. A junkyard approximately 5,000 ft from Franklin Pierce College, for example, had roughly 300 to 400 vehicles but did not appear in the database. According to the NHDES, the listing of junkyards included in the OneStop database were provided by the towns or operators through Fall 2002. The towns or operators indicated that the identified facilities met the criteria of processing 12 or more vehicles annually and/or storing 25 or more ELVs for a period longer than 60 days. No independent verification of the facilities was performed by NHDES. Therefore, it is possible that a junkyard may never have been included in the OneStop database, a new facility may have started after the Fall of 2002, and/or a facility may no longer meet the junkyard criteria.

The data regarding junkyards in Table 5-3 are the opposite of what might be expected for a probable risk factor. It may be because junkyards tend to be located in rural areas where fewer numbers of other potential MtBE sources are located.

End-of-Life Vehicles, whether in a documented automobile salvage yard or observed as one or several ELVs near a well, were identified as the sixth most prevalent potential risk factor in the detailed studies. Referring to Table 5-6, ELVs were identified as a risk factor for 39% of the wells overall. The averages did not follow the expected pattern (0.58, 0.22, and 0.50 for wells with exceedances, wells with detections, and clean wells, respectively).

Known and Potential Contaminant Sources

NHDES PWSAs ranked the risks from known and potential contaminant sources (refer to Table 5-5). These included the sources discussed above, as well as other potential point sources like hazardous waste generators, car washes, auto repair facilities, construction yards, fleet vehicle parking areas, and the like. The PWSA rankings of known contamination sources did not follow the expected pattern (0.75, 0.26, and 0.69, respectively, with an overall average of 0.50). However, medians of 1, 0, and 0, respectively, (with an overall median of 0) were consistent with the expected pattern. Similarly, PWSA rankings for potential contamination sources did not follow the expected pattern (0.25, 0.39, and 0.31, for wells with exceedances, detections, and clean wells, respectively, with an overall average of 0.33). (Median values were all 0.)

Table 5-6 indicates that vehicle repairs, either at commercial facilities or by "backyard mechanics," were identified as a risk factor for 29% of the wells overall. The averages followed the expected pattern for a potential risk factor (0.50, 0.26, and 0.14 for wells with exceedances, detections, and clean wells, respectively). Medians of 0.5, 0, and 0, with an overall median of 0, were consistent with this. Half of all wells with exceedances had this potential risk factor. Kings Towne Mobile Home Park recognizes this risk and strictly prohibits vehicle and boat repair activities on the property.

Septic Systems

Referring to Table 5-5, PWSA rankings of risks from septic systems were the highest of any of the SWSA categories, with an overall average value of 1.32, indicating medium to high risk. However, keep in mind that the PWSA rankings pertain to all types of contaminants, including coliform bacteria and other contaminants associated more strongly perhaps with septic systems than MtBE. Wells with exceedances and detects had higher average values (1.38 and 1.48) than clean wells (with a value of 1.00), suggestive of a potential risk factor. Median values of 2, 2, and 1, with an overall median of 1.5, were consistent with this. Although septic systems have been considered a potential risk factor during this study, they are not considered a confirmed source as no documented instances of MtBE contamination being a direct result of a septic system were encountered in this study. However, the relationship of the PWS and the proximity to a septic system may be indicative of other activities nearby which may result in MtBE spills or releases.

5.2.4 Nearby Potential Non-Point Sources

Nearby potential non-point sources include roads, ATV/snowmobile trails, surface water and boat traffic, and urban cover.

Roads

Referring to Table 5-3, the distance to the nearest road ranged from 15 to 1,299 ft. The average distances were similar for the three groups of wells but slightly larger for the clean wells (406 ft for wells with exceedances, 405 ft for wells with detects, and 545 ft for clean wells).

However, median distances followed the expected pattern for a potential risk factor, with values of 190, 230, and 526 ft, respectively, and an overall median of 251 ft. The data show that many wells are very close to roads, and roads are often present within the SPA. No wells were more than ¼ mile from a road. (Keep in mind that the roads here may be in or out of the WHPA/SWPA and may be at a higher or lower elevation than the PWS well.)

Table 5-4 summarizes information regarding the presence of roads in the SPA. Here, the presence of roads in the SPA appears to be associated with the presence or absence of MtBE: this condition was present at 67% of the wells with exceedances and 57% of the wells with detects, whereas this condition was present at only 7% of the clean wells. Median values of 1, 1, and 0, with an overall median of 0, support this conclusion. Taking all the wells as a group, 45% of them had public roads carrying traffic present within the SPA, indicating this is a very common condition.

Table 5-5 indicates that highways/railroads had the second highest overall ranking of the PWSA factors. (Railroads are not considered a significant potential risk factor; however, they are included here because the PWSA rankings lump together highways and railroads as one factor.) The PWSA rankings for risks from numbered highways and roads were highest for wells with exceedances (1.63), next highest for wells with detects (1.04), and lowest for clean wells (0.85), suggestive of a potential risk factor. The overall average ranking was 1.13. Median values of 2, 1, and 0, with an overall median of 1, support this conclusion.

In Table 5-6, road runoff was the most commonly identified potential risk factor in the detailed studies, identified at 90% of the wells overall. In general, road runoff was considered a potential risk factor if there were any roads present in the WHPA/SWPA at an elevation higher than the wellhead (and without a storm drainage system to carry water away from the WHPA/SWPA), if a road was present in the SPA, or if driveway or parking lot runoff was deemed a risk to the well. The averages followed the expected pattern (0.92, 0.91, and 0.86), but the values were very similar. All the medians were 1.

All-Terrain-Vehicle/Snowmobile Trails

Referring to Table 5-3, the distance to the nearest ATV trail ranged from 5 to 12,400 ft. The data are not very reliable or comparable from well to well for several reasons. First, the ATV trails in the database are only the major official trails in the state. There are many other established trails that are not included in the State ATV trail system. In addition, during the site visits, it was often difficult to see nearby trails unless they were very close to the well, and investigators varied in the extent to which they pursued ATV trail information within the WHPA/SWPA but outside of the SPA. In 12 of the 49 cases, ATV trails were so close to the well as to be in the SPA. ATV trails were identified as potential risk factors at 39% of the wells overall (see Table 5-6). The averages were 0.42 for wells with exceedances, 0.43 for wells with detects, and 0.29 for clean wells. (All medians were 0.)

Surface Water and Boat Traffic

Table 5-3 indicates that the distance to surface water ranged from 0 (in the case of the Manchester Water Works surface supply) to 4,000 ft. The wells with exceedances had an average distance of 781 ft, compared with about twice that for wells with detects (1,476 ft) and clean wells (1,356 ft). The data appear to suggest this may be a risk factor for MCL exceedances. However, it may be more of an indication of higher population density near surface water bodies than an indication that the surface water bodies are a source of the contamination. Keep in mind that surface water may or may not be used for boating. Median distances followed the expected pattern for a potential risk factor, with medians of 549, 700, and 900 ft, respectively, and an overall median of 624 ft. An evaluation of MtBE impacts to surface water sources and wells drawing water from surface water bodies is provided in Section 6.

Referring to Table 5-6, boat traffic on a surface water source or on a surface water body near a well was identified as a potential risk factor for 33% of the wells. The averages did not follow the expected pattern for a potential risk factor (17%, 43%, and 29%, respectively); medians were all 0. Manchester Water Works is a surface water supply (Massabesic Lake), and seasonal variations in MtBE concentrations indicate that boat traffic is a likely source of MtBE contamination in this water supply. Even though the concentrations are low (none exceed 3 μg/L), the seasonal pattern of higher concentrations in the summer months is apparent on the graph of MtBE concentrations (see Detailed Study Report in Appendix C). Pine Landing (on Ossippee Lake) and Patrician Shores (on Lake Winnipesaukee) are two PWSs with no remediation sites or registered USTs or ASTs in the WHPA/SWPAs; the primary potential risk factors in both cases appear to be limited to boat traffic, along with road runoff, septic systems, and unregistered ASTs and USTs.

Urban Cover

Referring to Table 5-5, PWSA rankings suggest that urban cover may be a potential risk factor for presence or absence of MtBE, based on an average ranking of 0.63 for wells with exceedances, 0.57 for wells with detects, and 0.08 for clean wells. Overall, the average ranking was 0.44. (All medians were 0.)

5.2.5 Other Potential Risk Factors

These include inactive potentially unabandoned wells, faulty well seals, inadequate well operator certification, proximity to lineaments, inadequate well stickup, and SPA susceptibility.

Inactive Potentially Unabandoned Wells

Table 5-4 summarizes information on the presence of an inactive potentially unabandoned well in the WHPA/SWPA at one time or another, at 39% of the wells. The averages were 25% of wells with exceedances, 43% of wells with detects, and 43% of clean wells. Medians were all 0. There is a reluctance to abandon wells that are taken out of service, because the need may arise to reactivate them at a future time if they are still functional. However, unless they were designed to prevent it, unabandoned wells can serve as open conduits into the aquifers they had drawn from. Contaminants entering from the surface can cross-contaminate a number of water-bearing formations within one well. Examples of unabandoned inactive wells include:

- Farmington Well 003 is inactive and has been sampled as recently as 2003. This well had MtBE exceedances of the MCL. It presumably has not been abandoned. In addition, there is evidence that surface water enters this well (algae were detected in water samples). It is approximately 0.9 miles from clean Wells 004 and 005.

- Franklin Pierce College Well 001 is 200 to 300 ft from the aforementioned LUST that was closed in place, and both the well and the LUST are near underground wastewater and stormwater piping that can serve as horizontal conduits of preferential groundwater flow. Lineaments may also serve as preferential pathways. Furthermore, this well is in a parking lot and has in the past had flooding of the top of the well; there is the potential for parking lot runoff to have entered this well. All of these features are within the WHPA/SWPA of impacted PWS wells.

- At Kings Towne Mobile Home Park, a new well was installed on 4 August 2004, to replace a shallower well with exceedances. The new deeper well was pumped before the old well was abandoned. A low concentration of MtBE (0.6 µg/L) was detected in the new well in a sample collected 24 August 2004, then at 11 µg/L in July 2005 and 8.5 µg/L in August 2005. It is not known if the old well served as a preferential pathway.

- Gilmanton Elementary School has an inactive but open well 100 ft from the active well. The unabandoned well at one time had an improper seal. However, MtBE has not been detected in the school's active PWS well.

Proximity to Lineaments

One of the spatial queries identified if the well is within 200 ft of a lineament. Lineaments are linear features on the ground surface that are often identified by viewing stereo pairs of aerial photographs. Lineaments often, but not always, indicate the presence of faults and fractures. Lineaments only provide preliminary information on potential faults and fractures; additional information (e.g., from subsurface investigation) is necessary in order to confirm that these linear features are indeed faults or fractures.

As shown in Table 5-4, 22% of the wells were within 200 ft of a lineament overall, including 17% of wells with exceedances, 13% of wells with detects, and 43% of the clean wells. (Medians were all 0.) Based on these results, a well location within 200 ft of a lineament did not appear to be associated with increased risk of MtBE contamination. However, lineaments were deemed important in several of the detailed studies. One example where lineaments may provide a preferential pathway for contaminant migration is Franklin Pierce College (see Figures 5-2a through d). Two lineaments meet north of the campus. One northwest-southeast trending lineament crosses the active wellfields and the other northeast-southwest trending lineament crosses the OPUF, UST, and parking areas of the campus.

Operator Certification

As shown in Table 5-4, problems with inadequate PWS operator certification were noted at 23% of the wells at one time or another. The averages did not follow the expected pattern (17, 26, and 23% for wells with exceedances, wells with detections, and clean wells, respectively). (Medians were all 0.)

Defective Well Seals

Table 5-4 summarizes information from the sanitary surveys regarding well seals. Taking all the wells as a group, 35% had a faulty well seal at one time or another, including 42% of the wells with exceedances, 39% of the wells with detects, and 21% of the clean wells. The averages follow the expected pattern for a potential risk factor. (Medians were all 0.)

Inadequate Well Stickup

The last potential risk factor indicated on Table 5-4 is whether the well stickup at one time or another was unsatisfactory, as indicated by the NHDES sanitary surveys. Overall, 20% of the wells had an inadequate stickup: 25% of the wells with exceedances, 13% of the wells with detects, and 29% of the clean wells. (Medians were all 0.) Table 5-5 lists the results of the PWSA surveys regarding well integrity. Problems with well integrity were not identified during the PWSAs. All of the wells were given a low hazard ranking in the PWSA surveys for well integrity.

Table 5-6 provides the investigators' opinions regarding compromised well integrity. A bad well seal or inadequate stickup was identified as a potential risk factor for 27% of the wells during the detailed studies, but did not appear to be associated with the presence of MtBE in wells (0.25, 0.30, and 0.21 for wells with exceedances, wells with detections, and clean wells, respectively). (Medians were all 0.) The sources of information taken into consideration when developing the opinions presented in Table 5-6 were the sanitary and PWSA surveys, field observations, and interviews with well owner/operators.

Sanitary Protective Area Susceptibility

The PWSA surveys provided an assessment of the amount of development not associated with the well within the SPA, including sewer lines, septic systems, or storage of regulated substances. Referring to Table 5-5, PWSA rankings of this hazard were low to moderate on average (0.59), and lower in the wells with exceedances (0.38) than in the wells with detects (0.64) and clean wells (0.69). This is the opposite of what would be expected for a potential risk factor. Medians were similarly the opposite of the expected pattern, with values of 0, 0.5, and 1, respectively, and an overall median of 0.

Petroleum storage or use in the SPA was the fourth most common potential risk factor in Table 5-6, which was identified at 49% of the wells overall. This covered a range of conditions, such as the presence of USTs, ASTs, ELVs, lawn mowers, gas cans, and the like. The averages followed the expected pattern (0.67, 0.52, and 0.29 for wells with exceedances, wells with detections, and clean wells, respectively). Medians were consistent with this relationship with values of 1, 1, and 0, respectively, and an overall median of 0.

In addition, the fifth most common potential risk factor in Table 5-6 was poor housekeeping in the WHPA/SWPA, which was identified for 43% of the wells. This covered conditions such as debris and junk accumulations at nearby residences and industrial facilities. The averages followed the expected pattern (0.67, 0.39, and 0.29 for wells with exceedances, detections, and clean wells, respectively). Medians were consistent with this, at 1, 0, and 0, respectively, and an overall median of 0.

5.2.6 Public Water Supply Assessment Survey Ranking Totals

Table 5-5 includes a sum of the individual rankings from the PWSA surveys for each well. The range was 1 to 7. No well was given low rankings for all criteria. The average total rankings were 5.00 for the wells with exceedances, 4.35 for the wells with detects, and 3.62 for the clean wells. The overall average ranking was 4.30. The lowest total ranking for an individual well with exceedances was 3. Although the averages from each of the categories followed the expected pattern, the results of the PWSAs were not particularly useful for predicting whether an individual well was likely to be contaminated with MtBE. The best predictions are achieved if a total ranking of 4 or higher is used to predict MtBE contamination in a well. This results in a correct prediction for only 64% of the wells. However, it is important to keep in mind that wells not contaminated to date may become contaminated in the future.

5.2.7 Detailed Study Opinions Regarding Risk Factors

The last column in Table 5-6 provides a sum of the risk factors identified by the detailed study investigators at each well. The range was 2 to 8. No well was given low rankings for all criteria. The average numbers of potential risk factors were 5.67 for the wells with exceedances, 4.35 for wells with detects, and 4.29 for the clean wells. The overall average number of potential risk factors was 4.65. The results are similar to those discussed above in Subsection 5.2.6. A correct prediction can be achieved only 65% of the time using a total ranking of 4 or higher as an indication of MtBE contamination. However, 100% of the wells with exceedances were predicted correctly (as noted above, wells not contaminated yet may become so in the future).

5.2.8 Additional Observations Regarding Risk Factors

Several detailed studies noted farm tractor operations adjacent to the wells as potential risk factors. Examples include Monroe Water Department and Coos County Farm.

Possible improper sampling procedures (contamination of a sample after collection) were identified as a potential cause of MtBE detection at one well with a single detection of 1.7 µg/L (Stewartstown Community School). Improper sampling procedure was confirmed at another well, Rosebrook Water Company, and this well was reclassified as a clean well even though a concentration of 28 µg/L had been detected. The false positive was caused by transportation of a cooler of samples in a car trunk along with an open gasoline can. On resampling, MtBE was not detected.

In general, NHDES was very effective at identifying risk factors near wells through sanitary surveys, PWSA surveys, and other activities. However, file reviews indicated that in some cases, identified problems persisted for some time before being rectified. For example, at Kings Towne Mobile Home Park, deficiencies in well construction and operation that would allow surface water to enter the well were noted. These deficiencies continued for 10 years or more.

5.2.9 Observations Regarding Data

In general, the databases agreed well with information obtained from detailed study paper files, OneStop research, interviews, and inspections. Databases were often less detailed, as would be expected. Well identification numbers were in some cases inconsistent and unclear; for example, the analytical database is sometimes not explicit about which wells were included in a blended sample. Also, in some cases, a consultant report or OneStop stated that a potential MtBE source was not in a WHPA/SWPA when in fact it was. Other than these two areas, no other notable database problems were encountered.

5.3 CONCLUSIONS FROM DETAILED STUDIES

There are a variety of potential risk factors present at the 49 wells studied, many of which are interrelated, and the situation is complex. Please recall the important caveats stated at the beginning of this discussion. Conclusions cannot be reduced to one or two explanatory risk factors. The findings that emerged for this group of wells can be summarized as follows:

1. Whether or not they were contaminated with MtBE, all of the wells studied had at least one of the potential risk factors that were being evaluated, and multiple potential risk factors were generally present in the WHPA/SWPAs of the studied wells.

2. In general, there was little discernable difference between land use activities and practices inside and outside of WHPA/SWPAs.

3. Wells with exceedances tended to be shallower overburden wells in RFG counties with lower safe yields and higher population densities.

4. The majority of all of the wells studied had at least one remediation site in their WHPA/SWPAs, the nearest of which was on average less than ½ mile away. The average number of remediation sites in the WHPA/SWPAs did not appear to be associated with MtBE contamination, but the distance to the nearest remediation site did appear to be associated with MCL exceedances. Typically, groundwater remediation was not performed at remediation sites. There appeared to be a strong reliance on natural attenuation of MtBE in groundwater at the source area. The extent of MtBE in groundwater was often not delineated.

5. The wells on average had 32 USTs and ASTs in their WHPA/SWPAs, the nearest of which was on average approximately ¼ mile away. Wells with more USTs and ASTs in their SPAs and WHPA/SWPAs were more likely to have MtBE contamination, as were wells with shorter distances to the nearest UST or AST.

6. Vehicle repairs were identified as a potential risk factor at 29% of the wells, and more frequently at wells with exceedances and less frequently at clean wells.

7. The situation with ATV trails is complicated because ATV trails may be more prevalent in non-urban areas where other risk factors may be less prevalent. The detailed studies identified the presence of ATV trails as a potential risk factor at 42% of the wells with exceedances, 43% of the wells with detects, and 29% of the clean wells.

8. Most wells were close to roads, 445 ft away on average, and none were more than ¼ mile away. Many wells had roads in the SPA (45% of the total), and wells with this condition were much more likely to have MtBE contamination. The detailed studies identified road runoff as a potential risk factor at 90% of the wells. In addition, a high hazard ranking in the PWSA surveys regarding highways/railroads appeared to be associated with MtBE contamination.

9. The detailed studies identified boat traffic as a potential risk factor for 33% of the wells. In general, however, this factor was not associated with MtBE concentrations. Seasonal variations in MtBE concentrations at Manchester Water Works' surface supply appeared to be related to seasonal boat traffic.

10. Inactive potentially unabandoned wells may be a potential risk factor if they serve as preferential flow pathways. These were present in the WHPA/SWPA of 39% of the wells investigated. However, such wells were not associated with the presence of MtBE contamination.

11. Many wells had problems with well construction at some point in time. Well seals were faulty at 35% of the wells, and well stickups were identified as inadequate at 20% of the wells, at one time or another (Table 5-4). These problems were often identified in sanitary surveys but were not noted during the PWSA surveys. The detailed studies identified compromised well integrity as a potential risk factor at 27% of the wells. Faulty well seals were positively associated with MtBE contamination, while inadequate stickups were not.

12. Petroleum use or storage of small volumes of petroleum in the SPA was identified as a potential risk factor for 49% of the wells, and this condition appeared to be associated with MtBE contamination.

13. Poor housekeeping in the WHPA/SWPA was identified as a potential risk factor at 43% of the wells, and this appeared to be associated with MtBE contamination.

14. Multiple potential risk factors associated with MtBE contamination were often identified at wells in or near mobile home parks. Mobile home parks often have numerous outdoor ASTs or USTs, extensive parking and driveway areas, nearby roads, mechanic activities, closely spaced residential units, and septic systems. If served by wells, the wells are often very close to the abovementioned features.

15. Fuel oil releases can result in measurable MtBE concentrations in groundwater, in some cases exceeding the MCL, and residential fuel oil tanks and OPUFs are likely risk factors.

SECTION 6

FOCUSED EVALUATION OF SURFACE WATER SOURCES

6. FOCUSED EVALUATION OF SURFACE WATER SOURCES

There are approximately 55 surface water bodies in the State of NH that are used as sources of PWS. As mentioned in Section 2.8, a study of MtBE in Paugus Bay by Kinner et al., (2003) looked at the temporal and spatial variability of MtBE to determine if the MtBE in the Laconia drinking water supply was correlated to boating activities. During the detailed study portion of this study, a seasonal trend of MtBE contamination was observed in the Massabesic Lake PWS source. Similar results were found in Paugus Bay which confirms that the seasonal trend observed in Massabesic Lake is likely indicative of boat traffic as a source of MtBE and may be representative of a larger problem in surface water drinking water supplies in NH. In addition, a similar trend was observed during the detailed study of the PWS source for the Patrician Shores, which obtains drinking water from two bedrock wells located near the shores of Lake Winnipesauke. To better evaluate whether boat traffic is a significant cause of MtBE contamination in surface waters, WESTON performed a focused study of drinking water supplies derived from surface water bodies or PWS wells located in proximity to a surface water body.

A total of nine surface water bodies and PWS wells with or without MtBE were evaluated in this study. It is important to note that this is a small subset of the total number of surface water PWSs and PWS wells located near surface water bodies. The discussion and findings below are only general comments and similarities noted during our study were not evaluated for statistical significance.

6.1 DESCRIPTION OF INVESTIGATION METHODS

The first step in selecting our surface water study subjects was to query the Microsoft Access database to find public water supplies with direct withdrawals from surface water bodies with detections of MtBE. Further evaluations of analytical data were performed by reviewing the analytical data posted on the OneStop website. Two surface water sources meeting these criteria were found, and are listed in Table 6-1. In addition, three surface water bodies with no MtBE detections were included in the study for comparison purposes.

Table 6-1
Subjects for Surface Water Study

PWS EPA ID #	PWS Name	Town	Water Body	Source	Proximity/Description	Number of Public Boat Ramps* on body	Motorized Boat Traffic Permitted	Maximum Detection
1581010 -002	Milton Water District	Milton	Northeast Pond	Ground	~275 feet (ft) from pond	0	Yes	3.8
2351020	Lochmere Village District	Tilton	Silver Lake	Ground	75 ft from lake, 10 ft deep	0	Yes	1.2
1656010	Lake Sunapee Trading Post	Newbury	Lake Sunapee	Ground	~500 ft from Lake Sunapee	2	Yes	2.8
0061010-002	Alton Water Works	Alton	Lake Winnipesauke	Ground	6.5 ft from river, 32 ft deep	1	Yes	1.1
1281010 -001	Laconia Water Works	Laconia	Paugus Bay	Surface	2 Intakes ~250 ft offshore, 10 and 15 ft deep	1	Yes	5.2
2051010-001	Salem Water Department	Salem	Canobie Lake	Surface	Intake 30-40 ft offshore, ~20 ft deep	1	Yes	2.5
1731010	Newmarket Water Department	Newmarket	Lamprey River	Surface	Intake ~450 ft offshore, 7-10 ft deep	0	No	None detected
1241010-005	Keene Water Department	Keene	Woodard Reservoir	Surface	Intake ~30 ft offshore, ~15 ft deep	0	No	None detected
0501010-002	City of Concord	Concord	Penacook Lake	Surface	On shoreline, at surface	0	No	None detected

Notes:
* Taken from 2002-2003 "New Hampshire Boating and Fishing Public Access Map"

The second step was to identify water supply wells adjacent to surface waters that had detections of MtBE, but did not have any obvious sources of MtBE within their WHPAs (other than boat traffic). To achieve this, a GIS/Microsoft Access query was run to list of PWS wells that met the following criteria:

- Located within 500 ft of a water body (lake, pond, stream, river).
- None of the following known sources were located in the WHPA of the well:
  - Leaking motor oil storage tank (MOST)
  - Immediate response spill (IRSPILL)
  - Oil spill or release (SPILL)
  - On premise use facility – leaking residential or commercial heating oil tank (OPUF)
  - Leaking bulk storage facility containing fuel oil (FUEL)
  - Automobile Salvage Yard (JUNKYD)
  - Leaking above ground storage tank (LAST)
  - Leaking underground storage tank (LUST)
- A minimum of one detection of MtBE.

These wells were then mapped to show their proximity to water bodies. Then the presence of boat ramps on the "2002 to 2003 New Hampshire Boating and Fishing Public Access Map" was used to evaluate the potential for boat traffic on the water bodies. Four additional PWS wells were identified based on these criteria. A file review of the selected water supplies was then conducted to obtain analytical data and Source Water Assessment Reports for each of the selected sources.

Surface Water Study Subjects

The study subjects chosen for evaluation during this part of the project are included in Table 6-1. The surface water study evaluated seasonal trends of MtBE contamination; the presence or likelihood of motor boat traffic; the location and depth of intakes; and the configuration, depths, physical features, and flow patterns in the surface water bodies and/or aquifers. The goal was to identify any physical features, method of water withdrawal, or patterns of human behavior that may contribute to the likelihood of a surface water supply becoming contaminated with MtBE. The information used to evaluate the PWS was compiled using a variety of methods, which included the review of laboratory analytical data, review of PWS information on the OneStop website, review of NHDES paper files in Concord, NH, review of information provided on the OneStop WebGIS mapping tool, and interviews with the PWS system operators. This information was then compiled into a brief write up with PWS Summary spreadsheets. MtBE analytical data, which were obtained from available databases, NHDES paper files, and the OneStop website, were entered into spreadsheets and plotted versus time to evaluate any trends that the data may show. The surface water detailed studies for this investigation are attached in Appendix D. The City of Manchester and the Patrician Shores detailed studies are included in Appendix B.

6.2 RESULTS OF FOCUSED EVALUATIONS OF SURFACE WATER SOURCES

According to a nationwide study performed by EPA in 1993, 2-stroke engines were found on approximately 75% of all boats and personal watercrafts. This study also reported that 2-stroke engines burn only 70 to 75% of their fuel resulting in the other 25 to 30% being released, uncombusted, to the environment or water column (USEPA, 1993). A report submitted to the NHDES (Kinner et al., 2003) concluded that the input of MtBE from motorized vessels operating in Paugus Bay, NH, is significant during the late spring and summer. The report also concluded that the sale of gasoline containing low percentages of MtBE by businesses bordering the bay appeared to have a significant impact on the MtBE concentrations in the bay. Water has been tested at the Laconia Water Works for MtBE since spring 2000 and the data shows that there is a correlation with summer months and increased boat traffic, confirming the findings of the UNH study. In addition to reviewing the Paugus Bay study, WESTON performed a detailed study on Massabesic Lake, the PWS for the City of Manchester, which included examining MtBE concentrations from winter 2003 to summer 2005. The results confirmed that when concentrations of MtBE in the PWS were plotted versus time, a seasonal trend was observed with higher detections in the summer months and lower detections in the winter months. A copy of the Manchester Water Works detailed study can be found in Appendix C.

As a result of the preliminary findings from the Massabesic Lake/Manchester Water Works study, additional surface water bodies, utilized as drinking water sources, were investigated. An obvious trend was apparent when looking at MtBE from surface water sources. From the six surface PWSs evaluated, including Massabesic Lake, the three PWSs which had little to no restriction on motorized boating traffic all had detectable levels of MtBE. For the three PWSs, which prohibited motorized boating traffic, MtBE concentrations were below the laboratory reporting limits. In addition, when levels of MtBE are plotted versus time, a seasonal pattern develops with higher MtBE detections during the summer months and lower detections of MtBE, if detected at all, during the winter months. This trend would be expected due to increased boating traffic during warmer months of the year. From the three PWSs with boating traffic, Laconia Water Works is the supply with the fewest restrictions and has also had the highest concentrations of MtBE detected, at 5.2 ppb.

Wells Near Surface Water Bodies

During the performance of the Patrician Shores PWS detailed study, a seasonal pattern of MtBE concentrations was observed with higher concentrations of MtBE detected during the summer months. The Patrician Shores obtains potable drinking water from two bedrock water supply wells located approximately 500 ft from the shores of Lake Winnipesauke, which is a surface water body with a large volume of boating traffic during the summer months. As a result, an additional investigation was performed on PWS wells located near surface water bodies. This study included three gravel packed wells and one bedrock well for comparison. Of the PWS wells, the Alton Water Works Well No. 0061010-002 had the lowest detection of MtBE and had the lowest frequency of detects with only one. This may be due to its location next to a river to which there is limited access for boats and there are speed limits for motorized boating traffic upstream. It also should be noted that the Alton Water Works PWS well is typically only sampled once a year. Annual sampling makes it impossible to identify the presence of any seasonal trends in a well.

Of the four PWS wells investigated for this study, Well No. 1581010-002, operated by Milton Water District, exhibited the most consistent detections of MtBE. However, when concentrations of MtBE are plotted versus time, no apparent trend develops. MtBE consistently is detected in the PWS well with the highest detection being 6.7 in July 2004.

Lake Sunapee Trading Post was the only bedrock PWS well looked at for this part of the study. MtBE has been detected in the PWS well but appears to be the result of a release from a gasoline service station located approximately 650 ft east of the PWS well. The service station is identified as a LUST site, and when comparing the concentrations of MtBE versus time, MtBE was detected consistently in the well from November 1997 to January 2001, which coincides with the discovery of the LUST site. The plot illustrates that MtBE is not consistently detected in the well and therefore does not appear to be the result of Lake Sunapee and associated boating traffic.

6.3 CONCLUSIONS OF FOCUSED EVALUATIONS OF SURFACE WATER SOURCES

Boating traffic appears to have a more significant impact on the concentrations of MtBE in a surface water body utilized as a PWS than in PWS wells located adjacent to surface water bodies. MtBE was detected in all of the studied surface water PWS which allow motorized boating traffic; however, all MTBE concentrations were below the MCL of 13 μg/L. The PWS sources that had restrictions on personal watercraft and human contact appeared to have slightly lower concentrations of MtBE when compared to those with virtually no restrictions at all. The surface water supplies evaluated, which prohibit motorized boating traffic, had no detections of MtBE. The design, placement, and pumping rate of the surface water supply intake did not appear to have a strong correlation with the detection of MtBE. Although the construction details of the surface water intake do not appear to have a significant impact on the concentrations of MtBE, very few surface water intakes were evaluated for this study; in order to make a definitive correlation a more comprehensive evaluation with a larger study group of surface water intakes would need to be performed. Seasonal patterns of MtBE concentrations were observed in the Patrician Shores PWS wells but not observed in any of the additional PWS wells located near surface water bodies. Again, additional study subjects would need to be investigated to support the hypothesis that PWS wells in proximity to surface water bodies are affected by seasonal boating traffic as strong conclusions can not be made utilizing such a small sample group. In most cases studied, the presence of MtBE in PWS wells appeared to be the result of other potential sources of contamination.

SECTION 7

FOCUSED EVALUATION OF REMEDIATION SITES

7. FOCUSED EVALUATION OF REMEDIATION SITES

7.1 DESCRIPTION OF INVESTIGATION METHODS

The objective of the focused evaluations of remediation sites was to evaluate whether remediation practices at gasoline release sites are appropriate for preventing MtBE contamination of nearby PWS wells. We reviewed the applicable cleanup standards, geology, hydrogeology, and site-specific information relative to six gasoline remediation sites in addition to those reviewed in the detailed studies described in Section 5.

Table 7-1 provides a summary of the remediation sites selected for this study. The remediation sites were located either in or near the WHPA of a PWS well. Although MtBE is typically detected in many different petroleum products, we chose to focus our study on gasoline related remediation sites because MtBE is typically a direct additive. MtBE detection in the PWS well was not necessarily a requirement so that we would be able to look at remediation sites which have impacted PWS wells along with remediation sites which have had no apparent impact on the PWS wells. The PWS well information including well type, aquifer type, aquifer transmissivity, etc. was also used for comparison to evaluate whether certain well types may be more prone to impact from remediation sites within an area.

Several methods were utilized to select which remediation sites would be suitable for this investigation, including the following:

1. Run GIS/Microsoft Access query to find remediation sites located within WHPAs of PWS well.

2. Review OneStop Web GIS to find PWS wells with gasoline related remediation sites within the WHPA.

3. Review information compiled by Diana Morgan of NHDES regarding potential contaminant sources in the WHPA of contaminated wells.

4. Review analytical data for each PWS well on OneStop to see which of the wells have MtBE detections.

Table 7-1
Subjects for Remediation Site Study

NHDES Remediation Site ID	Remediation Site Name	Town	Distance From PWS (ft)	PWS EPA ID No.	PWS Name	Well Type	MtBE Detection
199904006	Mt. Washington Trading Post	Carroll	725	382010	Rosebrook Water Co.	Large Community Well (Overburden)	Yes
199505031	Stratham Village Market	Stratham	1,500	2232050-001,002,003	Stratham Green Condos	Small Community Well (Bedrock)	Yes
199608005	Marlborough Sunoco	Marlborough	500	1481010-002	Marlborough Water Works	Large Community Well (Overburden)	Yes
199901007	Great Northern One Stop, Inc.	Errol	200	781010-002	Errol Water Works West	Small Community Well (Bedrock)	Yes
200112018	Plum Potter Auto Yard	Conway	500	0519020-001	Conway Town Hall	Public Well (Bedrock)	Yes
199204001	Derry Hillside Plaza	Derry	875	613030	Peaceful Acres	Mobile Home Park (Bedrock)	Yes

5. Review list of remediation sites provided by Gary Lynn of NHDES.
6. Review PWS wells sorted by distance to nearest junkyard.
7. Review PWS wells sorted by well type and distance to nearest LUST site.

From these methods, a preliminary list of approximately 20 remediation sites near PWS wells was generated. A review of NHDES files was then conducted to determine which of the remediation sites would be best suited for this study. The final selection included six remediation sites and was based on the age of the site, the level of remedial activities which had been performed, correlation of MtBE contamination in the PWS well to the remediation site timeline of specific events, and availability of detailed information.

The remediation sites were then evaluated with respect to the type of fuel released, the local hydrogeology, location of the spill or leak (whether the spill was to the ground surface or subsurface, in an unconsolidated aquifer or directly over fractured bedrock), distance from the well, the timing of the remedial response, the cleanup levels established, and whether or not groundwater impacts were evaluated or addressed. The hydrogeologic setting and operation of the nearby wells was also evaluated including the yield, pumping rate, pumping schedule, whether the wells were upgradient or downgradient of the remediation sites, whether the wells were in the same geologic unit as the remediation sites (unconsolidated overburden or bedrock), and any other factors that may have influenced the risk of the wells being impacted by the nearby remediation sites.

It is important to note that this is a small subset of remediation sites in the proximity of PWS. The discussion and findings below are only general comments and include observations noted during our study and were not evaluated for statistical significance.

7.2 RESULTS OF FOCUSED REMEDIATION SITE EVALUATIONS

Evaluations of each of the six remediation sites is summarized below. More detailed information is included in Appendix E.

7.2.1 Great North Woods One Stop, Inc.

The Great North Woods One Stop, Inc. was designated a LUST site in October 1998, during the removal and closure of six USTs. Contaminated soil and groundwater were encountered during the closure activities at the site. The repeated detection of light nonaqueous phase liquid in site monitoring wells resulted in a soil removal at the site in November of 2000. Since then, concentrations of MtBE have been in a general decline, but are still above the AGQS. A bedrock PWS well for the Town of Errol is located 200 ft east of the site. MtBE has been detected in past years within the water supply but concentrations have decreased to below laboratory detection limits since December 2001.

The following site characteristics were noted:

- The highest detection of MtBE in the PWS well occurred approximately 1 month after the removal of contaminated soils from the site. Some of the on-site monitoring wells exhibited spikes in MtBE concentration at that time as well. It is possible that excavation resulted in the mobilization of contaminants including MtBE. Since the removal, MtBE levels have decreased to levels below laboratory detection limits in the PWS well.

- The horizontal plume of contamination has not been defined, as MtBE was detected in all of the wells sampled at the site in November 2004, in excess of the AGQS. Concentrations of MtBE at the site ranged from 70 ppb to 19,000 ppb.

- No investigation of the bedrock aquifer has been completed to assess whether the site is the source of contamination for PWS Well No. 0781010-002 or to determine the direction of groundwater flow within the bedrock aquifer.

- The site and the PWS well are located within areas of high snowmobile traffic during the winter months of the year. The incomplete combustion of gasoline in 2-stroke engines may contribute to contamination of groundwater and surface water in the area.

- Remediation Site No. 200104024, a gasoline service station, is located across the street to the north of the site. Although MtBE has been detected in groundwater samples, the highest concentrations are approximately ten times less than those detected at the Great North Woods One Stop, Inc. It is possible that the service station contributed to the contamination of the PWS, but the much higher levels of contamination in the subject site groundwater make it a much higher risk.

7.2.2 Stratham Village Market

The Stratham Village Market was designated a LUST site NHDES in May of 1995. Remediation at the site has included soil excavation, oxygen release compound (ORC) injection, and MNA. Concentrations of MtBE in groundwater samples collected from site monitoring wells show a general decline, but the AGQS for MtBE continues to be exceeded in the wells directly downgradient from the UST and pump island areas. Concentrations of MtBE in the on-site and neighboring public and private bedrock water supply wells have shown gradual decreases but continue to exceed the AGQS for MtBE as well. The only other gasoline compound detected in the on-site bedrock water supply well has been toluene, which was detected at 1.0 ppb in November 1998. Three PWS wells for the Stratham Green Condominiums are located approximately 1,500 ft northwest of the site. One of the wells was installed for the condominium complex in 1998 because of the repeated detections of MtBE in the water supply.

The following site characteristics were noted:

- Low level concentrations of MtBE have repeatedly been detected in the PWS well for the Stratham Green Condominiums. The inferred flow direction for groundwater in the overburden at the remediation site is to the southwest. Therefore, the PWS wells would be located hydraulically cross gradient. However, no investigation of groundwater flow direction in the bedrock aquifer has been performed.

- A lineament identified by both low altitude and high altitude photography is located approximately 550 ft north-northwest of the site. The lineament trends from south-southeast to north-northwest and is approximately 500 ft from the PWS wells.

- The strongest correlation between the MtBE detections in the PWS well and site activities appears to be with the injection of ORC in November 2000. The highest detect occurred approximately 2 months after the injection and concentrations have seen a general decrease since that time.

- The relationship of the decreasing MtBE concentrations over time with continuous pumping of the water supply well is important. This signifies that under periods of excessive pumping, "clean" water is drawn toward the well with the end result being the dilution of MtBE in the water supply.

7.2.3 Marlborough Sunoco

Marlborough Sunoco was identified as a LUST Project by NHDES in June 1996, during the removal and replacement of four gasoline USTs. Subsurface investigations identified concentrations of MtBE in groundwater at the site as high as 5,000 ppb. The Fitch Court well, a gravel packed well which provides drinking water to the Town of Marlborough, is located approximately 400 ft northeast of the Marlborough Sunoco in a location which is inferred to be hydraulically down- and cross gradient of the remediation site. MtBE has been detected in the water supply well several times, of which the highest detection occurred directly before the removal of the UST system and associated contaminated soil at the site.

The following site characteristics were noted:

- Two deep overburden monitoring wells were installed in the spring of 2000, to evaluate the vertical extent of contamination at the site and determine whether the Marlborough Sunoco was the source of MtBE in the Fitch Court well. Although, MtBE was never detected in the two deep overburden wells, because of high laboratory detection limits, which were 1.0 ppb, a conclusive argument cannot be made to positively identify or reject the site as the source of MtBE contamination in the Fitch Court well if concentrations of MtBE in the water supply well were below 1.0 ppb.

- The high transmissivity of the aquifer associated with the remediation activities, which have occurred at the site, have significantly decreased and almost eliminated the detections of MtBE in the Fitch Court Well.

- Low concentrations of MtBE detected in the Fitch Court well in recent years may be the result of residual contamination in soils, which were not excavated due to constraints, caused by property boundaries and landscaped areas.

7.2.4 Mt. Washington Trading Post

The Mt. Washington Trading Post is a gasoline service station located along Route 302 in Carroll, NH. During the removal and replacement of the UST system at the property, it was determined that a release to the environment had occurred and the property was designated

Remediation Site No. 199904006 by NHDES. Since the discovery of the site, remedial activities have included the removal of approximately 15 cy of contaminated soil during the removal of the USTs, the treatment of approximately 20,000 gallons of contaminated groundwater during excavation dewatering activities associated with the removal of the USTs, and MNA. The overburden geology at the site consists of medium- to coarse-grained sands and has been identified as being part of the Rosebrook Aquifer. The aquifer has a relatively high transmissivity and it provides potable drinking water to approximately 1,300 people via two gravel packed PWS located approximately 750 ft southwest of the site adjacent to the Ammonoosuc River. Groundwater elevation maps indicate the wells are located hydraulically cross and down-gradient from the remediation site.

The following site characteristics were noted:

- The highest concentration of 2,090 ppb MtBE in site groundwater occurred in the most recent sampling round performed in June 2005, in a well hydraulically down gradient from the pump island.
- MtBE has been detected in the most down-gradient monitoring wells installed on abutting properties across Route 302 in the most recent sampling rounds as well.
- The contamination plume appears to be migrating to the south and southwest away from the site. However, excluding the MtBE detect of 28 ppb in August 2004, MtBE has not been detected in either of the PWS wells.

The lack of MtBE contamination in the PWS well operated by the Rosebrook Water Company, despite the proximity to the remediation site, is likely the combination of several factors. Some of those factors are as follows:

- Buried utilities underneath Route 302 may divert contaminated groundwater away, or inhibit flow beneath the road towards the PWS well.
- There is a relatively flat water table at the site with a hydraulic gradient of 0.001 ft per foot. Slow moving contaminated groundwater at the site has not reached the PWS well.
- Pump tests have confirmed that surface water from the Ammonoosuc River infiltrates Well 002. The high transmissivity of the aquifer combined with the infiltration of surface water from the river may result in the dilution of contaminated water.

7.2.5 Plum Potter Auto Yard

The Plum Potter Auto Yard, located in Conway, was designated a remediation site in December, 2001. Investigation of the area began when MtBE was detected in the PWS well serving the area in the vicinity of the Town Hall. Site investigations concluded that the impact to the PWS well was the result of the Plum Potter Auto Yard located at the abutting property to the west. The site is located approximately 500 ft from the PWS well and inferred to be hydraulically upgradient. Site remediation has included the excavation of approximately 265 tons of gasoline impacted soils from the site in the spring of 2004 and followed by MNA. Monitoring of site groundwater since the removal of gasoline impacted soils from the auto salvage area has shown a general decline in concentrations of MtBE in groundwater. Samples collected from the bedrock PWS well exhibited an increase in concentrations of MtBE the month after the removal of automobiles and contaminated soils from the auto yard, but concentrations have been below 1.0 ppb in the two most recent sampling rounds in September and October 2005.

The overburden at and around the site was observed to be 7 to 17 ft thick, consisting of well sorted fine- to medium-grained sand. Regionally the overburden is comprised largely of surficial deposits consisting of unconsolidated glacial sediments and alluvium. These deposits are generally well-sorted and highly transmissive. In addition, outcrops of "rotten rock" have been identified in the Conway area. This material has been encountered at depth and is capable of yielding substantial amounts of groundwater.

The impact to the PWS well for the Conway Town Hall area is likely the combination of several factors and include the following:

- The proximity of the site to the PWS well.
- The overburden geology of the area is inferred to be highly permeable allowing for the migration of contaminated groundwater to off-site locations.
- The weathered bedrock formation, capable of yielding substantial amounts of water, most likely allows for easier infiltration to the bedrock aquifer beneath the site.
- Shallow bedrock in the vicinity of the site incorporated with the seasonal fluctuation of the water table results in easier migration of site contaminants into the bedrock aquifer.

7.2.6 7-Eleven Store No. 32500

The 7-Eleven located along Rockingham Road in Derry, NH is identified as Remediation Site No. 199204001. Petroleum impacted soils were removed from the UST grave area of the site in 1998; however, soils beneath the pump island and dispenser area were left in place. Petroleum impacted groundwater discovered at the site included MtBE, benzene, toluene, and ethyl-benzene in excess of the AGQS. The contaminated soils which remain are believed to be an ongoing source of contamination in groundwater at the site. Wells downgradient from the pump island area continue to exhibit the highest concentrations of MtBE, including a detection of 63,000 ppb in the most recent sample event in July 2005. Concentrations of BTEX compounds were all below laboratory reporting limits during the July 2005 sampling round. However, laboratory reporting limits for benzene, toluene, TAME, and ethyl-benzene in the most contaminated wells were above the AGQS. Increasing concentrations of MtBE have been detected in down gradient monitoring wells suggesting that the source of contamination has not been mitigated and that the plume of contamination continues to migrate with the flow of groundwater. No BTEX compounds were detected above the laboratory reporting limits in the downgradient monitoring wells during the July 2005 sampling event.

The following site characteristics were noted:

- If layers of dense till are present beneath the documented overburden, as implied by area studies which have been completed (Cotton, 1977b), this may be acting as a confining layer, limiting the migration of contamination. However, documented contamination in the on-site and area bedrock water supply wells proves that MtBE has migrated to the bedrock groundwater aquifer beneath the site and neighboring properties.

- The PWS well for Peaceful Acres is located approximately 875 ft north of the remediation site and low concentrations of MtBE have been detected. No investigation has been performed to determine the direction of groundwater flow within the bedrock aquifer. The MtBE detections do not seem to correlate with site remediation activities performed, but the highest detect in the Peaceful Acres well (3.8 ppb, October, 2002) occurred in accordance with the first time the AGQS was exceeded in the on-site bedrock water supply well for the 7-Eleven store. Concentrations have been below laboratory detection limits in the Peaceful Acres well since October 2003. If the 7-Eleven store has not impacted the water supply for Peaceful Acres, it may be due to the direction of groundwater flow within the bedrock aquifer. Or sufficient time may not have passed to result in the migration of MtBE to the water supply well.

7.3 CONCLUSIONS OF FOCUSED EVALUATIONS OF REMEDIATION SITES

When utilizing a sample group of six remediation sites only general hypotheses can be made which in some cases may not identify factors that are statistically significant. In addition, investigations are still in progress at some of the sites discussed. However, even within the small group of sites which were evaluated as part of this study, and the information that was readily available for review, many similarities were identified.

The hydrogeologic settings for the six remediation sites studied varied, but there are a few common observations that can be made. The releases of petroleum product occurred in the overburden soils and the remedial actions performed generally included removal of contaminated soil (but not necessarily all of it). Although overburden groundwater was typically sampled and found to be contaminated, delineation of the full extent of the groundwater plume or treatment of the contaminated groundwater was generally not performed. The exceptions to this were the Mt. Washington Trading Post and the 7-Eleven where dewatering (and consequently treatment) were required for the excavation activities, and Stratham Village Market where ORC was injected for treatment of soil, but also apparently provided some treatment of groundwater. Often, tank and soil removal actions appeared to mobilize the contamination, based on the timing of MtBE detections in wells with respect to the removals.

It is important to note that no investigation of the connection between the impacted overburden aquifer and the underlying bedrock aquifer was performed at any of the sites, other than sampling of nearby bedrock water supply wells. There was no initial evaluation to determine if the bedrock aquifer was impacted even when bedrock water supply wells were present near the site of the release. Often, impacted bedrock water supply wells appeared to be located cross gradient from the site of the release, based on the overburden groundwater elevation contours. Without investigation of conditions in the bedrock aquifer, it would be difficult to determine if PWS wells are located up- or downgradient of the release.

Highly productive PWS wells that were installed in highly transmissive overburden aquifers seemed to be less impacted by contamination. This was likely due to dilution from clean water in the surrounding aquifer or a nearby surface water body. A thin saturated thickness with a water table that sometimes dropped into the bedrock appeared to provide a direct pathway from a spill in the overburden to the bedrock aquifer. In contaminated PWS wells, higher pumping rates tended to decrease concentrations of MtBE in wells.

Based on our review of remediation sites near PWS wells, it appears that more extensive characterization of groundwater contamination at remediation sites near PWS wells and active remediation of groundwater impacted by petroleum releases would likely reduce the risks of MtBE contamination in nearby PWS wells. Better delineation of groundwater plumes and an investigation into the connections between the overburden and bedrock aquifers could result in earlier identification of wells at risk, and possibly allow actions to be taken before the PWS wells were impacted. It is interesting to note, that although remedial actions at petroleum release sites often appeared to be inadequate to protect nearby PWS wells from MtBE contamination, the remedial actions were adequate to protect the same wells from contamination by BTEX constituents since none of these contaminants were detected in the PWS. The higher solubility and mobility of the MtBE made it a greater threat to nearby PWS wells than the less soluble and less mobile BTEX compounds.

To further investigate the apparent disparities between the frequencies of MtBE detections verses benzene detections in PWS wells, data from the WSEB Analytical Database were evaluated. Benzene was evaluated because it is the most water soluble of the BTEX compounds and it is a common contaminant of concern when dealing with petroleum based contamination. Table 7-2 provides a summary of the numbers of samples and wells that were impacted by MtBE and benzene. MtBE was detected in 21% of the samples verses 1% with detections of benzene. Although 36% of PWS water samples that contained benzene also contained MtBE, only 2% of the samples that contained MtBE also contained benzene. Moran et al., (2005) noted that addition of MtBE to gasoline would result in reduced benzene content in RFG and this may result in lower frequencies of benzene detections. However, they also speculated that because of the physical/chemical properties of benzene and its amenability to biodegradation, it would be expected to travel more slowly and diminish more quickly in the environment. Therefore, it would only be likely to be present in wells that were close to the release, or in wells that had high concentrations (> 20 µg/L) of MtBE. Their research confirmed that as concentrations of MtBE increase, the occurrence of gasoline hydrocarbons together with MtBE increases.

Table 7-2
Frequencies of MtBE and Benzene Detections

The total number of samples (only benzene detects, MtBE detects, and MtBE non-detects)	14814
The total number of these samples that have detections of benzene	152
The number of these sample records that have detections of both benzene and MtBE	54
The total number of these sample records that have detections of MtBE	3051
The number of wells with MtBE detects	658
The number of wells with benzene detects	47
The number of wells with both MtBE and benzene detects	19
The total number of wells in this data set	2656
Percent of samples with MtBE	21%
Percent of samples with Benzene	1%
Percent of samples with MtBE that also have Benzene	2%
Percent of samples with Benzene that also have MtBE	36%
Percent of wells with MtBE detects	25%
Percent of wells with both MtBE and Benzene detects	1%
Percent of wells with MtBE detects that also have Benzene detects	3%
Percent of wells with Benzene detects that also have MtBE detects	40%

Note: These data were extracted from the WSEB Analytical Database and include blended samples and transient wells.

Information regarding the presence of TBA, a biological breakdown product of MtBE, was reviewed as part of the Focused Remediation Site Evaluations to determine if biodegradation of the MtBE was occurring. The NHDES did not require the analysis and reporting of TBA concentrations until 1 January 2001. Some of the remediation activities reviewed for this part of the study pre-date the 2001 mandate and therefore do not report TBA concentrations. The TBA concentrations were reported or included in the VOC analyses for most of the sites monitoring after the 2001 mandate; however, few detections of TBA were documented. Three of the sites did report the presence of TBA in at least one shallow overburden monitoring well, although insufficient data would make it difficult to evaluate trends in TBA and MtBE concentrations. The sites included the Derry 7-Eleven, The Mount Washington Trading Post, and the Errol Enterprises/Great North Woods One Stop. None of the PWSs near the remediation site reported detectable concentrations of TBA.

A significant data gap at the sites is created by the laboratory reporting limits and the lack of time since TBA was included in the VOC analysis. Tert butyl alcohol by standard has a higher reporting limit than other compounds making low/trace level detections limited. In addition, in grossly contaminated wells which exhibit very high levels of MtBE and other compounds, the TBA reporting limit, along with other compounds, is extremely high, and therefore, often times the concentration of TBA falls below laboratory detection limits again.

In the cases reviewed during this study, no specific requests for TBA analysis were made to the consultants or the property owners. As a result, insufficient information regarding TBA was available to evaluate whether significant biodegradation was occurring at these sites.

SECTION 8

STATISTICAL ANALYSES OF STATEWIDE DATA (SUMMARIZED FROM UNH REPORT FULL UNH REPORT TO GO IN AS APPENDIX)

8. STATISTICAL ANALYSIS OF STATEWIDE DATA

The UNH Department of Mathematics and Statistics was subcontracted to WESTON to perform statistical analyses on the data generated from queries of the comprehensive statewide database constructed by WESTON. Two types of statistical analyses were conducted. The first was performed to evaluate temporal trends in the number of PWS wells impacted by MtBE contamination and in the concentrations of MtBE that were detected in the impacted wells. Only data from the WSEB Analytical Database was used for this analysis. The second type of statistical analysis was performed to develop a predictive model for classification of PWS wells with respect to their susceptibility to MtBE contamination as well as for identifying risk factors and their relationship to high levels of MtBE in PWS wells. This analysis utilized the analytical data from the WSEB Analytical Database, as well as over 300 other variables generated from querying the comprehensive GIS and Microsoft Access databases constructed by WESTON.

8.1 DATA PROVIDED TO UNIVERSITY OF NEW HAMPSHIRE FOR STATISTICAL ANALYSIS

As discussed in Subsections 4.3 and 4.4, Queries of the GIS and Microsoft Access databases were performed to generate Microsoft Excel tables of data for statistical analysis to identify positive correlations between MtBE contamination in a PWS well or surface water source and a series of over 300 different parameters. These parameters were related to the water supply sources, the potential contaminant sources, and the hydrogeological and geopolitical characteristics of both the water supply and the potential contaminant sources. The parameters generally fell into one of three categories:

1. Characteristics relating to the PWS. (These parameters are listed in Table 8-1.)
2. The distance between the PWS and the closest potential contaminant source and the closest mapped lineament. (These parameters are listed in Table 8-2.)
3. The number and types of potential contaminant sources within the WHPAs of the PWS. (These parameters are listed in Table 8-3.)

Table 8-1
PWS Characteristics Data

PWS_Master	Definition	Type of Data	Count of records (2831 possible)	Source of Data	Min	Max	Average Value or % Breakdown	Median
PWSID	Combined system and source identification numbers (WESTON)	ID	2745	Weston Generated	NA	NA	NA	NA
SYSTEM_ID	Identifies water system	ID	2745	WSEB	NA	NA	NA	NA
SOURCE	Identifies well within water supply system	ID	2745	WSEB	NA	NA	NA	NA
X_COORD	X-axis location of well	coordinate	2745	OneStop	NA	NA	NA	NA
Y_COORD	Y-axis location of well	coordinate	2745	OneStop	NA	NA	NA	NA
POPULATION	Approximate number of people using system	number	2687	WSEB	1.0	128,000	1,361	120
SYSTEM_TYP	Community (C), or Non-Transient/Non-Community (P)	2 categories: C or P	2745	WSEB	NA	NA	C = 68% P = 32%	NA
SOURCE_TYP	Groundwater (G), surface water (S), or entity/treatment facility (E)	3 categories: G, S, or E	2745	WSEB	NA	NA	G = 97% S = 3% E = 0%	NA
WELL_TYPE	Type of well	8 categories (see note 1)	2533	WSEB	NA	NA	ART = 1% BRW = 78% DUG = 4% GPW = 12% GRW = 1% INF = 1% PTW = 2% SPR = 2%	NA
WELL_DEPTH	Depth of well	feet below ground surface	2278	WSEB	0	1,600	348	300
PROVOL	Permitted Production Volume	gallons per day	257	WSEB	1,440	2,160,000	112,970	33120
YIELD	Well yield	gallons per minute	2090	WSEB	0.5	3,000	66	24
RFG_County	Identifies Counties for RFG	yes or no	2745	Weston Generated	NA	NA	RFG = 58% non-RFG = 42%	NA
DCOMP	Date Completed	date	116	Water Well Board Database	NA	NA	NA	NA
TOTD	Total depth of well	feet below ground surface	116	Water Well Board Database	37	1,206	384	363.5
BDKD	Depth to bedrock	feet below ground surface	89	Water Well Board Database	8	280	50	30
CASING	Total length of casing installed in well	feet	113	Water Well Board Database	23	300	73	60
YTQ	Discharge - estimated well yield	gallons per minute	111	Water Well Board Database	5	1,100	90	35
10ft_into Bedrock	Is Casing set at least 10 ft into Bedrock?	yes or no	116	Weston Generated from Water Well Board Database	NA	NA	Yes = 65% No = 41%	NA
SAFE_YIELD_GPM	Safe yield of well	gallons per minute	2069	WSEB	0.5	3,000	67	25
Permitted_Vol_GPM	Permitted Volume in GPM from WSEB database	gallons per minute	257	WSEB	1.0	1,500	78	23
BEDROCK_TY	Bedrock Type	2 Categories: (see note 2)	2745	WSEB	NA	NA	P = 42% M = 58%	NA
FLOODPLAIN	Is well located in floodplain?	yes or no	778	GRANIT	NA	NA	yes = 13% no = 87%	NA
PDENSITY	Population density from Census - smallest census block	4 categories (see note 3)	2744	GRANIT	NA	NA	0-10 = 11% 10-100 = 25% 100-1000 = 54% > 1000 = 9%	NA
NEAR_DIST_UST	Distance to nearest UST from PWS	feet	2745	Weston Generated	8.7	20,325	3,269	2345.31
NEAR_DIST_TRAIL	Distance to nearest trail (feet)	feet	2745	Weston Generated	11.3	72,776	15,841	11457.06
NEAR_DIST_ROAD	Distance to nearest road (feet)	feet	2745	Weston Generated	0.6	7,507	505	349.52
NEAR_DIST_REMED_	Distance to nearest remediation point (feet) {GWHIs with locations indicated by a single point in OneStop}	feet	2745	Weston Generated	0.0	21,151	2,276	1565.73

Table 8-1
PWS Characteristics Data

PWS_Master	Definition	Type of Data	Count of records (2831 possible)	Source of Data	Min	Max	Average Value or % Breakdown	Median
NEAR_DIST_REMED_	Distance to nearest remediation Area (feet) {GWHIs with locations indicated by a polygon in OneStop}	feet	2745	Weston Generated	462.3	36,671	10,238	9254.49
New_System_Categori	14 Categories of types of community served by water system	14 categories (see note 4)	2057	Weston Generated from WSEB	NA	NA	Category 1 = 4% 2 = 14% 3 = 5% 4 = 9% 5 = 12% 6 = 19% 7 = 0% 8 = 0% 9 = 13% 10 = 2% 11 = 0% 12 = 17% 13 = 0% 14 = 5%	NA
WHPA ACRES	Acreage of WHPA	acres	2064	Weston Generated	7.3	7,040	385	162.25
NWI	Is the PWS in a wetland?	yes or no	2744	Weston Generated from GRANIT	NA	NA	Yes = 7% No = 93%	NA
SPOT	Derived Saturated Thickness at that PWS location	feet	909	Weston Generated from GRANIT	0.1	280	43	40
SPOT_SWL_ELEV	Derived Static Water Level in Bedrock at that PWS location	Ft above sealevel	2693	Weston Generated from Water Well Board Database	NA	NA	NA	NA
BR GW Depth	Depth to Bedrock Groundwater	ft below ground surface	2082	Weston Generated from Water Well Board Database	0.0	1,426.3	107.2	37.9
SPOT_BDRK_ELEV	Derived Bedrock elevation at that PWS location	Ft above sealevel	2745	Weston Generated from Water Well Board Database	NA	NA	NA	NA
BR_DEPTH	Derived Depth to Bedrock at that PWS location	feet below ground surface	2095	Weston Generated from Water Well Board Database	0.0	1,491.2	132.0	65.38
WTR_TBL	Overburden groundwater elevation	Ft above sealevel	185	Weston Generated from GRANIT	NA	NA	NA	NA
OverburdenDepth	Depth to overburden groundwater from ground surface	feet below ground surface	184	Weston Generated from GRANIT	0.0	1,491.2	132.0	19
Na	Sodium Concentration	ug/L	2494	WSEB Analytical Database	10.0	4,802,000	30,884	15583.33
Cl	Chloride Concentration	ug/L	2295	WSEB Analytical Database	50.0	17,740,000	62,958	25000
Well/Intake	Integrity of well or intake	3 categories: Low (L), Medium (M), or High (H)	1808	Public Water Supply Assessment Database	NA	NA	L = 94% M = 0% H = 6%	NA
KCSs	Known Contaminant Sources as noted in PWSA Surveys conducted by NHDES	3 categories: L, M, or H	1812	Public Water Supply Assessment Database	NA	NA	L = 75% M = 14% H = 11%	NA
PCSs	Potential Contaminant Sources as noted in PWSA Surveys conducted by NHDES	3 categories: L, M, or H	1812	Public Water Supply Assessment Database	NA	NA	L = 54% M = 44% H = 3%	NA
Highways	Presence of Highways or Railroads in vicinity of well	3 categories: L, M, or H	1814	Public Water Supply Assessment Database	NA	NA	L = 37% M = 17% H = 45%	NA
Septics	Presence of Septic Systems/sewers in vicinity of well	3 categories: L, M, or H	1813	Public Water Supply Assessment Database	NA	NA	L = 18% M = 34% H = 48%	NA
Urban Land Cover	% of Urban Land Cover in vicinity of well	3 categories: L, M, or H	1809	Public Water Supply Assessment Database	NA	NA	L = 70% M = 8% H = 23%	NA
Ag Land Cover	% of Agricultural Land Cover in vicinity of well	3 categories: L, M, or H	1809	Public Water Supply Assessment Database	NA	NA	L = 13% M = 50% H = 37%	NA
Sanitary Radius	Presence of development in vicinity of well	3 categories: L, M, or H	1756	Public Water Supply Assessment Database	NA	NA	L = 45% M = 32% H = 23%	NA
BUW	TOP OF WELL IS BURIED	Number of this type of violation noted	129	Sanitary Survey Database	NA	NA	7%	NA

Table 8-1
PWS Characteristics Data

PWS_Master	Definition	Type of Data	Count of records (2831 possible)	Source of Data	Min	Max	Average Value or % Breakdown	Median
BWC	BEDROCK WELL CONSTRUCTION	Number of this type of violation noted	108	Sanitary Survey Database	NA	NA	6%	NA
CAP	CAPACITY DEVELOPMENT CANDIDATE SYSTEM	Number of this type of violation noted	33	Sanitary Survey Database	NA	NA	2%	NA
COP	NO CERTIFIED OPERATOR / LACKS REQ'D GRADE OR TYPE	Number of this type of violation noted	301	Sanitary Survey Database	NA	NA	17%	NA
DWC	DUG WELL CONSTRUCTION	Number of this type of violation noted	17	Sanitary Survey Database	NA	NA	1%	NA
ENF	ENFORCEMENT ACTION ISSUED (SEE COMMENTS FOR TYPE)	Number of this type of violation noted	16	Sanitary Survey Database	NA	NA	1%	NA
FLW	TOP OF WELL CAN BE FLOODED	Number of this type of violation noted	156	Sanitary Survey Database	NA	NA	9%	NA
FPH	FLOODING OCCURING INSIDE PUMPHOUSE	Number of this type of violation noted	115	Sanitary Survey Database	NA	NA	7%	NA
HPH	HAZARDOUS MATERIALS INSIDE OR AROUND PUMPHOUSE	Number of this type of violation noted	195	Sanitary Survey Database	NA	NA	11%	NA
HWR	HAZARDS WITHIN WELL RADIUS	Number of this type of violation noted	284	Sanitary Survey Database	NA	NA	16%	NA
MIN	MINOR DEFICIENCY (DESCRIPTION IN COMMENTS)	Number of this type of violation noted	958	Sanitary Survey Database	NA	NA	54%	NA
PCS	POTENTIAL CONTAMINANT SOURCE (OUTSIDE SPA)	Number of this type of violation noted	14	Sanitary Survey Database	NA	NA	1%	NA
SAN	WELL CAP / WELL COVER HAS SANITARY SEAL PROBLEMS	Number of this type of violation noted	833	Sanitary Survey Database	NA	NA	47%	NA
SIG	SIGNIFICANT DEFICIENCY (DESCRIPTION IN COMMENTS)	Number of this type of violation noted	323	Sanitary Survey Database	NA	NA	18%	NA
SPA	SANITARY PROTECTIVE AREA (LEACH FIELDS, ETC.)	Number of this type of violation noted	919	Sanitary Survey Database	NA	NA	52%	NA
VLT	WELL IN VAULT, EVIDENCE OF FLOODING	Number of this type of violation noted	15	Sanitary Survey Database	NA	NA	1%	NA
TOTAL_VIOL	Total number of violations	Total number of all violations noted	1758	Sanitary Survey Database	NA	NA	100%	NA
WHPA ROADS	Linear feet of roads in WHPA	feet	1940	Weston Generated from GRANIT	224	178,543	12,587	6405.61
WHPA TRAILS	Linear feet of trails in WHPA	feet	286	Weston Generated from GRANIT	802	284,379	41,996	30728.05
NEAR_DIST_LINEAME	Distance to nearest lineament	feet	2745	Weston Generated from GRANIT	0.1	4,169	548	401.77
LINEAMENT<1000 ft	Is the PWS well within 1000 ft of a lineament?	yes or no	2745	Weston Generated	NA	NA	Yes = 83% No = 17%	NA
Lineament <200 ft	Lineament is <200 ft from well (true or false)	true or false	2745	Weston Generated	NA	NA	True = 31% False = 69%	NA
Range_category	Transmissivity of Aquifer (ft^2/day)	7 categories (see note 5)	984	Weston Generated from GRANIT	NA	NA	A = 2% B = 2% C = 5% D = 10% E = 21% F = 47% G = 13%	NA
AV_DAILY USE	Average daily volume of water produced in 2003	gallons per day	160	Registered Water User Database	0	791	126	67.23
2003 Ave GPM	Average daily volume of water produced in 2003	gallons per minute	144	Weston Generated from Registered Water User Database	0.7	550	97	60.13

Notes:

Note 1: ART=Artesian Well, BRW=Bedrock Well, DUG=Dug Well, GPW=Gravel Packed Well, GRW=Gravel Well, INF=Infiltration Well, PTW=Point Well, SPR=Spring.

Note 2: P=Plutonic and associated volcanic rock, M=Metasedimentary and metavolcanic rock

Note 3: Four categories of population density are 0-10, 10-100, 100-1000, and >1000.

Note 4: 1=Apartments, 2=Condominiums, 3=Large CWS (>1000 pop or fire protection), 4=Major CWS (>1500 pop), 5=Mobile Home Park, 6=Single Family Residences, 7=Spring, 8=Service Station, 9=Commercial/Industrial, Town Offices, Libraries, Businesses, & other Workplaces, 10=Residence Homes, Senior Housing, Hospitals, Rehab Facilities, & Medical Offices, 11=Functional Halls, Churches, Restaurants, Motels, Hotels, Inns, Camps, Rest Areas, Seasonal Residences, Recreational Facilities, 12=Schools, Daycares, Dormitories, 13=Other or not-known, 14=Small CWS (<1000 pop & no fire protection).

Note 5: A=>8000, B=>6000, C=>4000, D=>2000, E=<2000, F=<1000, G=0 in ft^2/day

Table 8-2
Distances to Nearest Potential MtBE Sources Data

Data Label	Definition	Minimum	Maximum	Average	Median
PWSID	Combined System/Well ID	NA	NA	NA	NA
NEAR_DIST_UST	Distance to nearest UST from PWS	3	20,325	3,269	2,345
NEAR_DIST_trail	Distance to nearest trail	1	72,776	15,841	11,457
pws_near_road_NEAR_DIST	Distance to nearest road	0	7,507	505	350
NEAR_DIST_remedpt	Distance to nearest remediation point (GWHI point site)	0	21,151	2,276	1,566
NEAR_DIST_remed_poly	Distance to nearest remediation Area (GWHI polygon site)	187	36,671	10,238	9,254
pws_near_lineaments_NEAR_DIST	Distance to nearest lineament	0	4,169	548	402
junkyd_near_dist	Distance to nearest Junkyard	283	170,973	21,300	16,135
ast_near_dist	Distance to nearest AST	14	47,253	7,967	6,245
csite_FUEL_near_dist	Distance to nearest Leaking Bulk Fuel Storage Area	559	229,498	52,088	42,468
csite_IRSPILL_near_dist	Distance to nearest Initial Response Spill	0	118,440	26,917	20,972
csite_LAST_near_dist	Distance to nearest Leaking Above Ground Storage Tank	330	106,431	26,283	24,564
csite_LUST_near_dist	Distance to nearest Leaking Under Ground Storage Tank	11	31,516	5,338	4,152
csite_MOST_near_dist	Distance to nearest Leaking Motor Oil Storage Tank	119	286,093	48,450	39,826
csite_OPUF_near_dist	Distance to nearest Leaking Residential or Commercial Heating Oil Tanks	61	54,670	5,819	4,502
csite_SPILL_RLS_near_dist	Distance to nearest Oil Spill or Release	38	73,946	11,191	8,541
localinv_AST_near_dist	Distance to nearest Petroleum, Chemical, or Oil Storage AST Sites	582	709,958	189,112	166,626
localinv_CARD_near_dist	Distance to nearest Car Dealerships	180	291,757	53,231	39,679
localinv_EEE_near_dist	Distance to nearest Equipment Fueling & Maintenance Facilities	82	105,723	20,666	16,700
localinv_UST_near_dist	Distance to nearest Petroleum, Chemical, or Oil Storage UST Sites	216	161,703	40,134	35,959
localinv_VSR_near_dist	Distance to nearest Vehicle Service & Repair Shops	82	128,246	14,727	9,885
localinv_WSPS_near_dist	Distance to nearest Waste & Scrap Processing & Storage	113	159,184	18,393	14,511
npdes_near_dist	Distance to nearest NPDES Discharge	83	68,508	16,585	13,382

Table 8-3
Potential MtBE Sources in WHPAs

Data Label	Definition	Min	Max	Average	Median	% of WHPAs with at Least One of this Type of Potential Source
PWSID	Combined system and source identification numbers (WESTON)	NA	NA	NA	NA	NA
WHPA_ID	ID number for Wellhead Protection Area	NA	NA	NA	NA	NA
pws_near_lineaments_ NEAR_FID	ID number for lineament closest to PWS well	NA	NA	NA	NA	NA
GWHIs per_WHPA	Number of Groundwater Hazard Inventory Sites (remediation sites) within WHPA	0	107	2.3256	1	46%
GWHIs BR_under10	Number of Groundwater Hazard Inventory Sites (remediation sites) within WHPA with interpolated depth to bedrock less than 10 ft below ground surface	0	20	0.3313	0	12%
GWHIs BR_btwn10_25	Number of Groundwater Hazard Inventory Sites (remediation sites) within WHPA with interpolated depth to bedrock greater than 10 ft but less than 25 ft below ground surface	0	26	0.3303	0	9%
GWHIs BR_over25	Number of Groundwater Hazard Inventory Sites within WHPA with interpolated depth to bedrock greater than 25 ft below ground surface	0	61	1.6469	0	39%
GWHIs Sat_under10	Number of Groundwater Hazard Inventory Sites (remediation sites) within WHPA with saturated thickness less than 10 ft	0	12	0.0588	0	2%
GWHIs Sat_over10	Number of Groundwater Hazard Inventory Sites (remediation sites) within WHPA with saturated thickness greater than 10 ft	0	105	2.2299	1	44%
GWHIs Trans_under2,000	Number of Groundwater Hazard Inventory Sites (remediation sites) within WHPA with transmissivities less than 2,000 ft^2/day	0	79	2.1199	1	44%
GWHIs Trans_over2,000	Number of Groundwater Hazard Inventory Sites (remediation sites) within WHPA with transmissivities greater than 2,000 ft^2/day	0	23	0.1559	0	4%
GWHIs GS_OverWell	Number of Groundwater Hazard Inventory Sites (remediation sites) within WHPA with ground surface elevation higher than ground surface elevation at well	0	57	1.2597	0	30%
GWHIs GS_UnderWell	Number of Groundwater Hazard Inventory Sites (remediation sites) within WHPA with ground surface elevation lower than ground surface elevation at well	0	55	0.9227	0	29%
GWHIs GW_overWell	Number of Groundwater Hazard Inventory Sites (remediation sites) within WHPA with interpolated bedrock groundwater elevation higher than bedrock groundwater elevation at well	0	99	1.2408	0	29%
GWHIs GW_underWell	Number of Groundwater Hazard Inventory Sites (remediation sites) within WHPA with interpolated bedrock groundwater elevation lower than bedrock groundwater elevation at well	0	50	0.9844	0	29%
GWHIs OB_GW_overWell	Number of Groundwater Hazard Inventory Sites within WHPA with interpolated overburden groundwater elevation higher than bedrock groundwater elevation at well	0	9	0.0341	0	1%
GWHIs OB_GW_underWell	Number of Groundwater Hazard Inventory Sites (remediation sites) within WHPA with interpolated overburden groundwater elevation higher than bedrock groundwater elevation at well	0	4	0.0161	0	1%
GWHIs Equal_Well_Lineaments	Number of Groundwater Hazard Inventory Sites within WHPA that share the same nearest lineament as the well	0	16	0.6905	0	25%
GWHIs Risk_1_3	Number of Groundwater Hazard Inventory Sites (remediation sites) within WHPA that were identified as having a risk of 1 or 3	0	50	0.1588	0	3%
GWHIs Risk_4	Number of Groundwater Hazard Inventory Sites (remediation sites) within WHPA that were identified as having a risk of 4	0	1	0.0005	0	0%
GWHIs Risk_5_6_7	Number of Groundwater Hazard Inventory Sites (remediation sites) within WHPA that were identified as having a risk of 5, 6, or 7	0	1	0.0062	0	0%
R_SITEs & R_AREAs perWHPA	Number of RCRA Sites within WHPA	0	32	1.4190	0	30%
R_SITEs & R_AREAs BR_under10	Number of RCRA Sites within WHPA with interpolated depth to bedrock less than 10 ft below ground surface	0	9	0.1701	0	7%
R_SITEs & R_AREAs BR_btwn10_25	Number of RCRA Sites within WHPA with interpolated depth to bedrock greater than 10 ft but less than 25 ft below ground surface	0	14	0.2360	0	7%
R_SITEs & R_AREAs BR_over_25	Number of RCRA Sites within WHPA with interpolated depth to bedrock greater than 25 ft below ground surface	0	26	1.0118	0	25%
R_SITEs & R_AREAs GS_overWell	Number of RCRA Sites within WHPA with saturated thickness less than 10 ft	0	31	0.8417	0	19%
R_SITEs & R_AREAs GS_underWell	Number of RCRA Sites within WHPA with saturated thickness greater than 10 ft	0	21	0.5483	0	17%
R_SITEs & R_AREAs GW_overWell	Number of RCRA Sites within WHPA with transmissivities less than 2,000 ft^2/day	0	32	0.7341	0	18%
R_SITEs & R_AREAs GW_underWell	Number of RCRA Sites within WHPA with transmissivities greater than 2,000 ft^2/day	0	21	0.6682	0	19%

Table 8-3
Potential MtBE Sources in WHPAs

Data Label	Definition	Min	Max	Average	Median	% of WHPAs with at Least One of this Type of Potential Source
R_SITEs & R_AREAs OB_GW_overWell	Number of RCRA Sites within WHPA with ground surface elevation higher than ground surface elevation at well	0	6	0.0327	0	1%
R_SITEs & R_AREAs OB_GW_underWell	Number of RCRA Sites within WHPA with ground surface elevation lower than ground surface elevation at well	0	3	0.0071		0%
R_SITEs & R_AREAs Sat_over10	Number of RCRA Sites within WHPA with interpolated bedrock groundwater elevation higher than bedrock groundwater elevation at well	0	22	0.6365	0	14%
R_SITEs & R_AREAs Sat_under10	Number of RCRA Sites within WHPA with interpolated bedrock groundwater elevation lower than bedrock groundwater elevation at well	0	10	0.0962	0	4%
R_SITEs & R_AREAs Trans_over2,000	Number of RCRA Sites within WHPA with interpolated overburden groundwater elevation higher than bedrock groundwater elevation at well	0	0	0.0000	0	0%
R_SITEs & R_AREAs Trans_under2,000	Number of RCRA Sites within WHPA with interpolated overburden groundwater elevation higher than bedrock groundwater elevation at well	0	2	0.0047	0	0%
R_SITEs & R_AREAs equals_WellLine	Number of RCRA Sites within WHPA that share the same nearest lineament as the well	0	0	0.0000	0	0%
PCSs per_WHPA	Number of Potential Contaminant Sources within WHPA	0	39	1.2403	0	28%
PCSs BR_under10	Number of Potential Contaminant Sources within WHPA with interpolated depth to bedrock less than 10 ft below ground surface	0	9	0.1123	0	4%
PCSs BR_btwn10_25	Number of Potential Contaminant Sources within WHPA with interpolated depth to bedrock greater than 10 ft but less than 25 ft below ground surface	0	11	0.3735	0	12%
PCSs BR_over25	Number of Potential Contaminant Sources within WHPA with interpolated depth to bedrock greater than 25 ft below ground surface	0	36	0.7545	0	19%
PCSs Sat_under10	Number of Potential Contaminant Sources within WHPA with saturated thickness less than 10 ft	0	8	0.0668	0	2%
PCSs Sat_over10	Number of Potential Contaminant Sources within WHPA with saturated thickness greater than 10 ft	0	39	1.1654	0	26%
PCSs Trans_under2,000	Number of Potential Contaminant Sources within WHPA with transmissivities less than 2,000 ft^2/day	0	29	0.5062	0	12%
PCSs Trans_over2,000	Number of Potential Contaminant Sources within WHPA with transmissivities greater than 2,000 ft^2/day	0	9	0.0336	0	2%
PCSs GS_OverWell	Number of Potential Contaminant Sources within WHPA with ground surface elevation higher than ground surface elevation at well	0	39	0.7498	0	17%
PCSs GS_UnderWell	Number of Potential Contaminant Sources within WHPA with ground surface elevation lower than ground surface elevation at well	0	37	0.4588	0	15%
PCSs GW_overWell	Number of Potential Contaminant Sources within WHPA with interpolated bedrock groundwater elevation higher than bedrock groundwater elevation at well	0	0	0.0000	0	0%
PCSs GW_underWell	Number of Potential Contaminant Sources within WHPA with interpolated bedrock groundwater elevation lower than bedrock groundwater elevation at well	0	0	0.0000	0	0%
PCSs OB_GW_overWell	Number of Potential Contaminant Sources within WHPA with interpolated overburden groundwater elevation higher than bedrock groundwater elevation at well	0	4	0.0171	0	1%
PCSs OB_GW_underWell	Number of Potential Contaminant Sources within WHPA with interpolated overburden groundwater elevation higher than bedrock groundwater elevation at well	0	37	0.1251	0	2%
PCSs Equal_Well_Lineaments	Number of Potential Contaminant Sources within WHPA that share the same nearest lineament as the well	0	27	0.3512	0	12%
AST per_WHPA	Number of Above Ground Storage Tanks within WHPA	0	12	0.1867	0	9%
AST BR_under10	Number of Above Ground Storage Tanks within WHPA with interpolated depth to bedrock less than 10 ft below ground surface	0	2	0.0118	0	1%
AST BR_btwn10_25	Number of Above Ground Storage Tanks within WHPA with interpolated depth to bedrock greater than 10 ft but less than 25 ft below ground surface	0	12	0.0422	0	2%
AST BR_over25	Number of Above Ground Storage Tanks within WHPA with interpolated depth to bedrock greater than 25 ft below ground surface	0	9	0.1327	0	6%
AST Sat_under10	Number of Above Ground Storage Tanks within WHPA with saturated thickness less than 10 ft	0	12	0.0227	0	1%
AST Sat_over10	Number of Above Ground Storage Tanks within WHPA with saturated thickness greater than 10 ft	0	9	0.1630	0	8%
AST Trans_under2,000	Number of Above Ground Storage Tanks within WHPA with transmissivities less than 2,000 ft^2/day	0	6	0.0858	0	5%

Table 8-3
Potential MtBE Sources in WHPAs

Data Label	Definition	Min	Max	Average	Median	% of WHPAs with at Least One of this Type of Potential Source
AST Trans_over2,000	Number of Above Ground Storage Tanks within WHPA with transmissivities greater than 2,000 ft^2/day	0	4	0.0199	0	1%
AST GS_OverWell	Number of Above Ground Storage Tanks within WHPA with ground surface elevation higher than ground surface elevation at well	0	9	0.1137	0	5%
AST GS_UnderWell	Number of Above Ground Storage Tanks within WHPA with ground surface elevation lower than ground surface elevation at well	0	5	0.0687	0	4%
AST GW_OverWell	Number of Above Ground Storage Tanks within WHPA with interpolated bedrock groundwater elevation higher than bedrock groundwater elevation at well	0	6	0.0863	0	4%
AST GW_underWell	Number of Above Ground Storage Tanks within WHPA with interpolated bedrock groundwater elevation lower than bedrock groundwater elevation at well	0	11	0.0967	0	5%
AST OB_GW_OverWell	Number of Above Ground Storage Tanks within WHPA with interpolated overburden groundwater elevation higher than bedrock groundwater elevation at well	0	3	0.0033	0	0%
AST OB_GW_UnderWell	Number of Above Ground Storage Tanks within WHPA with interpolated overburden groundwater elevation higher than bedrock groundwater elevation at well	0	1	0.0019	0	0%
AST Equal_Well_Lineaments	Number of Above Ground Storage Tanks within WHPA that share the same nearest lineament as the well	0	1	0.0019	0	0%
LUST per_WHPA	Number of Leaking Underground Storage Tanks within WHPA	0	53	0.5019	0	17%
LUST BR_under10	Number of Leaking Underground Storage Tanks within WHPA with interpolated depth to bedrock less than 10 ft below ground surface	0	6	0.0645	0	3%
LUST BR_btwn10_25	Number of Leaking Underground Storage Tanks within WHPA with interpolated depth to bedrock greater than 10 ft but less than 25 ft below ground surface	0	18	0.0801	0	3%
LUST BR_over25	Number of Leaking Underground Storage Tanks within WHPA with interpolated depth to bedrock greater than 25 ft below ground surface	0	29	0.3555	0	15%
LUST Sat_under10	Number of Leaking Underground Storage Tanks within WHPA with saturated thickness less than 10 ft	0	3	0.0133	0	1%
LUST Sat_over10	Number of Leaking Underground Storage Tanks within WHPA with saturated thickness greater than 10 ft	0	53	0.4829	0	17%
LUST Trans_under2,000	Number of Leaking Underground Storage Tanks within WHPA with transmissivities less than 2,000 ft^2/day	0	41	0.4640	0	17%
LUST Trans_over2,000	Number of Leaking Underground Storage Tanks within WHPA with transmissivities greater than 2,000 ft^2/day	0	12	0.0379	0	1%
LUST GS_OverWell	Number of Leaking Underground Storage Tanks within WHPA with ground surface elevation higher than ground surface elevation at well	0	51	0.3275	0	11%
LUST GS_UnderWell	Number of Leaking Underground Storage Tanks within WHPA with ground surface elevation lower than ground surface elevation at well	0	22	0.1687	0	8%
LUST GW_overWell	Number of Leaking Underground Storage Tanks within WHPA with interpolated bedrock groundwater elevation higher than bedrock groundwater elevation at well	0	52	0.3052	0	10%
LUST GW_underWell	Number of Leaking Underground Storage Tanks within WHPA with interpolated bedrock groundwater elevation lower than bedrock groundwater elevation at well	0	25	0.1934	0	10%
LUST OB_GW_overWell	Number of Leaking Underground Storage Tanks within WHPA with interpolated overburden groundwater elevation higher than bedrock groundwater elevation at well	0	1	0.0005	0	0%
LUST OB_GW_underWell	Number of Leaking Underground Storage Tanks within WHPA with interpolated overburden groundwater elevation higher than bedrock groundwater elevation at well	0	1	0.0019	0	0%
LUST Equal_Well_Lineaments	Number of Leaking Underground Storage Tanks within WHPA that share the same nearest lineament as the well	0	6	0.1133	0	6%
LAST per_WHPA	Number of Leaking Above Ground Storage Tanks within WHPA	0	2	0.0156	0	1%
LAST BR_under10	Number of Leaking Above Ground Storage Tanks within WHPA with interpolated depth to bedrock less than 10 ft below ground surface	0	1	0.0009	0	0%
LAST BR_btwn10_25	Number of Leaking Above Ground Storage Tanks within WHPA with interpolated depth to bedrock greater than 10 ft but less than 25 ft below ground surface	0	0	0.0000	0	0%
LAST BR_over25	Number of Leaking Above Ground Storage Tanks within WHPA with interpolated depth to bedrock greater than 25 ft below ground surface	0	1	0.0128	0	1%
LAST Sat_under10	Number of Leaking Above Ground Storage Tanks within WHPA with saturated thickness less than 10 ft	0	0	0.0000	0	0%
LAST Sat_over10	Number of Leaking Above Ground Storage Tanks within WHPA with saturated thickness greater than 10 ft	0	2	0.0156	0	1%

Table 8-3
Potential MtBE Sources in WHPAs

Data Label	Definition	Min	Max	Average	Median	% of WHPAs with at Least One of this Type of Potential Source
LAST Trans_under2,000	Number of Leaking Above Ground Storage Tanks within WHPA with transmissivities less than 2,000 ft^2/day	0	1	0.0137	0	1%
LAST Trans_over2,000	Number of Leaking Above Ground Storage Tanks within WHPA with transmissivities greater than 2,000 ft^2/day	0	2	0.0019	0	0%
LAST GS_OverWell	Number of Leaking Above Ground Storage Tanks within WHPA with ground surface elevation higher than ground surface elevation at well	0	1	0.0095	0	1%
LAST GS_UnderWell	Number of Leaking Above Ground Storage Tanks within WHPA with ground surface elevation lower than ground surface elevation at well	0	1	0.0043	0	0%
LAST GW_overWell	Number of Leaking Above Ground Storage Tanks within WHPA with interpolated bedrock groundwater elevation higher than bedrock groundwater elevation at well	0	2	0.0100	0	1%
LAST GW_underWell	Number of Leaking Above Ground Storage Tanks within WHPA with interpolated bedrock groundwater elevation lower than bedrock groundwater elevation at well	0	1	0.0057	0	0%
LAST OB_GW_overWell	Number of Leaking Above Ground Storage Tanks within WHPA with interpolated overburden groundwater elevation higher than bedrock groundwater elevation at well	0	1	0.0005	0	0%
LAST OB_GW_underWell	Number of Leaking Above Ground Storage Tanks within WHPA with interpolated overburden groundwater elevation higher than bedrock groundwater elevation at well	0	0	0.0000	0	0%
LAST Equal_Well_Lineaments	Number of Leaking Above Ground Storage Tanks within WHPA that share the same nearest lineament as the well	0	1	0.0019	0	0%
JUNKYD per_WHPA	Number of Junkyards within WHPA	0	2	0.0227	0	2%
JUNKYD BR_under10	Number of Junkyards within WHPA with interpolated depth to bedrock less than 10 ft below ground surface	0	1	0.0028	0	0%
JUNKYD BR_btwn10_25	Number of Junkyards within WHPA with interpolated depth to bedrock greater than 10 ft but less than 25 ft below ground surface	0	1	0.0005	0	0%
JUNKYD BR_over25	Number of Junkyards within WHPA with interpolated depth to bedrock greater than 25 ft below ground surface	0	2	0.0194	0	1%
JUNKYD Sat_under10	Number of Junkyards within WHPA with saturated thickness less than 10 ft	0	0	0.0000	0	0%
JUNKYD Sat_over10	Number of Junkyards within WHPA with saturated thickness greater than 10 ft	0	2	0.0223	0	2%
JUNKYD Trans_under2,000	Number of Junkyards within WHPA with transmissivities less than 2,000 ft^2/day	0	2	0.0227	0	2%
JUNKYD Trans_over2,000	Number of Junkyards within WHPA with transmissivities greater than 2,000 ft^2/day	0	0	0.0000	0	0%
JUNKYD GS_OverWell	Number of Junkyards within WHPA with ground surface elevation higher than ground surface elevation at well	0	1	0.0114	0	1%
JUNKYD GS_UnderWell	Number of Junkyards within WHPA with ground surface elevation lower than ground surface elevation at well	0	2	0.0114	0	1%
JUNKYD GW_overWell	Number of Junkyards within WHPA with interpolated bedrock groundwater elevation higher than bedrock groundwater elevation at well	0	1	0.0066	0	1%
JUNKYD GW_underWell	Number of Junkyards within WHPA with interpolated bedrock groundwater elevation lower than bedrock groundwater elevation at well	0	2	0.0156	0	1%
JUNKYD OB_GW_overWell	Number of Junkyards within WHPA with interpolated overburden groundwater elevation higher than bedrock groundwater elevation at well	0	1	0.0005	0	0%
JUNKYD OB_GW_underWell	Number of Junkyards within WHPA with interpolated overburden groundwater elevation higher than bedrock groundwater elevation at well	0	1	0.0005	0	0%
JUNKYD Equal_Well_Lineaments	Number of Junkyards within WHPA that share the same nearest lineament as the well	0	1	0.0057	0	0%
VSR per_WHPA	Number of Vehicle Service & Repair Shops within WHPA	0	11	0.2313	0	10%
VSR BR_under10	Number of Vehicle Service & Repair Shops within WHPA with interpolated depth to bedrock less than 10 ft below ground surface	0	3	0.0209	0	1%
VSR BR_btwn10_25	Number of Vehicle Service & Repair Shops within WHPA with interpolated depth to bedrock greater than 10 ft but less than 25 ft below ground surface	0	3	0.0678	0	4%
VSR BR_over25	Number of Vehicle Service & Repair Shops within WHPA with interpolated depth to bedrock greater than 25 ft below ground surface	0	11	0.1427	0	7%
VSR Sat_under10	Number of Vehicle Service & Repair Shops within WHPA with saturated thickness less than 10 ft	0	3	0.0152	0	1%

Table 8-3
Potential MtBE Sources in WHPAs

Data Label	Definition	Min	Max	Average	Median	% of WHPAs with at Least One of this Type of Potential Source
VSR Sat_over10	Number of Vehicle Service & Repair Shops within WHPA with saturated thickness greater than 10 ft	0	11	0.2152	0	10%
VSR Trans_under2,000	Number of Vehicle Service & Repair Shops within WHPA with transmissivities less than 2,000 ft^2/day	0	11	0.0957	0	4%
VSR Trans_over2,000	Number of Vehicle Service & Repair Shops within WHPA with transmissivities greater than 2,000 ft^2/day	0	4	0.0066	0	0%
VSR GS_OverWell	Number of Vehicle Service & Repair Shops within WHPA with ground surface elevation higher than ground surface elevation at well	0	10	0.1351	0	7%
VSR GS_UnderWell	Number of Vehicle Service & Repair Shops within WHPA with ground surface elevation lower than ground surface elevation at well	0	4	0.0934	0	5%
VSR GW_overWell	Number of Vehicle Service & Repair Shops within WHPA with interpolated bedrock groundwater elevation higher than bedrock groundwater elevation at well	0	8	0.1213	0	6%
VSR GW_underWell	Number of Vehicle Service & Repair Shops within WHPA with interpolated bedrock groundwater elevation lower than bedrock groundwater elevation at well	0	10	0.1095	0	6%
VSR OB_GW_overWell	Number of Vehicle Service & Repair Shops within WHPA with interpolated overburden groundwater elevation higher than bedrock groundwater elevation at well	0	1	0.0052	0	0%
VSR OB_GW_underWell	Number of Vehicle Service & Repair Shops within WHPA with interpolated overburden groundwater elevation higher than bedrock groundwater elevation at well	0	7	0.0209	0	1%
VSR Equal_Well_Lineaments	Number of Vehicle Service & Repair Shops within WHPA that share the same nearest lineament as the well	0	4	0.0664	0	4%
WSPS per_WHPA	Number of Waste & Scrap Processing & Storage Sites within WHPA	0	4	0.0545	0	4%
WSPS BR_under10	Number of Waste & Scrap Processing & Storage Sites within WHPA with interpolated depth to bedrock less than 10 ft below ground surface	0	1	0.0019	0	0%
WSPS BR_btwn10_25	Number of Waste & Scrap Processing & Storage Sites within WHPA with interpolated depth to bedrock greater than 10 ft but less than 25 ft below ground surface	0	2	0.0218	0	1%
WSPS BR_over25	Number of Waste & Scrap Processing & Storage Sites within WHPA with interpolated depth to bedrock greater than 25 ft below ground surface	0	2	0.0308	0	2%
WSPS Sat_under10	Number of Waste & Scrap Processing & Storage Sites within WHPA with saturated thickness less than 10 ft	0	1	0.0009	0	0%
WSPS Sat_over10	Number of Waste & Scrap Processing & Storage Sites within WHPA with saturated thickness greater than 10 ft	0	4	0.0536	0	4%
WSPS Trans_under2,000	Number of Waste & Scrap Processing & Storage Sites within WHPA with transmissivities less than 2,000 ft^2/day	0	2	0.0147	0	1%
WSPS Trans_over2,000	Number of Waste & Scrap Processing & Storage Sites within WHPA with transmissivities greater than 2,000 ft^2/day	0	1	0.0024	0	0%
WSPS GS_OverWell	Number of Waste & Scrap Processing & Storage Sites within WHPA with ground surface elevation higher than ground surface elevation at well	0	2	0.0251	0	2%
WSPS GS_UnderWell	Number of Waste & Scrap Processing & Storage Sites within WHPA with ground surface elevation lower than ground surface elevation at well	0	4	0.0265	0	2%
WSPS GW_overWell	Number of Waste & Scrap Processing & Storage Sites within WHPA with interpolated bedrock groundwater elevation higher than bedrock groundwater elevation at well	0	4	0.0270	0	2%
WSPS GW_underWell	Number of Waste & Scrap Processing & Storage Sites within WHPA with interpolated bedrock groundwater elevation lower than bedrock groundwater elevation at well	0	2	0.0246	0	2%
WSPS OB_GW_overWell	Number of Waste & Scrap Processing & Storage Sites within WHPA with interpolated overburden groundwater elevation higher than bedrock groundwater elevation at well	0	1	0.0005	0	0%
WSPS OB_GW_underWell	Number of Waste & Scrap Processing & Storage Sites within WHPA with interpolated overburden groundwater elevation higher than bedrock groundwater elevation at well	0	2	0.0028	0	0%
WSPS Equal_Well_Lineaments	Number of Waste & Scrap Processing & Storage Sites within WHPA that share the same nearest lineament as the well	0	2	0.0123	0	1%
EEE per_WHPA	Number of Fueling & Maintenance of Excavation & Earthmoving Equipment Sites within WHPA	0	4	0.1000	0	6%
EEE BR_under10	Number of Fueling & Maintenance of Excavation & Earthmoving Equipment Sites within WHPA with interpolated depth to bedrock less than 10 ft below ground surface	0	1	0.0052	0	0%
EEE BR_btwn10_25	Number of Fueling & Maintenance of Excavation & Earthmoving Equipment Sites within WHPA with interpolated depth to bedrock greater than 10 ft but less than 25 ft below ground surface	0	3	0.0213	0	1%
EEE BR_over25	Number of Fueling & Maintenance of Excavation & Earthmoving Equipment Sites within WHPA with interpolated depth to bedrock greater than 25 ft below ground surface	0	3	0.0735	0	4%

Table 8-3
Potential MtBE Sources in WHPAs

Data Label	Definition	Min	Max	Average	Median	% of WHPAs with at Least One of this Type of Potential Source
EEE Sat_under10	Number of Fueling & Maintenance of Excavation & Earthmoving Equipment Sites within WHPA with saturated thickness less than 10 ft	0	1	0.0005	0	0%
EEE Sat_over10	Number of Fueling & Maintenance of Excavation & Earthmoving Equipment Sites within WHPA with saturated thickness greater than 10 ft	0	4	0.0995	0	6%
EEE Trans_under2,000	Number of Fueling & Maintenance of Excavation & Earthmoving Equipment Sites within WHPA with transmissivities less than 2,000 ft^2/day	0	3	0.0531	0	3%
EEE Trans_over2,000	Number of Fueling & Maintenance of Excavation & Earthmoving Equipment Sites within WHPA with transmissivities greater than 2,000 ft^2/day	0	1	0.0043	0	0%
EEE GS_OverWell	Number of Fueling & Maintenance of Excavation & Earthmoving Equipment Sites within WHPA with ground surface elevation higher than ground surface elevation at well	0	3	0.0550	0	3%
EEE GS_UnderWell	Number of Fueling & Maintenance of Excavation & Earthmoving Equipment Sites within WHPA with ground surface elevation lower than ground surface elevation at well	0	4	0.0398	0	2%
EEE GW_overWell	Number of Fueling & Maintenance of Excavation & Earthmoving Equipment Sites within WHPA with interpolated bedrock groundwater elevation higher than bedrock groundwater elevation at well	0	3	0.0507	0	3%
EEE GW_underWell	Number of Fueling & Maintenance of Excavation & Earthmoving Equipment Sites within WHPA with interpolated bedrock groundwater elevation lower than bedrock groundwater elevation at well	0	3	0.0559	0	3%
EEE OB_GW_overWell	Number of Fueling & Maintenance of Excavation & Earthmoving Equipment Sites within WHPA with interpolated overburden groundwater elevation higher than bedrock groundwater elevation at well	0	0	0.0000	0	0%
EEE OB_GW_underWell	Number of Fueling & Maintenance of Excavation & Earthmoving Equipment Sites within WHPA with interpolated overburden groundwater elevation higher than bedrock groundwater elevation at well	0	3	0.0076	0	0%
EEE Equal_Well_Lineaments	Number of Fueling & Maintenance of Excavation & Earthmoving Equipment Sites within WHPA that share the same nearest lineament as the well	0	2	0.0218	0	1%
CARD per_WHPA	Car Dealerships within WHPA	0	3	0.0261	0	1%
CARD BR_under10	Car Dealerships within WHPA with interpolated depth to bedrock less than 10 ft below ground surface	0	0	0.0000	0	0%
CARD BR_btwn10_25	Car Dealerships within WHPA with interpolated depth to bedrock greater than 10 ft but less than 25 ft below ground surface	0	2	0.0118	0	1%
CARD BR_over25	Car Dealerships within WHPA with interpolated depth to bedrock greater than 25 ft below ground surface	0	2	0.0142	0	1%
CARD Sat_under10	Car Dealerships within WHPA with saturated thickness less than 10 ft	0	1	0.0019	0	0%
CARD Sat_over10	Car Dealerships within WHPA with saturated thickness greater than 10 ft	0	3	0.0242	0	1%
CARD Trans_under2,000	Car Dealerships within WHPA with transmissivities less than 2,000 ft^2/day	0	3	0.0180	0	1%
CARD Trans_over2,000	Car Dealerships within WHPA with transmissivities greater than 2,000 ft^2/day	0	0	0.0000	0	0%
CARD GS_OverWell	Car Dealerships within WHPA with ground surface elevation higher than ground surface elevation at well	0	3	0.0199	0	1%
CARD GS_UnderWell	Car Dealerships within WHPA with ground surface elevation lower than ground surface elevation at well	0	2	0.0062	0	0%
CARD GW_overWell	Car Dealerships within WHPA with interpolated bedrock groundwater elevation higher than bedrock groundwater elevation at well	0	3	0.0161	0	1%
CARD GW_underWell	Car Dealerships within WHPA with interpolated bedrock groundwater elevation lower than bedrock groundwater elevation at well	0	0	0.0000	0	0%
CARD OB_GW_overWell	Car Dealerships within WHPA with interpolated overburden groundwater elevation higher than bedrock groundwater elevation at well	0	1	0.0005	0	0%
CARD OB_GW_underWell	Car Dealerships within WHPA with interpolated overburden groundwater elevation higher than bedrock groundwater elevation at well	0	3	0.0033	0	0%
CARD Equal_Well_Lineaments	Car Dealerships within WHPA that share the same nearest lineament as the well	0	1	0.0033	0	0%
FUEL PerWHPA	Leaking Bulk Fuel Oil Storage Facilities within WHPA	0	1	0.0005	0	0%
FUEL BR_under10	Leaking Bulk Fuel Oil Storage Facilities within WHPA with interpolated depth to bedrock less than 10 ft below ground surface	0	1	0.0005	0	0%
FUEL BR_btwn10_25	Leaking Bulk Fuel Oil Storage Facilities within WHPA with interpolated depth to bedrock greater than 10 ft but less than 25 ft below ground surface	0	0	0.0000	0	0%

Table 8-3
Potential MtBE Sources in WHPAs

Data Label	Definition	Min	Max	Average	Median	% of WHPAs with at Least One of this Type of Potential Source
FUEL BR_over_25	Leaking Bulk Fuel Oil Storage Facilities within WHPA with interpolated depth to bedrock greater than 25 ft below ground surface	0	0	0.0000	0	0%
FUEL GS_overWell	Leaking Bulk Fuel Oil Storage Facilities within WHPA with saturated thickness less than 10 ft	0	1	0.0005	0	0%
FUEL GS_underWell	Leaking Bulk Fuel Oil Storage Facilities within WHPA with saturated thickness greater than 10 ft	0	0	0.0000	0	0%
FUEL GW_overWell	Leaking Bulk Fuel Oil Storage Facilities within WHPA with transmissivities less than 2,000 ft^2/day	0	1	0.0005	0	0%
FUEL GW_underWell	Leaking Bulk Fuel Oil Storage Facilities within WHPA with transmissivities greater than 2,000 ft^2/day	0	0	0.0000	0	0%
FUEL OB_GW_overWell	Leaking Bulk Fuel Oil Storage Facilities within WHPA with ground surface elevation higher than ground surface elevation at well	0	0	0.0000	0	0%
FUEL OB_GW_underWell	Leaking Bulk Fuel Oil Storage Facilities within WHPA with ground surface elevation lower than ground surface elevation at well	0	0	0.0000	0	0%
FUEL Sat_over10	Leaking Bulk Fuel Oil Storage Facilities within WHPA with interpolated bedrock groundwater elevation higher than bedrock groundwater elevation at well	0	0	0.0000	0	0%
FUEL Sat_under10	Leaking Bulk Fuel Oil Storage Facilities within WHPA with interpolated bedrock groundwater elevation lower than bedrock groundwater elevation at well	0	1	0.0005	0	0%
FUEL Trans_over2,000	Leaking Bulk Fuel Oil Storage Facilities within WHPA with interpolated overburden groundwater elevation higher than bedrock groundwater elevation at well	0	0	0.0000	0	0%
FUEL Trans_under2,000	Leaking Bulk Fuel Oil Storage Facilities within WHPA with interpolated overburden groundwater elevation higher than bedrock groundwater elevation at well	0	1	0.0005	0	0%
FUEL equals_WellLine	Leaking Bulk Fuel Oil Storage Facilities within WHPA that share the same nearest lineament as the well	0	0	0.0000	0	0%
OPUF per_WHPA	Leaking Heating Oil Tanks within WHPA	0	7	0.3085	0	15%
OPUF BR_under10	Leaking Heating Oil Tanks within WHPA with interpolated depth to bedrock less than 10 ft below ground surface	0	5	0.0502	0	3%
OPUF BR_btwn10_25	Leaking Heating Oil Tanks within WHPA with interpolated depth to bedrock greater than 10 ft but less than 25 ft below ground surface	0	3	0.0360	0	2%
OPUF BR_over25	Leaking Heating Oil Tanks within WHPA with interpolated depth to bedrock greater than 25 ft below ground surface	0	7	0.2185	0	12%
OPUF Sat_under10	Leaking Heating Oil Tanks within WHPA with saturated thickness less than 10 ft	0	3	0.0081	0	0%
OPUF Sat_over10	Leaking Heating Oil Tanks within WHPA with saturated thickness greater than 10 ft	0	7	0.2877	0	15%
OPUF Trans_under2,000	Leaking Heating Oil Tanks within WHPA with transmissivities less than 2,000 ft^2/day	0	6	0.2972	0	15%
OPUF Trans_over2,000	Leaking Heating Oil Tanks within WHPA with transmissivities greater than 2,000 ft^2/day	0	1	0.0114	0	1%
OPUF GS_OverWell	Leaking Heating Oil Tanks within WHPA with ground surface elevation higher than ground surface elevation at well	0	7	0.1787	0	9%
OPUF GS_UnderWell	Leaking Heating Oil Tanks within WHPA with ground surface elevation lower than ground surface elevation at well	0	4	0.1223	0	7%
OPUF GW_overWell	Leaking Heating Oil Tanks within WHPA with interpolated bedrock groundwater elevation higher than bedrock groundwater elevation at well	0	7	0.1649	0	9%
OPUF GW_underWell	Leaking Heating Oil Tanks within WHPA with interpolated bedrock groundwater elevation lower than bedrock groundwater elevation at well	0	6	0.1398	0	8%
OPUF OB_GW_overWell	Leaking Heating Oil Tanks within WHPA with interpolated overburden groundwater elevation higher than bedrock groundwater elevation at well	0	5	0.0090	0	0%
OPUF OB_GW_underWell	Leaking Heating Oil Tanks within WHPA with interpolated overburden groundwater elevation higher than bedrock groundwater elevation at well	0	1	0.0005	0	0%
OPUF Equal_Well_Lineaments	Leaking Heating Oil Tanks within WHPA that share the same nearest lineament as the well	0	4	0.0829	0	5%
SPILL PerWHPA	Oil Spills or Releases within WHPA	0	8	0.0967	0	6%
SPILL BR_under10	Oil Spills or Releases within WHPA with interpolated depth to bedrock less than 10 ft below ground surface	0	1	0.0095	0	1%

Table 8-3
Potential MtBE Sources in WHPAs

Data Label	Definition	Min	Max	Average	Median	% of WHPAs with at Least One of this Type of Potential Source
SPILL BR_btwn10_25	Oil Spills or Releases within WHPA with interpolated depth to bedrock greater than 10 ft but less than 25 ft below ground surface	0	7	0.0194	0	1%
SPILL BR_over_25	Oil Spills or Releases within WHPA with interpolated depth to bedrock greater than 25 ft below ground surface	0	2	0.0678	0	5%
SPILL GS_overWell	Oil Spills or Releases within WHPA with saturated thickness less than 10 ft	0	8	0.0630	0	4%
SPILL GS_underWell	Oil Spills or Releases within WHPA with saturated thickness greater than 10 ft	0	2	0.0332	0	2%
SPILL GW_overWell	Oil Spills or Releases within WHPA with transmissivities less than 2,000 ft2/day	0	8	0.0592	0	3%
SPILL GW_underWell	Oil Spills or Releases within WHPA with transmissivities greater than 2,000 ft^2/day	0	2	0.0360	0	3%
SPILL OB_GW_overWell	Oil Spills or Releases within WHPA with ground surface elevation higher than ground surface elevation at well	0	2	0.0019	0	0%
SPILL OB_GW_underWell	Oil Spills or Releases within WHPA with ground surface elevation lower than ground surface elevation at well	0	1	0.0005	0	0%
SPILL Sat_over10	Oil Spills or Releases within WHPA with interpolated bedrock groundwater elevation higher than bedrock groundwater elevation at well	0	8	0.0919	0	5%
SPILL Sat_under10	Oil Spills or Releases within WHPA with interpolated bedrock groundwater elevation lower than bedrock groundwater elevation at well	0	2	0.0019	0	0%
SPILL Trans_over2,000	Oil Spills or Releases within WHPA with interpolated overburden groundwater elevation higher than bedrock groundwater elevation at well	0	1	0.0024	0	0%
SPILL Trans_under2,000	Oil Spills or Releases within WHPA with interpolated overburden groundwater elevation higher than bedrock groundwater elevation at well	0	8	0.0943	0	6%
SPILL equals_WellLine	Oil Spills or Releases within WHPA that share the same nearest lineament as the well	0	7	0.0332	0	2%
IRSPILL PerWHPA	Initial Response Spills within WHPA	0	2	0.0199	0	1%
IRSPILL BR_under10	Initial Response Spills within WHPA with interpolated depth to bedrock less than 10 ft below ground surface	0	1	0.0066	0	1%
IRSPILL BR_btwn10_25	Initial Response Spills within WHPA with interpolated depth to bedrock greater than 10 ft but less than 25 ft below ground surface	0	1	0.0028	0	0%
IRSPILL BR_over_25	Initial Response Spills within WHPA with interpolated depth to bedrock greater than 25 ft below ground surface	0	2	0.0104	0	1%
IRSPILL GS_overWell	Initial Response Spills within WHPA with saturated thickness less than 10 ft	0	2	0.0114	0	1%
IRSPILL GS_underWell	Initial Response Spills within WHPA with saturated thickness greater than 10 ft	0	1	0.0081	0	1%
IRSPILL GW_overWell	Initial Response Spills within WHPA with transmissivities less than 2,000 ft^2/day	0	2	0.0147	0	1%
IRSPILL GW_underWell	Initial Response Spills within WHPA with transmissivities greater than 2,000 ft^2/day	0	1	0.0052	0	0%
IRSPILL OB_GW_overWell	Initial Response Spills within WHPA with ground surface elevation higher than ground surface elevation at well	0	0	0.0000	0	0%
IRSPILL OB_GW_underWell	Initial Response Spills within WHPA with ground surface elevation lower than ground surface elevation at well	0	0	0.0000	0	0%
IRSPILL Sat_over10	Initial Response Spills within WHPA with interpolated bedrock groundwater elevation higher than bedrock groundwater elevation at well	0	2	0.0194	0	1%
IRSPILL Sat_under10	Initial Response Spills within WHPA with interpolated bedrock groundwater elevation lower than bedrock groundwater elevation at well	0	1	0.0005	0	0%
IRSPILL Trans_over2,000	Initial Response Spills within WHPA with interpolated overburden groundwater elevation higher than bedrock groundwater elevation at well	0	1	0.0005	0	0%
IRSPILL Trans_under2,000	Initial Response Spills within WHPA with interpolated overburden groundwater elevation higher than bedrock groundwater elevation at well	0	2	0.0194	0	1%
IRSPILL equals_WellLine	Initial Response Spills within WHPA that share the same nearest lineament as the well	0	1	0.0062	0	0%
UST PerWHPA	Number of Underground Storage Tanks within WHPA	0	216	3.8934	0	30%

Table 8-3
Potential MtBE Sources in WHPAs

Data Label	Definition	Min	Max	Average	Median	% of WHPAs with at Least One of this Type of Potential Source
UST BR_under10	Number of Underground Storage Tanks within WHPA with interpolated depth to bedrock less than 10 ft below ground surface	0	17	0.2370	0	4%
UST BR_btwn10_25	Number of Underground Storage Tanks within WHPA with interpolated depth to bedrock greater than 10 ft but less than 25 ft below ground surface	0	216	1.0033	0	9%
UST BR_over_25	Number of Underground Storage Tanks within WHPA with interpolated depth to bedrock greater than 25 ft below ground surface	0	144	2.6531	0	22%
UST GS_overWell	Number of Underground Storage Tanks within WHPA with saturated thickness less than 10 ft	0	216	2.3758	0	20%
UST GS_underWell	Number of Underground Storage Tanks within WHPA with saturated thickness greater than 10 ft	0	108	1.4592	0	16%
UST GW_overWell	Number of Underground Storage Tanks within WHPA with transmissivities less than 2,000 ft^2/day	0	90	1.9322	0	19%
UST GW_underWell	Number of Underground Storage Tanks within WHPA with transmissivities greater than 2,000 ft^2/day	0	216	1.8820	0	18%
UST OB_GW_overWell	Number of Underground Storage Tanks within WHPA with ground surface elevation higher than ground surface elevation at well	0	28	0.0938	0	1%
UST OB_GW_underWell	Number of Underground Storage Tanks within WHPA with ground surface elevation lower than ground surface elevation at well	0	4	0.0123	0	0%
UST Sat_over10	Number of Underground Storage Tanks within WHPA with interpolated bedrock groundwater elevation higher than bedrock groundwater elevation at well	0	216	3.7161	0	29%
UST Sat_under10	Number of Underground Storage Tanks within WHPA with interpolated bedrock groundwater elevation lower than bedrock groundwater elevation at well	0	36	0.1507	0	1%
UST Trans_over2,000	Number of Underground Storage Tanks within WHPA with interpolated overburden groundwater elevation higher than bedrock groundwater elevation at well	0	27	0.2028	0	2%
UST Trans_under2,000	Number of Underground Storage Tanks within WHPA with interpolated overburden groundwater elevation higher than bedrock groundwater elevation at well	0	36	0.1507	0	1%
UST equals_WellLine	Number of Underground Storage Tanks within WHPA that share the same nearest lineament as the well	0	48	1.0019	0	13%
UST withVAC2	Number of Underground Storage Tanks within WHPA that have Stage II Vapor Recovery Systems	0	31	0.5294	0	4%
UST withoutVAC2	Number of Underground Storage Tanks within WHPA that do not have Stage II Vapor Recovery Systems	0	144	1.4318	0	12%
UST withFCP	Number of Underground Storage Tanks within WHPA that have Fiberglass, Composite, or Plastic Construction.	0	72	1.0697	0	18%
UST withoutFCP	Number of Underground Storage Tanks within WHPA that do not have Fiberglass, Composite, or Plastic Construction.	0	207	2.8237	0	28%
UST withDBLWALL	Number of Underground Storage Tanks within WHPA that have double wall construction.	0	88	1.3142	0	22%
UST withoutDBLWALL	Number of Underground Storage Tanks within WHPA that do not have double wall construction.	0	144	2.5791	0	27%
UST withGAS	Number of Underground Storage Tanks within WHPA that contain gasoline.	0	38	1.4431	0	20%
UST withOTHER	Number of Underground Storage Tanks within WHPA with contents other than gasoline.	0	207	2.4502	0	27%
MOST PerWHPA	Leaking Motor Oil Storage Tanks within WHPA	0	1	0.0052	0	0%
MOST BR_under10	Leaking Motor Oil Storage Tanks within WHPA with interpolated depth to bedrock less than 10 ft below ground surface	0	1	0.0038	0	0%
MOST BR_btwn10_25	Leaking Motor Oil Storage Tanks within WHPA with interpolated depth to bedrock greater than 10 ft but less than 25 ft below ground surface	0	0	0.0000	0	0%
MOST BR_over_25	Leaking Motor Oil Storage Tanks within WHPA with interpolated depth to bedrock greater than 25 ft below ground surface	0	1	0.0014	0	0%
MOST GS_overWell	Leaking Motor Oil Storage Tanks within WHPA with saturated thickness less than 10 ft	0	0	0.0000	0	0%
MOST GS_underWell	Leaking Motor Oil Storage Tanks within WHPA with saturated thickness greater than 10 ft	0	0	0.0000	0	0%
MOST GW_overWell	Leaking Motor Oil Storage Tanks within WHPA with transmissivities less than 2,000 ft^2/day	0	1	0.0043	0	0%

Table 8-3
Potential MtBE Sources in WHPAs

Data Label	Definition	Min	Max	Average	Median	% of WHPAs with at Least One of this Type of Potential Source
MOST GW_underWell	Leaking Motor Oil Storage Tanks within WHPA with transmissivities greater than 2,000 ft^2/day	0	1	0.0009	0	0%
MOST OB_GW_overWell	Leaking Motor Oil Storage Tanks within WHPA with ground surface elevation higher than ground surface elevation at well	0	0	0.0000	0	0%
MOST OB_GW_underWell	Leaking Motor Oil Storage Tanks within WHPA with ground surface elevation lower than ground surface elevation at well	0	0	0.0000	0	0%
MOST Sat_over10	Leaking Motor Oil Storage Tanks within WHPA with interpolated bedrock groundwater elevation higher than bedrock groundwater elevation at well	0	1	0.0052	0	0%
MOST Sat_under10	Leaking Motor Oil Storage Tanks within WHPA with interpolated bedrock groundwater elevation lower than bedrock groundwater elevation at well	0	0	0.0000	0	0%
MOST Trans_over2,000	Leaking Motor Oil Storage Tanks within WHPA with interpolated overburden groundwater elevation higher than bedrock groundwater elevation at well	0	0	0.0000	0	0%
MOST Trans_under2,000	Leaking Motor Oil Storage Tanks within WHPA with interpolated overburden groundwater elevation higher than bedrock groundwater elevation at well	0	1	0.0052	0	0%
MOST equals_WellLine	Leaking Motor Oil Storage Tanks within WHPA that share the same nearest lineament as the well	0	0	0.0000	0	0%
LEAKS/SPILLS PerWHPA	LUSTs, LASTs, FUELs, OPUFs, SPILL/RLSs, IRSPILLs, MOSTs combined within WHPA	0	60	0.9303	0	29%
LEAKS/SPILLS BR_under10	LUSTs, LASTs, FUELs, OPUFs, SPILL/RLSs, IRSPILLs, MOSTs combined within WHPA with interpolated depth to bedrock less than 10 ft below ground surface	0	9	0.1275	0	6%
LEAKS/SPILLS BR_btwn10_25	LUSTs, LASTs, FUELs, OPUFs, SPILL/RLSs, IRSPILLs, MOSTs combined within WHPA with interpolated depth to bedrock greater than 10 ft but less than 25 ft below ground surface	0	19	0.1360	0	5%
LEAKS/SPILLS BR_over_25	LUSTs, LASTs, FUELs, OPUFs, SPILL/RLSs, IRSPILLs, MOSTs combined within WHPA with interpolated depth to bedrock greater than 25 ft below ground surface	0	32	0.6592	0	24%
LEAKS/SPILLS GS_overWell	LUSTs, LASTs, FUELs, OPUFs, SPILL/RLSs, IRSPILLs, MOSTs combined within WHPA with saturated thickness less than 10 ft	0	57	0.5815	0	18%
LEAKS/SPILLS GS_underWell	LUSTs, LASTs, FUELs, OPUFs, SPILL/RLSs, IRSPILLs, MOSTs combined within WHPA with saturated thickness greater than 10 ft	0	28	0.3327	0	15%
LEAKS/SPILLS GW_overWell	LUSTs, LASTs, FUELs, OPUFs, SPILL/RLSs, IRSPILLs, MOSTs combineds within WHPA with transmissivities less than 2,000 ft^2/day	0	57	0.5436	0	17%
LEAKS/SPILLS GW_underWell	LUSTs, LASTs, FUELs, OPUFs, SPILL/RLSs, IRSPILLs, MOSTs combined within WHPA with transmissivities greater than 2,000 ft^2/day	0	30	0.3782	0	17%
LEAKS/SPILLS OB_GW_overWell	LUSTs, LASTs, FUELs, OPUFs, SPILL/RLSs, IRSPILLs, MOSTs combined within WHPA with ground surface elevation higher than ground surface elevation at well	0	8	0.0166	0	1%
LEAKS/SPILLS OB_GW_underWell	LUSTs, LASTs, FUELs, OPUFs, SPILL/RLSs, IRSPILLs, MOSTs combined within WHPA with ground surface elevation lower than ground surface elevation at well	0	1	0.0028	0	0%
LEAKS/SPILLS Sat_over10	LUSTs, LASTs, FUELs, OPUFs, SPILL/RLSs, IRSPILLs, MOSTs combined within WHPA with interpolated bedrock groundwater elevation higher than bedrock groundwater elevation at well	0	58	0.8848	0	27%
LEAKS/SPILLS Sat_under10	LUSTs, LASTs, FUELs, OPUFs, SPILL/RLSs, IRSPILLs, MOSTs combined within WHPA with interpolated bedrock groundwater elevation lower than bedrock groundwater elevation at well	0	6	0.0242	0	1%
LEAKS/SPILLS Trans_over2,000	LUSTs, LASTs, FUELs, OPUFs, SPILL/RLSs, IRSPILLs, MOSTs combined within WHPA with interpolated overburden groundwater elevation higher than bedrock groundwater elevation at well	0	13	0.0517	0	1%
LEAKS/SPILLS Trans_under2,000	LUSTs, LASTs, FUELs, OPUFs, SPILL/RLSs, IRSPILLs, MOSTs combined within WHPA with interpolated overburden groundwater elevation higher than bedrock groundwater elevation at well	0	47	0.8787	0	28%
LEAKS/SPILLS equals_WellLine	LUSTs, LASTs, FUELs, OPUFs, SPILL/RLSs, IRSPILLs, MOSTs combined within WHPA that share the same nearest lineament as the well	0	8	0.2327	0	11%

The queries of potential contaminant sources within the WHPAs were further refined to attempt to evaluate the impacts of localized hydrogeologic factors on the probability of a potential source impacting a nearby PWS. This was done in an effort to separate out potential contaminant sources with likely pathways to the PWS from those potential contaminant sources that may be in close proximity to the PWS, but did not have a likely pathway to reach the PWS. One example of this type of analysis was comparison of ground surface elevations at the PWS and the potential contaminant source to infer if the potential contaminant source is likely to be upgradient or downgradient of the PWS. Another strategy was to identify the nearest mapped lineament to the PWS and the nearest mapped lineament to the potential contaminant source. Potential contaminant sources that were located within the WHPA of the PWS and which shared the same nearest lineament as the PWS were identified.

Other local hydrogeologic factors were evaluated for their potential to create a likely pathway between a potential contaminant source and a PWS. These included depth-to-bedrock, saturated thickness of overburden, aquifer transmissivity, and overburden and bedrock groundwater elevations (relative to those at the PWS locations). Information on overburden groundwater elevations was limited to small areas of the State where aquifer mapping had been performed. Information on bedrock groundwater elevations was interpolated from the Water Well Board Well Completion Report Database and were of limited accuracy, particularly in the more rural areas of the State. Therefore, for an indication of whether a potential contaminant source was likely to be upgradient or downgradient of a PWS, three types of data: overburden groundwater, bedrock groundwater, and ground surface elevations were included in the statistical analysis.

Additional characteristics were available for evaluation of USTs as potential contaminant sources. In addition to the hydrogeologic factors, the materials of construction, whether double containment was employed, and whether Stage II Vapor Recovery was in use was information that was included in the statistical analyses for USTs.

8.2 PATHWAY ANALYSES

WESTON provided data regarding a total of 364 potential risk factors to UNH for the statistical analysis and modeling. These variables were grouped into nine categories relating to different pathways or root causes for MtBE to enter PWS wells/sources. Table 8-4 summarizes these

Table 8-4
Categories for Pathway Analyses

Risk Factors	Categories for Grouping Risk Factors								
	GW Pathway	SW Pathway	Tanks as Potential Sources	Geopolitical Factors	Well Construction & Operation	BR Lineament Pathway	Overburden Pathway	Potential Sources in WHPA	Best Management Practices
"PWSID"	Y	Y	Y	Y	Y	Y	Y	Y	Y
"X.COORD"				Y					
"Y.COORD"				Y					
"max" (MtBE conc)	Y	Y	Y	Y	Y	Y	Y	Y	Y
"mean" (MtBE conc)	Y	Y	Y	Y	Y	Y	Y	Y	Y
"MtBE detect"	Y	Y	Y	Y	Y	Y	Y	Y	Y
"pws.near.road.NEAR.DIST"		Y		Y	Y				
"NEAR.DIST.trail"		Y		Y	Y				
"RSITE.Near.Dist"	Y	Y		Y					
"RAREA.NEAR.Dist"	Y	Y		Y					
"NEAR.DIST.remed.poly"	Y					Y	Y		
"NEAR.DIST.remedpt"	Y					Y	Y		
"NEAR.DIST.UST"	Y		Y						
"ast.near.dist"	Y	Y	Y						
"pws.near.lineaments.NEAR.DIST"					Y	Y			
"csite.IRSPILL.near.dist"	Y	Y				Y	Y		Y
"junkyd.near.dist"	Y	Y		Y		Y	Y		
"csite.LUST.near.dist"	Y		Y			Y	Y		
"csite.FUEL.near.dist"	Y	Y	Y			Y	Y		
"csite.OPUF.near.dist"	Y	Y	Y			Y	Y		
"csite.LAST.near.dist"	Y	Y	Y			Y	Y		
"localinv.AST.near.dist"	Y	Y	Y						
"csite.MOST.near.dist"	Y	Y	Y			Y	Y		
"localinv.EEE.near.dist"	Y	Y		Y					
"csite.SPILL.RLS.near.dist"	Y	Y	Y			Y	Y		Y
"localinv.VSR.near.dist"		Y		Y					
"localinv.CARD.near.dist"	Y	Y		Y					
"npdes.near.dist"		Y							
"localinv.UST.near.dist"	Y		Y						
"localinv.WSPS.near.dist"	Y	Y		Y					
"SYSTEM.TYP"				Y	Y				
"WELL.TYPE"					Y	Y	Y		
"POPULATION"				Y	Y				
"YIELD"					Y	Y	Y		
"SOURCE.TYP"					Y				
"X10ft.into.Bedrock"					Y	Y	Y		
"WELL.DEPTH"					Y	Y	Y		
"floodplain"		Y		Y	Y				Y
"RFG.county"				Y					
"bedrock.ty"					Y	Y			
"WHPA.Acres"					Y				Y
"PDENSITY"				Y					
"Spot"					Y				
"New.System.Categories"				Y	Y				Y
"BR.Depth"					Y				
"nwi"		Y		Y	Y				Y
"Well.Intake"					Y				Y
"BR.GW.Depth"			Y		Y	Y			
"PCSs"									Y
"OverburdenDepth"					Y	Y	Y		
"Septics"									Y
"KCSs"									Y
"Ag.LC"				Y					Y
"Highways"		Y		Y					Y
"Urban.LC"				Y	Y				Y
"Sanitary.radius"									Y
"BUW"					Y				Y
"COP"									Y
"ENF"									Y
"BWC"					Y				Y
"FPH"		Y			Y				Y
"DWC"					Y				Y
"HWR"		Y							Y
"FLW"		Y			Y				Y
"PCS"									Y
"HPH"									Y
"SIG"									Y
"MIN"									Y
"VLT"		Y			Y				Y
"SAN"		Y			Y				Y
"SPA"									Y
"TOTAL"									Y
"Range.category"					Y		Y		
"X2003.Ave.GPM"					Y	Y	Y		Y
"Chloride.min"		Y							

Table 8-4
Categories for Pathway Analyses

Risk Factors	Categories for Grouping Risk Factors								
	GW Pathway	SW Pathway	Tanks as Potential Sources	Geopolitical Factors	Well Construction & Operation	BR Lineament Pathway	Overburden Pathway	Potential Sources in WHPA	Best Management Practices
"Chloride.avg"		Y							
"Chloride.max"		Y							
"Sodium.max"		Y							
"Sodium.min"		Y							
"Sodium.avg"		Y							
"GWHIs.per.WHPA"	Y	Y						Y	
"GWHIs.BR.btwn10.25"						Y	Y	Y	
"GWHIs.Sat.under10"							Y	Y	
"GWHIs.BR.under10"						Y	Y	Y	
"GWHIs..Trans.under2000"							Y	Y	
"GWHIs.BR.over25"						Y	Y	Y	
"GWHIs..GS.OverWell"		Y					Y	Y	
"GWHIs..Sat.over10"							Y	Y	
"GWHIs..GW.overWell"	Y					Y		Y	
"GWHIs..Trans.over2000"							Y	Y	
"GWHIs..OB.GW.overWell"	Y						Y	Y	
"GWHIs..GS.UnderWell"							Y	Y	
"GWHIs..Equal.Well.Lineaments"						Y		Y	
"GWHIs..GW.underWell"	Y					Y		Y	
"GWHIs..Risk.4"	Y	Y						Y	Y
"GWHIs..OB.GW.underWell"	Y						Y	Y	
"GWHIs..Risk.1.3"	Y					Y	Y	Y	Y
"GWHIs..Risk.5.6.7"	Y					Y	Y	Y	Y
"R.SITEs...R.AREAs..perWHPA"	Y	Y		Y				Y	
"R.SITEs...R.AREAs..BR.btwn10.25"								Y	
"R.SITEs...R.AREAs..GS.overWell"		Y						Y	
"R.SITEs...R.AREAs..BR.under10"								Y	
"R.SITEs...R.AREAs..GW.overWell"	Y							Y	
"R.SITEs...R.AREAs..BR.over.25"								Y	
"R.SITEs...R.AREAs..OB.GW.overWell"	Y							Y	
"R.SITEs...R.AREAs..GS.underWell"		Y						Y	
"R.SITEs...R.AREAs..Sat.over10"				Y				Y	
"R.SITEs...R.AREAs..GW.underWell"	Y							Y	
"R.SITEs...R.AREAs..Trans.over2000"				Y				Y	
"R.SITEs...R.AREAs..OB.GW.underWell"	Y							Y	
"R.SITEs...R.AREAs..equals.WellLine"								Y	
"R.SITEs...R.AREAs..Sat.under10								Y	
"R.SITEs...R.AREAs..Trans.under2000"								Y	
"PCSs.BR.under10"								Y	
"PCSs.BR.over25"								Y	
"PCSs.per.WHPA"	Y	Y						Y	
"PCSs.Sat.over10"				Y				Y	
"PCSs.BR.btwn10.25"								Y	
"PCSs.Trans.over2000"				Y				Y	
"PCSs.Sat.under10"								Y	
"PCSs.GS.UnderWell"		Y						Y	
"PCSs.Trans.under2000"								Y	
"PCSs.GW.underWell"	Y							Y	
"PCSs.GS.OverWell"		Y						Y	
"PCSs.OB.GW.underWell"	Y							Y	
"PCSs.GW.overWell"								Y	
"UST..PerWHPA"	Y		Y	Y				Y	
"PCSs.OB.GW.overWell"								Y	
"UST..BR.btwn10.25"			Y					Y	
"PCSs.Equal.Well.Lineaments"								Y	
"UST..GS.overWell"			Y					Y	
"UST..BR.under10"			Y					Y	
"UST..GW.overWell"	Y		Y					Y	
"UST..BR.over.25"			Y					Y	
"UST..OB.GW.overWell"	Y		Y					Y	
"UST..GS.underWell"		Y	Y					Y	
"UST..Sat.over10"			Y	Y				Y	
"UST..GW.underWell"	Y		Y					Y	
"UST..Trans.over2000"			Y	Y				Y	
"UST..OB.GW.underWell"	Y		Y					Y	
"UST..equals.WellLine"			Y					Y	
"UST..Sat.under10"	Y		Y					Y	
"UST..withoutVAC2"			Y					Y	
"UST..Trans.under2000"			Y					Y	
"UST..withoutFCP"			Y					Y	
"UST..withVAC2"			Y					Y	
"UST..withoutDBLWALL"			Y					Y	
"UST..withFCP"			Y					Y	
"UST..withOTHER"			Y					Y	
"UST..withDBLWALL"			Y					Y	

Table 8-4
Categories for Pathway Analyses

Risk Factors	Categories for Grouping Risk Factors								
	GW Pathway	SW Pathway	Tanks as Potential Sources	Geopolitical Factors	Well Construction & Operation	BR Lineament Pathway	Overburden Pathway	Potential Sources in WHPA	Best Management Practices
"AST..BR.under10"			Y					Y	
"UST..withGAS"			Y					Y	
"AST..BR.over25"			Y					Y	
"AST..per.WHPA"	Y	Y	Y					Y	
"AST..Sat.over10"			Y	Y				Y	
"AST..BR.btwn10.25"			Y					Y	
"AST..Trans.over2000"			Y	Y				Y	
"AST..Sat.under10"	Y		Y					Y	
"AST..GS.UnderWell"		Y	Y					Y	
"AST..Trans.under2000"			Y					Y	
"AST..GW.underWell"	Y		Y					Y	
"AST..GS.OverWell"		Y	Y					Y	
"AST..OB.GW.UnderWell"	Y		Y					Y	
"AST..GW.OverWell"	Y		Y					Y	
"LUST..per.WHPA"	Y		Y	Y				Y	Y
"AST..OB.GW.OverWell"	Y		Y					Y	
"LUST..BR.btwn10.25"			Y			Y	Y	Y	Y
"AST..Equal.Well.Lineaments"			Y					Y	
"LUST..Sat.under10"			Y	Y			Y	Y	Y
"LUST..BR.under10"			Y			Y	Y	Y	
"LUST..Trans.under2000"			Y	Y			Y	Y	Y
"LUST..BR.over25"			Y			Y	Y	Y	
"LUST..GS.OverWell"			Y				Y	Y	Y
"LUST..Sat.over10"	Y		Y				Y	Y	
"LUST..GW.overWell"	Y		Y			Y		Y	Y
"LUST..Trans.over2000"			Y				Y	Y	
"LUST..OB.GW.overWell"	Y		Y				Y	Y	Y
"LUST..GS.UnderWell"		Y	Y				Y	Y	
"LUST..Equal.Well.Lineaments"			Y			Y		Y	Y
"LUST..GW.underWell"	Y		Y			Y		Y	
"LAST..BR.under10"			Y			Y	Y	Y	Y
"LUST..OB.GW.underWell"	Y		Y				Y	Y	
"LAST..BR.over25"			Y			Y	Y	Y	Y
"LAST..per.WHPA"	Y	Y	Y					Y	
"LAST..Sat.over10"			Y	Y			Y	Y	Y
"LAST..BR.btwn10.25"			Y			Y	Y	Y	
"LAST..Trans.over2000"			Y	Y			Y	Y	Y
"LAST..Sat.under10"			Y				Y	Y	
"LAST..GS.UnderWell"		Y	Y				Y	Y	Y
"LAST..Trans.under2000"			Y				Y	Y	
"LAST..GW.underWell"	Y		Y			Y		Y	Y
"LAST..GS.OverWell"		Y	Y				Y	Y	
"LAST..OB.GW.underWell"	Y		Y				Y	Y	Y
"LAST..GW.overWell"	Y		Y			Y		Y	
"JUNKYD..per.WHPA"	Y	Y		Y				Y	
"LAST..OB.GW.overWell"	Y		Y				Y	Y	
"JUNKYD..BR.btwn10.25"						Y	Y	Y	
"LAST..Equal.Well.Lineaments"			Y			Y		Y	
"JUNKYD..Sat.under10"							Y	Y	
"JUNKYD..BR.under10"						Y	Y	Y	
"JUNKYD..Trans.under2000"							Y	Y	
"JUNKYD..BR.over25"						Y	Y	Y	
"JUNKYD..GS.OverWell"		Y					Y	Y	
"JUNKYD..Sat.over10"							Y	Y	
"JUNKYD..GW.overWell"	Y					Y		Y	
"JUNKYD..Trans.over2000"							Y	Y	
"JUNKYD..OB.GW.overWell"	Y						Y	Y	
"JUNKYD..GS.UnderWell"		Y					Y	Y	
"JUNKYD..Equal.Well.Lineaments"						Y		Y	
"JUNKYD..GW.underWell"	Y					Y		Y	
"JUNKYD..OB.GW.underWell"	Y						Y	Y	
"VSR..BR.under10"								Y	
"VSR..BR.over25"								Y	
"VSR..per.WHPA"	Y	Y		Y				Y	
"VSR..Sat.over10"				Y				Y	
"VSR..BR.btwn10.25"								Y	
"VSR..Trans.over2000"				Y				Y	
"VSR..Sat.under10"								Y	
"VSR..GS.UnderWell"		Y						Y	
"VSR..Trans.under2000"								Y	
"VSR..GW.underWell"	Y							Y	
"VSR..GS.OverWell"		Y						Y	
"VSR..OB.GW.underWell"	Y							Y	
"VSR..GW.overWell"	Y							Y	
"VSR..OB.GW.overWell"	Y							Y	

Table 8-4
Categories for Pathway Analyses

Risk Factors	**Categories for Grouping Risk Factors**								
	GW Pathway	SW Pathway	Tanks as Potential Sources	Geopolitical Factors	Well Construction & Operation	BR Lineament Pathway	Overburden Pathway	Potential Sources in WHPA	Best Management Practices
"VSR..Equal.Well.Lineaments"								Y	
"WSPS.per.WHPA"	Y	Y		Y				Y	
"WSPS..BR.btwn10.25"								Y	
"WSPS..Sat.under10"								Y	
"WSPS..BR.under10"								Y	
"WSPS..Trans.under2000"								Y	
"WSPS..BR.over25"								Y	
"WSPS..GS.OverWell"		Y						Y	
"WSPS..Sat.over10"								Y	
"WSPS..GW.overWell"	Y							Y	
"WSPS..Trans.over2000"								Y	
"WSPS..OB.GW.overWell"	Y							Y	
"WSPS..GS.UnderWell"		Y						Y	
"WSPS..Equal.Well.Lineaments"								Y	
"WSPS..GW.underWell"	Y							Y	
"WSPS..OB.GW.underWell"	Y							Y	
"EEE..BR.under10"								Y	
"EEE..BR.over25"								Y	
"EEE..per.WHPA"	Y	Y		Y				Y	
"EEE..Sat.over10"				Y				Y	
"EEE..BR.btwn10.25"								Y	
"EEE..Trans.over2000"				Y				Y	
"EEE..Sat.under10"								Y	
"EEE..GS.UnderWell"		Y						Y	
"EEE..Trans.under2000"								Y	
"EEE..GW.underWell"	Y							Y	
"EEE..GS.OverWell"		Y						Y	
"EEE..OB.GW.underWell"	Y							Y	
"EEE..GW.overWell"	Y							Y	
"EEE..OB.GW.overWell"	Y							Y	
"EEE..Equal.Well.Lineaments"								Y	
"CARD..per.WHPA"	Y	Y		Y				Y	
"CARD..BR.btwn10.25"								Y	
"CARD..Sat.under10"								Y	
"CARD..BR.under10"								Y	
"CARD..Trans.under2000"								Y	
"CARD..BR.over25"								Y	
"CARD..GS.OverWell"		Y						Y	
"CARD..Sat.over10"								Y	
"CARD..GW.overWell"	Y							Y	
"CARD..Trans.over2000"								Y	
"CARD..OB.GW.overWell"	Y							Y	
"CARD..GS.UnderWell"		Y						Y	
"CARD..Equal.Well.Lineaments"								Y	
"CARD..GW.underWell"	Y							Y	
"CARD..OB.GW.underWell"	Y							Y	
"FUEL..BR.under10"			Y			Y	Y	Y	
"FUEL.BR.over.25"			Y			Y	Y	Y	
"FUEL.PerWHPA"	Y	Y	Y					Y	
"FUEL.GS.underWell"		Y	Y				Y	Y	
"FUEL.BR.btwn10.25"			Y			Y	Y	Y	
"FUEL.GW.underWell"	Y		Y			Y		Y	
"FUEL.GS.overWell"		Y	Y				Y	Y	
"FUEL.OB.GW.underWell"	Y		Y				Y	Y	
"FUEL.GW.overWell"	Y		Y			Y		Y	
"FUEL.Sat.under10"			Y				Y	Y	
"FUEL.OB.GW.overWell"	Y		Y				Y	Y	
"FUEL.Trans.under2000"			Y				Y	Y	
"FUEL.Sat.over10"			Y				Y	Y	
"FUEL.Trans.over2000"			Y				Y	Y	
"FUEL.equals.WellLine"			Y			Y		Y	
"OPUF..per.WHPA"	Y	Y	Y					Y	Y
"OPUF..BR.btwn10.25"			Y			Y	Y	Y	
"OPUF..Sat.under10"			Y				Y	Y	
"OPUF..BR.under10"			Y			Y	Y	Y	
"OPUF..Trans.under2000"			Y				Y	Y	
"OPUF..BR.over25"			Y			Y	Y	Y	
"OPUF..GS.OverWell"		Y	Y				Y	Y	
"OPUF..Sat.over10"			Y				Y	Y	
"OPUF..GW.overWell"	Y		Y			Y		Y	
"OPUF..Trans.over2000"			Y				Y	Y	
"OPUF..OB.GW.overWell"	Y		Y				Y	Y	
"OPUF..GS.UnderWell"		Y	Y				Y	Y	
"OPUF..Equal.Well.Lineaments"			Y			Y		Y	
"OPUF..GW.underWell"	Y		Y			Y		Y	

Table 8-4
Categories for Pathway Analyses

Risk Factors	**Categories for Grouping Risk Factors**								
	GW Pathway	SW Pathway	Tanks as Potential Sources	Geopolitical Factors	Well Construction & Operation	BR Lineament Pathway	Overburden Pathway	Potential Sources in WHPA	Best Management Practices
"OPUF..OB.GW.underWell"	Y		Y				Y	Y	
"SPILL..BR.under10"						Y	Y	Y	
"SPILL..BR.over.25"						Y	Y	Y	
"SPILL..PerWHPA"	Y	Y						Y	Y
"SPILL..GS.underWell"		Y					Y	Y	
"SPILL..BR.btwn10.25"						Y	Y	Y	
"SPILL..GW.underWell"	Y					Y		Y	
"SPILL..GS.overWell"		Y					Y	Y	
"SPILL..OB.GW.underWell"	Y						Y	Y	
"SPILL..GW.overWell"	Y					Y		Y	
"SPILL..Sat.under10"							Y	Y	
"SPILL..OB.GW.overWell"	Y						Y	Y	
"SPILL..Trans.under2000"							Y	Y	
"SPILL..Sat.over10"							Y	Y	
"SPILL..Trans.over2000"							Y	Y	
"SPILL..equals.WellLine"						Y		Y	
"IRSPILL..PerWHPA"	Y	Y						Y	Y
"IRSPILL.BR.btwn10.25"						Y	Y	Y	
"IRSPILL..GS.overWell"		Y					Y	Y	
"IRSPILL..BR.under10"						Y	Y	Y	
"IRSPILL..GW.overWell"	Y					Y		Y	
"IRSPILL..BR.over.25"						Y	Y	Y	
"IRSPILL..OB.GW.overWell"	Y						Y	Y	
"IRSPILL..GS.underWell"		Y					Y	Y	
"IRSPILL..Sat.over10"							Y	Y	
"IRSPILL..GW.underWell"	Y					Y		Y	
"IRSPILL..Trans.over2000"							Y	Y	
"IRSPILL..OB.GW.underWell"	Y						Y	Y	
"IRSPILL..equals.WellLine"						Y		Y	
"IRSPILL..Sat.under10"							Y	Y	
"IRSPILL..Trans.under2000"							Y	Y	
"MOST..BR.under10"			Y			Y	Y	Y	
"MOST..BR.over.25"			Y			Y	Y	Y	
"MOST.PerWHPA"	Y	Y	Y					Y	
"MOST..GS.underWell"		Y	Y				Y	Y	
"MOST..BR.btwn10.25"			Y			Y	Y	Y	
"MOST..GW.underWell"	Y		Y			Y		Y	
"MOST..GS.overWell"		Y	Y				Y	Y	
"MOST..OB.GW.underWell"	Y		Y				Y	Y	
"MOST..GW.overWell"	Y		Y			Y		Y	
"MOST..Sat.under10"			Y				Y	Y	
"MOST..OB.GW.overWell"	Y		Y				Y	Y	
"MOST..Trans.under2000"			Y				Y	Y	
"MOST..Sat.over10"			Y				Y	Y	
"MOST..Trans.over2000"			Y				Y	Y	
"MOST..equals.WellLine"			Y			Y		Y	
"LEAKS.SPILLS..PerWHPA"	Y	Y						Y	Y
"LEAKS.SPILLS..BR.btwn10.25"						Y	Y	Y	
"LEAKS.SPILLS..GS.overWell"		Y					Y	Y	
"LEAKS.SPILLS..BR.under10"						Y	Y	Y	
"LEAKS.SPILLS..GW.overWell"	Y					Y		Y	
"LEAKS.SPILLS..BR.over.25"						Y	Y	Y	
"LEAKS.SPILLS..OB.GW.overWell"	Y						Y	Y	
"LEAKS.SPILLS..GS.underWell"		Y					Y	Y	
"LEAKS.SPILLS..Sat.over10"							Y	Y	
"LEAKS.SPILLS..GW.underWell"	Y					Y		Y	
"LEAKS.SPILLS..Trans.over2000"							Y	Y	
"LEAKS.SPILLS..OB.GW.underWell"	Y						Y	Y	
"LEAKS.SPILLS..equals.WellLine"						Y		Y	
"LEAKS.SPILLS..Sat.under10"							Y	Y	
"LEAKS.SPILLS..Trans.under2000"							Y	Y	
"WHPA Roads"		Y		Y	Y			Y	
"WHPA Trails"		Y		Y	Y			Y	
"Lineament<200 ft"	Y		Y		Y	Y			
"Lineament<1000 ft"					Y	Y			
Category TOTALS	**117**	**87**	**128**	**50**	**35**	**85**	**133**	**286**	**57**

categories. Many variables were included in several categories. Although statistical modeling was performed incorporating all of the parameters at once, additional statistical modeling was also performed on the nine subsets of the parameters that made up the different pathways. The number of different pathways for which a parameter demonstrated a significant correlation with the presence of MtBE was considered to be one indication of its importance as a predictive factor. By dividing the data into multiple pathways, the effects of one variable would be less likely to mask the effects of another. A discussion of the reasoning for including specific variables in each category, and examples of the types of variables included is discussed below.

Groundwater Pathway: This analysis evaluated parameters that would be expected to influence migration of contamination through the groundwater pathway, and excluded parameters related to operation and maintenance of the water systems, parameters related to the surface water pathway, and political factors such as type of community served. Included in this pathway were parameters such as distances to nearest potential sources, numbers of various types of potential sources within the WHPA, and information regarding whether the potential sources were likely to be upgradient or downgradient of the well (as inferred from the ground surface and groundwater elevations).

Surface Water Pathway: This analysis attempted to evaluate parameters related to surface discharges or parameters that would influence migration of contamination via surface runoff or surface water bodies. Included in this pathway were parameters such as distances to, and presence in the WHPA of, potential surface discharge sources [National Pollutant Discharge Elimination System (NPDES), AST, UST, RCRA sites, roads, trails, spills, miscellaneous GWHI and PCS], whether the potential sources were upslope of the well (as inferred from ground surface elevation), well integrity factors (well seals, stickup), sodium and chloride concentrations, and whether the well was located in a wetland or a flood plain. Underground storage tanks were included from the standpoint of potential spills during filling or pumping gas.

Tanks as Potential Sources: Included in this category were all parameters related to all types of tanks (AST, UST, OPUF, MOST, etc.). Information such as distances to nearest, number of various types of tanks present in WHPA, the likelihood of the tanks being upgradient or upslope of the well (inferred from elevations), as well as hydrogeologic parameters that could influence movement of MtBE from the contaminant source to the well (transmissivity, depth-to-bedrock, saturated thickness, etc.) were included.

Geopolitical Factors: This analysis was performed to evaluate the significance of various geographical, cultural, or political factors on the likelihood of MtBE being present in wells. Hydrogeologic factors or parameters related to the construction or operation of the wells were generally not included in this analysis. Parameters included in this category were location coordinates, distance to nearest, and linear ft within WHPA of roads and trails; distance to nearest and number within WHPA of certain types of land uses such as junkyards, RCRA sites, car dealerships, vehicle service and repair shops. Urban and agricultural land cover, category of PWS system (i.e., condominium, single family residences, industrial, etc.) were also included in this category.

Well Construction and Operation: The purpose of evaluating this pathway was to look for significant correlations between the construction or operation of a well and the likelihood of that well becoming contaminated with MtBE. Included in this category were parameters such as type of well (bedrock, gravel packed, etc.), well depth, well yield, population served by well, bedrock type, WHPA size, whether it is located in a floodplain or wetland, various sanitary survey violations, average water use by the registered water users, and distances to nearest roads, trails, and lineaments.

Bedrock Lineament Pathway: This pathway was created to evaluate whether lineaments provided a preferred pathway for migration of MtBE contamination from a contaminant source to a PWS well. Therefore, distance to nearest sources and number of sources in WHPA were only included for known contaminant sources (LUST, LAST, remediation sites, various types of documented spills, etc.). Other parameters considered for this pathway included well type and construction information and hydrogeologic setting (depth-to-bedrock, distance to nearest lineaments, whether the well and the MtBE source shared the same nearest lineament).

Overburden Pathway: This pathway was created to evaluate whether overburden aquifer conditions impacted the migration of MtBE contamination from known contaminant sources to a PWS well. As for the Bedrock Lineament Pathway, distance to nearest sources, and number of sources in WHPA were only included for known contaminant sources. Well type and construction information was also included. However, the major difference was the inclusion of overburden aquifer characteristics such as transmissivity, thickness of saturated overburden, depth-to-groundwater, and depth-to-bedrock.

Potential Sources in WHPA: The purpose of this pathway analysis was to evaluate whether the presence within the WHPA of particular types of potential sources of MtBE were more likely than others to be correlated with MtBE contamination in a well. This category focused on the number and types of various potential contaminant sources in the WHPA and the hydrogeologic setting at the location of these potential sources. All known and potential contaminant sources in the WHPA were included. Whether the potential sources were likely to be upgradient or downgradient of the PWS well was inferred from ground surface and groundwater elevations at the well and potential contaminant source.

Best Management Practices: This category used the data from the NHDES sanitary and PWSA surveys to evaluate if violations or relative rankings of potential contaminant sources near a PWS were a good predictor of MtBE contamination in the well. In addition to the survey parameters, this evaluation included whether the well was located in a wetland or floodplain, the size of the WHPA, the type of community served by the well, the average water usage of registered water users, whether there were documented leaks or spills or groundwater hazard inventory sites with Risks of 1, 3, 4, 5, 6, or 7 in the WHPA (see descriptions of these risk levels in the metadata for GWHI in Appendix B).

8.3 TREND ANALYSIS

An analysis of trends in the numbers of wells impacted by MtBE contamination and the MtBE concentrations in impacted wells was performed by UNH. Three types of analyses were performed to evaluate whether the problem of MtBE contamination in PWS wells/sources has been improving or worsening over the past few years. The first was to calculate statewide annual mean MtBE concentrations including all of the wells/sources in the WSEB Analytical Database. The second method was to calculate trends in MtBE concentrations using the Kendall's Trend Test for each of the individual wells where sufficient data were available. The third method was to evaluate the number of new instances of MtBE detections in PWS wells/sources discovered each year, the number of wells/sources previously contaminated with MtBE that were resolved each year, and the running total number of wells with unresolved MtBE contamination issues.

8.3.1 Statewide Annual Mean MtBE Concentrations

The annual mean MtBE concentrations for all of the wells in the WSEB Analytical Database were calculated. Since wells with MtBE detections are generally sampled more frequently than other wells, an average yearly concentration was calculated for each individual well or blend before calculating the yearly average for all wells and blends. Although the frequency of MtBE detections in PWS wells appears to be increasing during the years 1999 through 2004, when the non-detect wells are deleted from the data set, the average concentration in the detect wells has remained nearly constant. Therefore, although the number of PWS wells being impacted by MtBE has been increasing in recent years, MtBE concentrations in the impacted wells do not appear to have been increasing. However, this may be a result of some of the impacted wells with the highest concentrations being taken out of service and no longer sampled.

8.3.2 Kendall's Trend Test

A trend analysis of individual wells/sources was conducted on data from the WSEB Analytical Database from the years 1993 through 2004. Kendall's Trend Test was used to evaluate each of the wells that had at least one detection of MtBE and had at least four sample records in the database. Of the 1,482 wells, 500 were ineligible for Kendall's Trend Test because of insufficient number of samples (less than four), 900 wells showed no trend, 36 wells showed a positive or increasing trend, and 46 wells showed a negative or decreasing trend.

Plots for each of the wells (date verses log (MtBE concentration)) are provided in UNH's *Report on Status and Trends of MtBE in Public NH Water Sources* provided in Appendix F. Whether the wells exhibited an increasing, decreasing, or no trend, the graphs of the data tended to be "spiky" rather than showing smooth gradual increasing or decreasing trends. This is probably at least partially attributable to MtBE's high solubility and low retardation factor which results in MtBE moving through the subsurface as quickly as the groundwater in which it is dissolved. It may also indicate that most releases of MtBE tend to be more intermittent than continuous.

8.3.3 Annual Status of Individual Wells

To further evaluate annual trends in the severity of MtBE contamination in PWS sources in the state, the number of new cases of MtBE detections, the number of PWS sources in the state, the number of cases resolved each year (closed cases), and a running total of PWS sources with continuing MtBE detections (open cases) were evaluated. Table 8-5 provides a summary of the new, closed, and open cases of MtBE detections for each year from 1993 to 2004. For the purposes of this evaluation, at least two consecutive non-detects after at least one detection of MtBE were required at the end of the record for a well to be considered a "closed case". However, if a well had a detection of MtBE after two or more consecutive non-detects, it was still considered to be an "open" case.

Also included in Table 8-5 is an estimated yearly tally of wells that were taken out of service (put on "inactive" status) because of MtBE detections. Since the WSEB database records were not always specific with regard to the reason why a well was taken out of service, this list was devised by identifying the wells that were taken out of service that had previously had detections of MtBE (either as a unique sample collected from the individual well, or as part of a blended sample from multiple wells within a water supply system). Based on this analysis, an estimated total of 83 PWS wells were taken out of service between 1993 and 2004 because of MtBE contamination.

The total number of new cases peaked in 1999, but the total number of open cases has been increasing steadily each year, with the exception of 2004, during which the number of open cases dropped from 189 to 187. One possible reason for the leveling off/decrease of the "new" and "open" cases is the change in underground storage tank regulations beginning in 1998. The new regulations require double containment for all tank replacements and new installations. During interviews, NHDES personnel who handle remediation sites indicated that there have been fewer large volume releases of petroleum product from UST with double containment, and the frequency of occurrence of free product on the water table has diminished.

8.3.4 Seasonal Trends

UNH also evaluated seasonal trends in the MtBE data to determine if sample collection during certain months or seasons of the year impacted the magnitude of the concentrations detected.

Table 8-5
Annual Statewide Status of Wells with MtBE Contamination

Year	Number of Wells with New Detections of MtBE ("New Cases")	Number of Previously Contaminated Wells that No Longer have MtBE Detections [(1)] ("Closed Cases")	Running Total of Wells with Unresolved MtBE Contamination ("Open Cases")	Total Number of Wells with MtBE DetectsTaken Offline
1993	20	1	19	0
1994	6	1	24	6
1995	8	1	31	4
1996	27	0	58	6
1997	29	0	87	5
1998	36	0	123	8
1999	56	31	148	7
2000	36	18	166	14
2001	26	20	172	9
2002	25	14	183	5
2003	34	28	189	14
2004	22	24	187	5

Note (1): Wells are considered "Closed Cases" if 2 consecutive rounds of non-detections followed any detections of MtBE.

When all sample data were included (non-detects and detects) and data were evaluated on a monthly basis, July samples exhibited the highest mean concentrations and December samples exhibited the lowest mean concentrations. When evaluated on a seasonal basis, summer (July, August, and September) samples exhibited the highest mean concentrations and fall (October, November, and December) samples exhibited the lowest mean concentrations. July/summer tends to be a period of low rainfall and lowered water table elevations, but high water usage. MtBE contamination present in the subsurface may be more likely to be drawn into water supply wells during this time, and less likely to be diluted by infiltration. Surface water supplies would be more susceptible to contamination by boating activities during the summer.

When this analysis was repeated using only samples with detections, the seasonal variations were less significant, but similar. July/summer sample collection continued to produce the highest MtBE results, but similarly low MtBE results were observed both in the spring and fall. More details on the seasonal analysis are provided in Appendix F.

8.4 PREDICTIVE MODELING

One of the goals of this study was to develop a model that would be able to predict whether or not a PWS well was likely to become contaminated with MtBE. A statistical analysis was performed by UNH to identify parameters that were significantly correlated with the presence of MtBE in PWS wells and to develop a predictive model incorporating these parameters that could be used by NHDES or PWS owners/operators to evaluate whether their well was at risk of becoming contaminated with MtBE. The following subsections describe the methodology used to identify the significant parameters and to develop predictive models.

8.5 PRELIMINARY DATA PREPARATION FOR PREDICTIVE MODELING

Upon receipt of the data from WESTON, UNH evaluated the data for use in the statistical analysis. A total of 359 parameters (potential risk factors) were provided to UNH; however, not all of the parameters were available for all of the PWS wells. There were an insufficient number of entries to conduct a statistical analysis on some of the parameters. The data fields for these parameters were removed from the database. Data in some of the categories of “number of potential sources in WHPA" data were converted to a "yes" or "no" format, if there were fewer than four non-zero entries in a category.

When fitting regression models, it is important to avoid using predictors that have a few very "high influence" points that could spuriously inflate the regression coefficients. A simple method to avoid high influence points is transforming predictor variables that have a highly skewed distribution to a scale that has roughly a symmetric distribution. We found that overall for the nearest distance variables, the square root transformation worked well for this purpose. The logarithm transformation tended to overcorrect and produce extreme values on the negative for the nearest distance variables, but was useful for some of the other variables.

The distribution of two variables, POPULATION and YIELD were highly skewed and were transformed to the log base 10 scale for the statistical analysis. These transformations were performed to reduce or eliminate the biasing influence of a handful of extreme high values present in the original scale of these variables. After trimming down the database, a total of 187 potential risk factors remained. More details on data preparation and the list of parameters included in the statistical analysis are provided in Chapter 1 of UNH's report "*MtBE Study: Risk Factor Identification*" provided in Appendix G.

8.6 VARIABLE SELECTION ROUTINES

Two types of models/variable selection routines were used to evaluate (1) whether or not MtBE was detected in a well, and (2) the maximal level of MtBE measured in a well. The two variable selection routines are (i) classification and regression trees (CART), and (ii) stepwise regression modeling. This resulted in four analyses for the full data set and for each of the nine pathways described above.

8.6.1 Classification and Regression Trees

A classification tree consists of a series of successive splits of the parameters to sort the data. At each split, important variables that predict an MtBE detect (denoted by "y") or an MtBE non-detect (denoted by "n") are identified. The CART algorithm searches among all candidate variables at each step and all possible splits and finds the variable/split combination that best predicts the correct outcome ("y" or "no" for MtBE detect). The result of the CART analysis is best summarized by a graph (See Figure 8-1). The graph depicts the splits as decision statements followed by two branches (left if condition is true, right if condition is false). The higher the parameter is on the decision tree, the number of times the parameter is "split", and the lengths of the vertical branches representing the parameter are indications of the importance of the parameter in the predictive model.

Figure 8-1 shows the classification tree for the Bedrock Lineament Pathway. A total of 1304 wells were included in this classification tree. Note that the parameter "GWHI..Equal.well.lineaments" shows up at the top of the classification tree. This first split separates wells into two categories: those for which "<0.5 GWHI..Equal.Well.Lineaments" is a true statement (the left branch) predicting "n" for non-detect, and those wells for which this statement is false (the right branch). This indicates that 802 wells fall into the category represented by the far left branch; 690 of the 802 did not have MtBE detects, and 112 did have MtBE detects. This first split, "GWHI..Equal.Well.Lineaments <0.5" splits the data between those wells that had zero groundwater hazard inventory sites (remediation sites) within their WHPA sharing the same nearest lineament and those that had one or more remediation sites sharing the same nearest lineament. Wells that fell into the right branch are subsequently further sorted. The next split is "GWHI..Equal.Well.Lineaments <2.5. This second split sorts the data into wells with one or two remediation sites within their WHPA sharing the same lineament (left branch), and wells with three or more remediation sites within their WHPA sharing the same lineament (right branch). The sorting process continues, with the wells falling into the lower right branches having a higher and higher probability of MtBE detects at each step. The classification tree correctly predicts "y" for MtBE detects for 9 out of 9 wells falling into the right branch on the final split at the bottom of the classification tree. Other parameters that appear to be important predictors of MtBE detects based on this particular model include the distances to nearest remediation site, initial response spill, and LAST; and well depth.

A regression tree uses the same type of algorithm as a classification tree. The only difference is that the response is not a "yes" or "no" for detection of MtBE, but rather a prediction of the maximum MtBE concentration. The values at the final nodes of the tree are the predicted averages of the maximum concentrations of MtBE in the wells that were sorted into that "branch" of the regression tree. Figure 8-2 is an example of a regression tree for the Bedrock Lineament Pathway. The expression "n=760" at the far left terminal node indicates that

Figure 8-1

Bedrock Lineament Pathway: Classification Tree

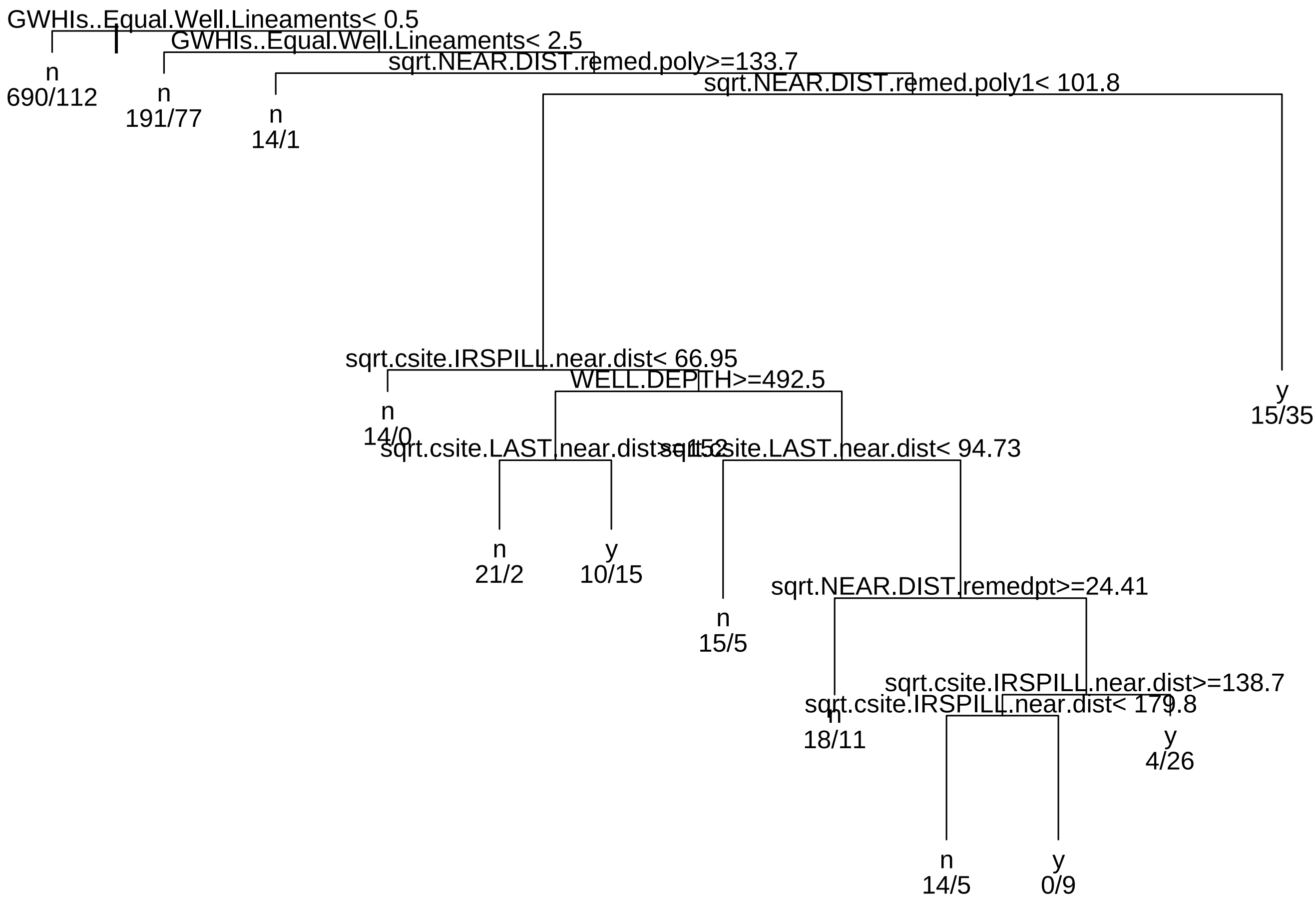
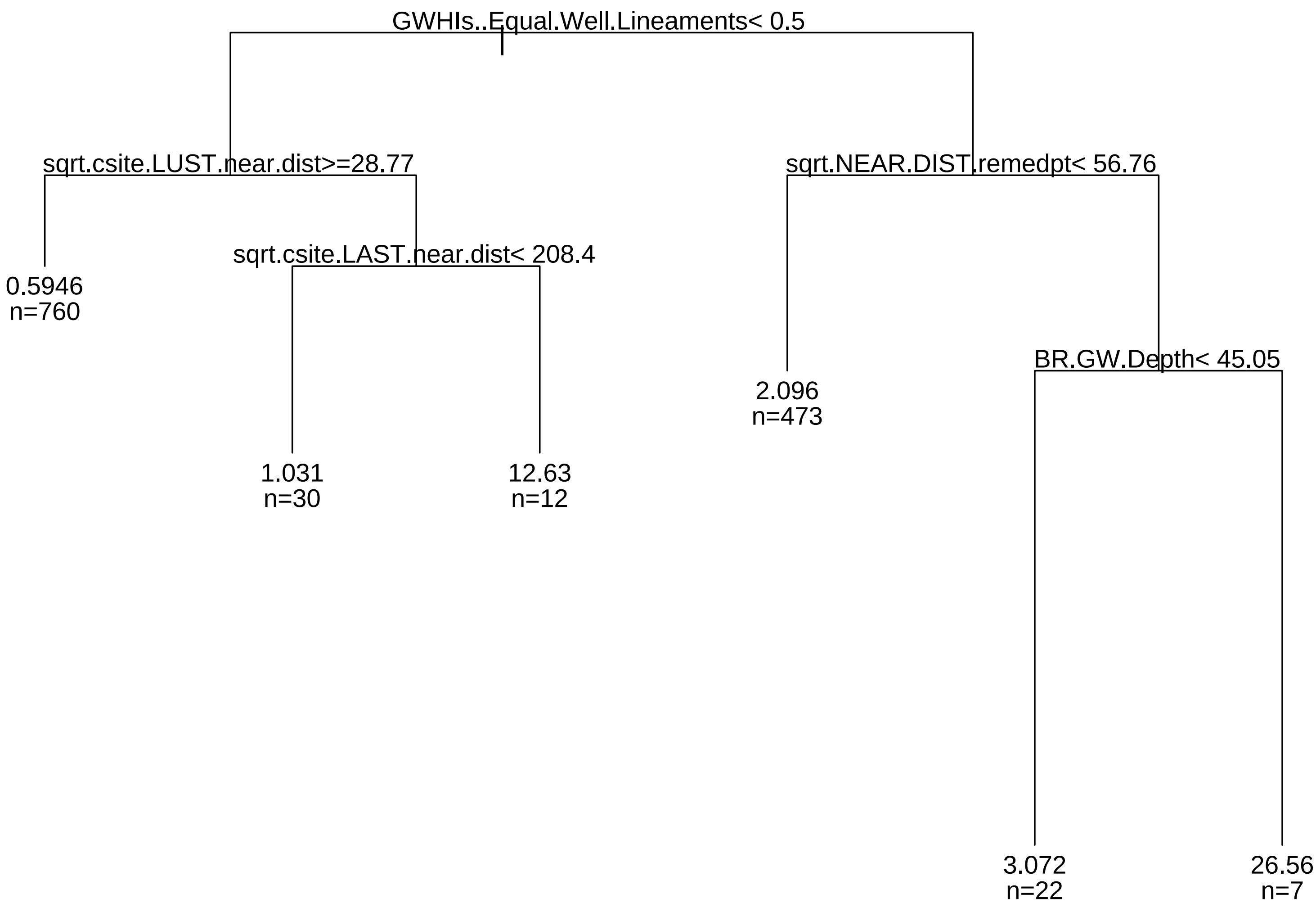


Figure 8-2

Bedrock Lineament Pathway: Optimal Regression Tree for Max MtBE



760 wells fell into the far left branch of the regression tree. The average concentration of those 760 wells was 0.5946. All of the wells that fell into the far left branch had less than 0.5, that is, no GWHIs in their WHPA that shared the same nearest lineament and the square root of the distance to the nearest LUST was greater than or equal to 28.77 ft.

One advantage of using CART analysis is that it can be used to perform an analysis on a data set with missing values. Not all parameters were available for every well in the data set used for this study. The CART allowed data, such as well yield or PWSA survey data, to be included in the analysis even though this data was not available for all wells.

8.6.2 Stepwise Logistic and Stepwise Linear Regression

Logistic regression is part of a category of statistical models called generalized linear models. Logistic regression allows one to predict a discrete outcome, such as group membership, from a set of variables that may be continuous, discrete, dichotomous, or a mix of any of these. Generally, the dependent or response variable is dichotomous, such as presence/absence or success/failure. In this study, the dependent variable is "yes" or "no" for detection of MtBE and the independent or predictor variables are the potential risk factors listed in Tables 8-1, 8-2, and 8-3. The goal of logistic regression is to create a model to correctly predict the category of outcome for individual cases. To accomplish this goal, a model is created that includes all predictor variables that are useful in predicting the response variable. Several different options are available during model creation. Variables can be entered into the model in the order specified by the researcher or logistic regression can test the fit of the model after each coefficient is added or deleted, called stepwise regression.

Stepwise logistic regression models were applied for the classification of wells as either detect or non-detect for MtBE. The model tries to predict the probability of detection of MtBE. A fitted model describes the contribution of potential risk factors to the natural logarithm (ln) of the odds ratio:

$$\ln \{Prob(detect)/(1 - Prob(detect)\}.$$

For example if variable x enters the model linearly with coefficient 0.5, then exp (0.5) = 1.649 is the multiplicative contribution to the odds ratio. (Using this example of a linear relationship, if the variable increases in value by 1, the coefficient would increase by 0.5. However, for many of the variables, the relationship between the value of the variable and its coefficient were not linear.) Taking the exponent of the coefficient then gives the contribution to the odds ratio. A multiplicative contribution to the odds ratio of 1.649, as shown in this example, means that the odds of a detect would be increased by 164.9% as a result of an increase of 1 in the value of this variable. Each "important" variable contributes to the overall odds ratio for a well (the likelihood that there will be an MtBE detection in that well). The probability of detection for a particular well is a nonlinear function of the contributions of each of the "important" variables. The risk factors that were found to significantly contribute to correct prediction of MtBE detections are listed in Table 8-6 for each of the pathways analyzed.

Stepwise linear regression models were applied for predicting log of maximum MtBE for the reduced set of wells (n = 298) that had at least one MtBE detection. These models identify risk factors that are significantly correlated with levels of MtBE above the detection limit. The logarithm transform was required to better conform with linear regression model assumptions and to reduce the biasing effect of a few very extreme cases with very high maximum MtBE levels. The purpose of this analysis was to complement the logistic model variable selection; the former mainly tries to correctly predict the majority of the 77% of non-detect cases, but variables associated with high MtBE levels are likely to be masked. Risk factors that were identified as being important in prediction of maximum levels of MtBE are listed in Table 8-7 for each of the pathways analyzed.

Stepwise regression methods require a full set of data. Missing values in any of the variables will require the elimination of that well. The initial data trimming produced a more balanced and reduced data set. However, for application of stepwise regression methods, additional data trimming was necessary by eliminating variables with more than 10 missing values to avoid elimination of two many cases (wells) for the model fitting.

8.6.3 Nonlinearities and Interactions

The statistical modeling did not take into account the temporal nature of the MtBE data. For the 11 year period evaluated (1993 to 2004), there was no consideration given to the dates that MtBE was detected or the fluctuations of concentrations in any particular well over time. This resulted in considerable noise in the data when attempting to associate the MtBE detection with risk

Table 8-6
Important Variables Identified by Pathway

Pathway:	All Pathways Combined	GW Pathway	SW Pathway	Tanks as Potential Sources	Geopolitical Factors
Important Variables	**GWHIs..Equal.Well.Lineaments**	**GWHIs.per.WHPA**	**GWHIs.per.WHPA**	**sqrt.csite.LUST.near.dist**	**New.System.Categories**
	sqrt.localinv.CARD.near.dist	**sqrt.localinv.CARD.near.dist**	**sqrt.localinv.CARD.near.dst**	**sqrt.localinv.UST.near.dist**	**log.POPULATION**
	New.System.Categories	**sqrt.localinv.AST.near.dist**	**PCSs.GS.OverWell**	**OPUF..GS.UnderWell**	**sqrt.localinv.CARD.near.dist**
	log.POPULATION	**sqrt.csite.OPUF.near.dist**	**log.Chloride.avg**	**sqrt.localinv.AST.near.dist**	**RFG.county**
	log.Chloride.avg	**sqrt.NEAR.DIST.remedpt**	**sqrt.npdes.near.dist**	**sqrt.csite.OPUF.near.dist**	**sqrt.RSITE.Near.Dist**
	PCSs.BR.btwn10.25	**sqrt.localinv.UST.near.dist**	**sqrt.localinv.AST.near.dist**	**sqrt.NEAR.DIST.UST**	**sqrt.localinv.WSPS.near.dist**
	sqrt.RSITE.Near.Dist	**sqrt.localinv.WSPS.near.dist**	**sqrt.NEAR.DIST.trail**	**UST..withoutDBLWALL**	**UST..PerWHPA**
	sqrt.npdes.near.dist	**UST..GW.underWell**	**sqrt.csite.IRSPILL.near.dist**	**LUST..GS.OverWell**	**UST..Sat.over10**
	sqrt.pws.near.lineaments.NEAR.DIST	**sqrt.ast.near.dist**	**OPUF..GS.UnderWell**	**sqrt.csite.LAST.near.dist**	**sqrt.RAREA.NEAR.Dist**
	sqrt.localinv.UST.near.dist	**sqrt.NEAR.DIST.remed.poly1**	**sqrt.localinv.WSPS.near.dist**	**UST..withGAS**	**LUST..per.WHPA**
	sqrt.csite.OPUF.near.dist	sqrt.NEAR.DIST.UST	**sqrt.csite.MOST.near.dist**	sqrt.csite.SPILL.RLS.near.dist	sqrt.localinv.EEE.near.dist
	sqrt.localinv.EEE.near.dist	sqrt.csite.FUEL.near.dist	**PCSs.per.WHPA**	UST..withFCP	sqrt.localinv.VSR.near.dist
	PCSs.GS.UnderWell	sqrt.RAREA.NEAR.Dist	sqrt.ast.near.dist	UST..GS.overWell	sqrt.pws.near.road.NEAR.DIST
	log.Sodium.min	sqrt.csite.MOST.near.dist	sqrt.csite.LAST.near.dist	sqrt.ast.near.dist	Y.COORD
	log.Chloride.max	RSITES...R.AREAs..GW.underWell	sqrt.pws.near.road.NEAR.DIST	UST..equals.WellLine	X.COORD
	LUST..GW.overWell	VSR..per.WHPA	sqrt.RAREA.NEAR.DIST	UST..GW.underWell	PCSs.Sat.over10
	sqrt.pws.near.road.NEAR.DIST	sqrt.csite.IRSPILL.near.dist	sqrt.RSITE.Near.Dist	UST..BR.btwn10.25	sqrt.junkyd.near.dist
	R.SITEs…R.AREAs..BR.over.25	sqrt.csite.SPILL.RLS.near.dist	sqrt.csite.FUEL.near.dist	UST..BR.under10	EEE..Sat.over10
	sqrt.junkyd.near.dist	sqrt.localinv.EEE.near.dist	sqrt.csite.OPUF.near.dist	OPUF..GS.OverWell	PDENSITY
	R.SITEs…R.AREAs..GS.overWell		sqrt.csite.SPILL.RLS.near.dist	OPUF..BR.over25	sqrt.NEAR.DIST.trail
	WELL.DEPTH		sqrt.localinv.EEE.near.dist	LUST..GS.UnderWell	
	sqrt.ast.near.dist		sqrt.localinv.VSR.near.dist	AST..GS.UnderWell	
	sqrt.localinv.WSPS.near.dist		R.SITEs…R.AREAs..perWHPA	sqrt.csite.FUEL.near.dist	
	sqrt.csite.MOST.near.dist		R.SITEs…R.AREAs..GS.underWell	Lineament..200.ft	
	KCSs		LUST..GS.UnderWell		
	sqrt.csite.SPILL.RLS.near.dist		VSR..GS.UnderWell		
			EEE..per.WHPA		
			LEAKS.SPILLS..PerWHPA		
Probability of Correct Predictions	**P(n) - 0.97**	**P(n) - 0.963**	**P(n) - 0.967**	**P(n) - 0.974**	**P(n) - 0.983**
	P(y) - 0.50	**P(y) - 0.473**	**P(y) - 0.376**	**P(y) - 0.332**	**P(y) - 0.279**

Table 8-6
Important Variables Identified by Pathway

Pathway:	Well Construction & Operation	BR Lineament Pathway	Overburden Pathway	Potential Sources in WHPA	Best Management Practices
Important Variables	**New.System.Categories**	**GWHIs.Equal.Well.Lineaments**	**GWHIs..Trans.under2000**	**GWHIs..Equal.Well.Lineaments**	**New.System.Categories**
	log.POPULATION	**sqrt.junkyd.near.dist**	**sqrt.NEAR.DIST.remedpt**	**GWHIs.per.WHPA**	**sqrt.csite.IRSPILL.near.dist**
	sqrt.pws.near.road.NEAR.DIST	**OPUF..BR.over25**	**OPUF..GS.UnderWell**	**PCSs.Trans.under2000**	**WHPA.Acres**
	WHPA.Acres	**sqrt.csite.LUST.near.dist**	**WELL.DEPTH**	**VSR..GW.underWell**	**TOTAL**
	WELL.DEPTH	**WELL.DEPTH**	**sqrt.csite.SPILL.RLS.near.dist**	**UST..Sat.over10**	**KCSs**
	log.YIELD	**OPUF..Equal.Well.Lineaments**	**LEAKS.SPILLS..GS.underWell**	**GWHIs..Sat.over10**	**SAN**
	Lineament..200.ft	**sqrt.csite.LAST.near.dist**	**GWHIs..Trans.over2000**	**PCSs.BR.under10**	**LUST..GS.OverWell**
	Spot	**sqrt.csite.OPUF.near.dist**	**sqrt.csite.OPUF.near.dist**	**PCSs.GS.OverWell**	sprt.csite.SPILL.RLS.near.dist
	Urban.LC	**sqrt.NEAR.DIST.remedpt**	**OPUF..GS.OverWell**	**LEAKS.SPILLS..GS.overWell**	Ag.LC
	BR.Depth	**sqrt.csite.FUEL.near.dist**	**LEAKS.SPILLS..Trans.under2000**	**LEAKS.SPILLS..BR.over25**	LEAKS.SPILLS..PerWHPA
	sqrt.pws.near.lineaments.NEAR.DIST	**sqrt.NEAR.DIST.remed.poly**	sqrt.NEAR.DIST.remed.poly1	**PCSs.Sat.over10**	Septics
	BR.GW.Depth	bedrock.ty	sqrt.csite.FUEL.near.dist	GWHIs..Trans.under2000	LUST..Trans.under2000
	sqrt.NEAR.DIST.trail	BR.GW.Depth	GWHIs..GS.UnderWell	GWHIs.BR.under10	
		OPUF..GW.underWell	sqrt.csite.LAST.near.dist	R.SITEs…R.AREAs..GS.underWell	
		SPILL..BR.over.25	sqrt.NEAR.DIST.remed.poly	PCSs.GS.UnderWell	
		sqrt.csite.IRSPILL.near.dist	sqrt.csite.LUST.near.dist	AST..BR.over25	
		sqrt.csite.MOST.near.dist	sqrt.csite.IRSPILL.near.dist	R.SITEs…R.AREAs..Sat.under10	
		sqrt.csite.SPILL.RLS.near.dist	GWHIs.BR.over25	LEAKS.SPILLS..equals.WellLine	
		sqrt.NEAR.DIST.remed.poly1	log.YIELD	GWHIs..GW.underWell	
			sqrt.junkyd.near.dist	GWHIs..GW.overWell	
			GWHIs.BR.btwn10.25	LEAKS.SPILLS..BR.btwn10.25	
			GWHIs..Sat.over10	PCSs.BR.over25	
			LUST..Trans.under2000	SPILL..PerWHPA	
			LUST..GS.OverWell	UST..BR.btwn10.25	
			OPUF..Trans.under2000	LUST..GS.OverWell	
				UST..withOTHER	
				R.SITEs…R.AREAs..BR.btwn10.25	
				R.SITEs…R.AREAs..GW.underWell	
				R.SITEs…R.AREAs..Sat.over10	
				PCSs.BR.btwn10.25	
				PCSs.Equal.Well.Lineaments	
				AST..GS.UnderWell	
				LUST..GW.underWell	
				VSR..Trans.under2000	
				VSR..GS.OverWell	
				WSPS.per.WHPA	
				OPUF..BR.over25	
				OPUF..GS.OverWell	
				OPUF..GS.UnderWell	
				LEAKS.SPILLS..PerWHPA	
				LEAKS.SPILLS..GS.underWell	
				UST..GW.underWell	
				UST..vithoutVAC2	
				UST..withFCP	
				UST..withoutFCP	
Probability of Correct Predictions	**P(n) - 0.979**	**P(n) - 0.971**	**P(n) - 0.96**	**P(n) - 0.961**	**P(n) - 0.976**
	P(y) - 0.191	**P(y) - 0.285**	**P(y) - 0.517**	**P(y) - 0.336**	**P(y) - 0.191**

Table 8-7
Importance of Variables in Predictive Model

PATHWAYS		ALL				Best-MGT				BR-Lineament				Geo-Political				GW				Overburden				Sources WHPA				SW				Tanks				Well Constr & Op			
Variable	Weighting Factor	ClasTree	Reg Tree	Logi Reg	Line Reg	ClasTree	Reg Tree	Logi Reg	Line Reg	ClasTree	Reg Tree	Logi Reg	Line Reg	ClasTree	Reg Tree	Logi Reg	Line Reg	ClasTree	Reg Tree	Logi Reg	Line Reg	ClasTree	Reg Tree	Logi Reg	Line Reg	ClasTree	Reg Tree	Logi Reg	Line Reg	ClasTree	Reg Tree	Logi Reg	Line Reg	ClasTree	Reg Tree	Logi Reg	Line Reg	ClasTree	Reg Tree	Logi Reg	Line Reg
sqrt.RAREA.NEAR.Dist	000													4			13	6			14											15	13								
sqrt.RSITE.Near.Dist	112		3	21										3	6		2				1											18	11								
X.COORD	000														9		8																								
Y.COORD	000			25												9	9																								
sqrt.NEAR.DIST.UST	001				14													5																8	3	5					
sqrt.NEAR.DIST.trail	001															12	10													7		3								5	
sqrt.pws.near.road.NEAR.DIST	011	7	8	26										7	7	6	7													6		9	14						2	4	3
sqrt.NEAR.DIST.remedpt	120									9	4	4	7							2	8		2	1	10																
sqrt.NEAR.DIST.remed.poly	000									6			4												14																
sqrt.pws.near.lineaments.NEAR.DIST	000		4		6																																		7		
Lineament..200.ft	001			22																8																7				3	
sqrt.junkyd.near.dist	011	20			19					3		2	11			7	5							10	8																
sqrt.ast.near.dist	000		9															8	4	5	7									5	5	11	12			19					
sqrt.csite.FUEL.near.dist	000									4			8					11			11				11							16	15				5				
sqrt.csite.IRSPILL.near.dist	102			27		4	3	1	1	8			13					7			6				12					3			16								
sqrt.csite.LAST.near.dist	001				13					5	3		5												13							20	19	4	4	20	6				
sqrt.csite.LUST.near.dist	220										2		9											7										1	1	2					
sqrt.csite.MOST.near.dist	000		7									7	10					13														4									
sqrt.csite.OPUF.near.dist	021	19										10	3					9			2		5	12	4							14	5		6		2				
sqrt.csite.SPILL.RLS.near.dist	002		6					6				8	12							9	9	3		11	9								9	7		21	3				
sqrt.localinv.AST.near.dist	031																	2		6										4	3	10		2	2	18	4				
sqrt.localinv.CARD.near.dist	410	15	1		2										1	11	11		1	10	10									8	1	13	17								
sqrt.localinv.EEE.near.dist	000	11												6			12				12											17	10								
sqrt.localinv.UST.near.dist	101		5	4														3		4	13													6	5	1					
sqrt.localinv.VSR.near.dist	000													8	5	10	6															19									
sqrt.localinv.WSPS.near.dist	002		10	28											3	8			3	7	5										4	12	18								
sqrt.npdes.near.dist	010	4			16																											2									
log.POPULATION	320	12		9	1									5		4	1																					2		2	1
SYSTEM.TYP	000			16																																					
WELL.DEPTH	022	6								2												2	3															3			
log.YIELD	001																						6																3		
RFG.county	021			3										2		2	4																								

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PATHWAYS		ALL				Best-MGT				BR-Lineament				Geo-Political				GW				Overburden				Sources WHPA				SW				Tanks				Well Constr & Op			
Variable	Weighting Factor	ClasTree	Reg Tree	Logi Reg	Line Reg	ClasTree	Reg Tree	Logi Reg	Line Reg	ClasTree	Reg Tree	Logi Reg	Line Reg	ClasTree	Reg Tree	Logi Reg	Line Reg	ClasTree	Reg Tree	Logi Reg	Line Reg	ClasTree	Reg Tree	Logi Reg	Line Reg	ClasTree	Reg Tree	Logi Reg	Line Reg	ClasTree	Reg Tree	Logi Reg	Line Reg	ClasTree	Reg Tree	Logi Reg	Line Reg	ClasTree	Reg Tree	Logi Reg	Line Reg
bedrock.ty	000			11								9																													
PDENSITY	000															5																									
sqrt.NEAR.DIST.remed.poly1	000									7			6					4							15																
New.System.Categories	820	5		1		1	1	2						1	2	1																						1	1	1	
WHPA.Acres	021				3			4	2																															6	2
Spot	000	13																																				4			
BR.GW.Depth	000										5																												5		
BR.Depth	000																																						6		
KCSs	010				8		2																																		
Septics	000						6																																		
Urban.LC	000																																						4		
Ag.LC	000						7																																		
SAN	001					3	4																																		
TOTAL	010					2																																			
log.Chloride.max	000	18																																							
log.Chloride.avg	020	2																												2											
log.Sodium.min	000	9																																							
GWHIs.per.WHPA	630																	1	2	1	4							1	1	1	2	1	2								
GWHIs.BR.under10	000																									15	6														
GWHIs.BR.btwn10.25	000																							9																	
GWHIs.BR.over25	000																						7																		
GWHIs..Sat.over10	002																								5	10	3	3													
GWHIs..Trans.under2000	220																					1	1	2	2	13															
GWHIs..Trans.over2000	001																								3																
GWHIs..GS.OverWell	000				4																																				
GWHIs..GS.UnderWell	000				7																				7																
GWHIs..GW.overWell	000				17																					20		23													
GWHIs..GW.underWell	000																									6			15												
GWHIs..Equal.Well.Lineaments	730	1	2	2						1	1	1	1													1	1	2													
R.SITEs...R.AREAs..perWHPA	000	16																															8								
R.SITEs...R.AREAs..BR.btwn10.25	000			10	11																							10	16												
R.SITEs...R.AREAs..BR.over.25	000	10																																							

Table 8-7
Importance of Variables in Predictive Model

PATHWAYS		ALL				Best-MGT				BR-Lineament				Geo-Political				GW				Overburden				Sources WHPA				SW				Tanks				Well Constr & Op			
Variable	Weighting Factor	ClasTree	Reg Tree	Logi Reg	Line Reg	ClasTree	Reg Tree	Logi Reg	Line Reg	ClasTree	Reg Tree	Logi Reg	Line Reg	ClasTree	Reg Tree	Logi Reg	Line Reg	ClasTree	Reg Tree	Logi Reg	Line Reg	ClasTree	Reg Tree	Logi Reg	Line Reg	ClasTree	Reg Tree	Logi Reg	Line Reg	ClasTree	Reg Tree	Logi Reg	Line Reg	ClasTree	Reg Tree	Logi Reg	Line Reg	ClasTree	Reg Tree	Logi Reg	Line Reg
R.SITEs...R.AREAs..GS.overWell	000	8																																							
R.SITEs...R.AREAs..GS.underWell	000			12	15																					8		17	10				7								
R.SITEs...R.AREAs..GW.underWell	000																	10											7												
R.SITEs...R.AREAs..Sat.over10	000			15																								25													
R.SITEs...R.AREAs..Sat.under10	000																									9			12												
PCSs.per.WHPA	000																																4								
PCSs.BR.under10	001																									3															
PCSs.BR.btwn10.25	001	3																										12													
PCSs.BR.over25	000																									7															
PCSs.Sat.over10	000														8														4												
PCSs.Trans.under2000	010			6																						2		4													
PCSs.GS.OverWell	101	14		17																								14	3				1								
PCSs.GS.UnderWell	000	21																								14															
PCSs.Equal.Well.Lineaments	000			18																								16													
AST..BR.over25	000																									18															
AST..GS.UnderWell	000				12																							19								6					
LUST..per.WHPA	000														4																										
LUST..BR.over25	000			19																																					
LUST..Trans.under2000	000							7																8																	
LUST..GS.OverWell	002			7				3																5		19		6								3					
LUST..GS.UnderWell	000																															5				17					
LUST..GW.overWell	000	17																																							
LUST..GW.underWell	000																												5												
VSR..per.WHPA	000																	14																							
VSR..Trans.under2000	000			8	5																							7													
VSR..GS.OverWell	000			5																								5													
VSR..GS.UnderWell	000																															7									
VSR..GW.underWell	010																									12	2		8												
WSPS.per.WHPA	000				18																							20													
EEE..per.WHPA	000																			12												6									
EEE..Sat.over10	000															13																									
EEE..GS.OverWell	000				10																																				

Table 8-7
Importance of Variables in Predictive Model

PATHWAYS		ALL				Best-MGT				BR-Lineament				Geo-Political				GW				Overburden				Sources WHPA				SW				Tanks				Well Constr & Op			
Variable	Weighting Factor	ClasTree	Reg Tree	Logi Reg	Line Reg	ClasTree	Reg Tree	Logi Reg	Line Reg	ClasTree	Reg Tree	Logi Reg	Line Reg	ClasTree	Reg Tree	Logi Reg	Line Reg	ClasTree	Reg Tree	Logi Reg	Line Reg	ClasTree	Reg Tree	Logi Reg	Line Reg	ClasTree	Reg Tree	Logi Reg	Line Reg	ClasTree	Reg Tree	Logi Reg	Line Reg	ClasTree	Reg Tree	Logi Reg	Line Reg	ClasTree	Reg Tree	Logi Reg	Line Reg
OPUF..BR.over25	010												2															11								15					
OPUF..Trans.under2000	000																								6																
OPUF..GS.OverWell	000																							4					17							9					
OPUF..GS.UnderWell	201																								1			13	14			8	3			14	1				
OPUF..GW.underWell	000											6								11																					
OPUF..Equal.Well.Lineaments	001											3																													
SPILL..PerWHPA	000																			13						11															
SPILL..BR.over.25	000			20								5																													
LEAKS.SPILLS..PerWHPA	000						5	5																				18					6								
LEAKS.SPILLS..BR.btwn10.25	000																									17															
LEAKS.SPILLS..BR.over.25	000			14																							4														
LEAKS.SPILLS..GS.overWell	000																									4		8													
LEAKS.SPILLS..GS.underWell	001			13																				3				9													
LEAKS.SPILLS..Trans.under2000	000				9																		4	6																	
LEAKS.SPILLS..equals.WellLine	000																									16															
UST..PerWHPA	002																3				3																				
UST..BR.under10	000																																			8					
UST..BR.btwn10.25	000																									5										11					
UST..GS.overWell	000				20																													5							
UST..GW.underWell	001			23														12		3								24	6							10					
UST..Sat.over10	011															3												21	2												
UST..equals.WellLine	000			24																																13					
UST..withoutVAC2	000																												9												
UST..withFCP	000																												13							12					
UST..withoutFCP	000																											22													
UST..withoutDBLWALL	001																																	3		16					
UST..withGAS	000																																			4					
UST..withOTHER	000																										5	15	11												

Note: Weighting Factor is a compilation of the number of times a variable was one of the top three important variables in a pathway. For example, a weighting factor of 112 means that the variable was identified as the most important variable in one pathway analysis, the second most important variable in one pathway analysis, and the third most important variable in two pathway analyses.

factors. For example, MtBE detected in a well at any time during the 11 year period would have been statistically associated with a release from a LUST in the WHPA that occurred before the detection and may have continued after the detection.

Furthermore, it is expected that risk factors are related in complicated ways through interactions between the variables. A release of MtBE at a nearby LUST site may be a risk factor, but only if the release was upgradient of the well (approximated in the study by relative ground surface elevation or groundwater elevation). This type of complicated relationship would exist because both a source of MtBE and a pathway from the source to the well must exist for the MtBE to enter the well. Several factors related to pathways (e.g., lineaments, transmissivity, groundwater elevation, etc.) could also be interrelated.

8.7 RESULTS OF PREDICTIVE MODELING

The results of the predictive modeling were very complex. As discussed in the previous subsection, the effect of many of the variables on predicting the presence or concentration of MtBE in a well is often dependent on the values of other variables in the model. In the presence of interacting variables, the effect of a variable on predicting MtBE presence or concentration can change and even reverse direction. For the purpose of this study, we have identified the "main" effects for each variable, although, there may be less frequent occasions when the reverse effect is observed. Further discussion of interacting variables is provided on Page 12 of "*MtBE Study: Risk Factor Identification*" in Appendix G.

For each of the pathways evaluated, the variables with the greatest effect in predicting the detection of MtBE in a well were identified. Table 8-6 lists the variables that were important in the individual models for each of the pathways. A variable was considered to be "important" if, when incorporated into the statistical model, it reduced the error in predicting an outcome. For example, in Figure 8-1, if one of the variables in the decision tree were omitted, the model would be less accurate in predicting whether or not there would be MtBE detections in wells.

A total of 124 of the variables evaluated were shown to have some effect on prediction of MtBE in PWS wells. The significant variables for each pathway are listed in Table 8-6 in order of importance, with the most important variables highlighted in bold print. For each pathway modeled, the probability of the model correctly predicting whether a well is contaminated or not is listed at the bottom of the column. Generally, the probability of correctly predicting that a well will not be contaminated with MtBE (greater than 94% for all pathways) is much better than the probability of correctly predicting that a well will be contaminated with MtBE (19 to 51% depending on pathway).

To further narrow the list of variables to a more manageable list of the most significant risk factors statewide, the three most important variables from each pathway analysis were identified. Table 8-7 lists 124 variables that were identified as having an impact on the prediction of MtBE. For each pathway, the number shown indicates how early in the analysis (how high on the decision tree) that variable appeared. Lower value numbers indicate greater influence on the prediction of the presence of MtBE. If a variable appeared in the first, second, or third position of importance for a pathway, the number of times it appeared in these positions was tallied and used as a weighting factor for that variable. Table 8-8 provides a summary of the 45 most important variables in the overall analysis, along with the weighting factor developed in Table 8-7.

Also included in Table 8-8 is the description of the variable and what conditions are likely to create a higher risk of MtBE contamination in a PWS well. These are the overall "main" effects. Strong interactions with other variables can sometimes reverse this effect as described above. "WELL DEPTH" is an example of a variable that had a "main" effect of increasing risk with shallower depths. However, under some conditions, this reversed, and risk increased with greater depths.

This analysis indicates that the risk factor with the most significant correlation with detection of MtBE in PWS wells was "New.System.Categories". This variable is related to the type of community served by the PWS well. The category of "Mobile Home Park" was a strong predictor of the likelihood of a well being contaminated with MtBE. This is not surprising considering the information that was presented in Table 4-4. Forty-eight percent of the wells

Table 8-8
Ranking of Variables
45 Most Important Parameters

Variable	Description of Variable	Weighting Factor
New System Categories	Types of communities served by well (Mobile Home Park category was high risk category)	820
GWHIs Equal Well Lineaments	Number of GWHI sites within WHPA that share the same nearest lineament with well (higher number = higher risk)	730
GWHIs per WHPA	Number of GWHI sites within WHPA (higher number = higher risk)	630
Sqrt localinv CARD near dist	{This result is considered suspect because of the extremely small data set for this risk} factor Square root of distance to nearest car dealership (shorter distance = higher risk)	410
Log POPULATION	Log of population served by well (larger population = higher risk)	320
Sqrt csite LUST near dist	Square root of distance to nearest LUST (shorter distance = higher risk)	220
GWHIs Trans under 2000	Number of GWHI sites in areas of low transmissivity overburden aquifers (greater number = higher risk)	220
OPUF GS under Well	Number of OPUF sites in WHPA with ground surface elevations lower than ground surface elevation of well (greater number = higher risk)	201
Sqrt NEAR DIST remedpt	Square root of distance to nearest remediation site (shorter distance = higher risk)	120
Sqrt RSITE Near Dist	Square root of distance to nearest RCRA site (shorter distance = higher risk)	112
Sqrt csite IRSPILL near dist	Square root of distance to nearest initial response spill (shorter distance = higher risk)	102
Sqrt localinv UST near dist	Square root of distance to nearest PCS inventory UST (shorter distance = higher risk)	101
PCSs GS OverWell	Number of PCS sites in WHPA with ground surface elevations higher than ground surface elevation of well (great number = higher risk)	101
Sqrt localinv AST near dist	Square root of distance to nearest AST (shorter distance = higher risk)	031
WELL DEPTH	Depth of well (generally greater depth = less risk, but under some conditions, shallow depth = less risk)	022
Sqrt csite OPUF near dist	Square root of distance to nearest OPUF site (shorter distance = greater risk)	021
RFG county	Is well located in an RFG county? (yes = higher risk)	021
WHPA Acres	Area of WHPA in acres (larger WHPA = lower risk)	021
Log Chloride avg	Log of average chloride concentration in well (lower average concentration = lower risk)	020
Sqrt pws near road NEAR DIST	Square root of the distance to the nearest road (shorter distance = higher risk)	011
Sqrt junkyd near dist	Square root of the distance to the nearest junkyard (shorter distance = higher risk)	011
UST Sat over 10	Number of USTs within WHPA with saturated thickness greater than 10 ft (higher number = greater risk)	011
Sqrt npdes near dist	Square root of distance to nearest NPDES discharge (shorter distance = higher risk)	010

Table 8-8
Ranking of Variables
45 Most Important Parameters

Variable	Description of Variable	Weighting Factor
KCSs	Known contaminant sources identified in NHDES PWSA surveys (higher ranking = higher risk)	010
TOTAL	Total number of violations identified by NHDES sanitary surveys (greater number = higher risk)	010
PCSs Trans under 2000	Number of PCS sites in WHPA with low transmissivity overburden aquifer (greater number = higher risk)	010
VSR GW under Well	Number of vehicle service and repair sites in WHPA with grounwater elevations below groundwater elevation at well (greater number = higher risk)	010
OPUF BR over 25	Number of leaking residential or commercial heating oil tanks in WHPA with depth to bedrock greater than 25 ft (greater number = higher risk)	010
Sqrt localinv WSPS near dist	Square root of distance to nearest waste and scrap processing and storage (shorter distance = higher risk)	002
GWHIs Sat over 10	Number of GWHI sites in WHPA with saturated thickness greater than 10 ft (greater number = higher risk)	002
LUST GS OverWell	Number of LUST sites in WHPA with ground surface elevations higher than ground surface elevation of well (greater number = higher risk)	002
Sqrt csite SPILL RLS near dist	Square root of distance to nearest oil spill or release (shorter distance = higher risk)	002
UST per WHPA	Number of USTs within WHPA (greater number = higher risk)	002
Log YIELD	Log of well yield (lower well yield = higher risk)	001
Sqrt NEAR DIST UST	Square root of distance to nearest UST (shorter distance = higher risk)	001
Sqrt NEAR DIST trail	Square root of distance to nearest mapped trail (shorter distance = higher risk)	001
Sqrt csite LAST near dist	Square root of distance to nearest LAST (shorter distance = higher risk)	001
GWHIs Trans over 2000	Number of GWHI sites in WHPA in high transmissivity aquifer area (greater number = higher risk)	001
PCSs BR under 10	Number of PCS sites in WHPA with depth to bedrock less than 10 ft (higher number = greater risk)	001
PCSs BR btwn 10 and 25	Number of PCS sites in WHPA with depth to bedrock between 10 and 25 ft (higher number = greater risk)	001
OPUF Equal Well Lineaments	Number of leaking residential or commercial heating oil tanks in WHPA that share same nearest lineament as well (greater number = greater risk)	001
LEAKS SPILLS GS under Well	Number of various types of fuel leaks and spills in WHPA with ground surface elevations lower than ground surface elevation of well (greater number = higher risk)	001
UST GW under Well	Number of USTs within WHPA with groundwater elevations lower than groundwater elevation at well (greater number = higher risk)	001
UST without DBL WALL	Number of USTs within WHPA without secondary containment (greater number = higher risk)	001

serving Mobile Home Parks had detections of MtBE based on the data in the WSEB Analytical Database.

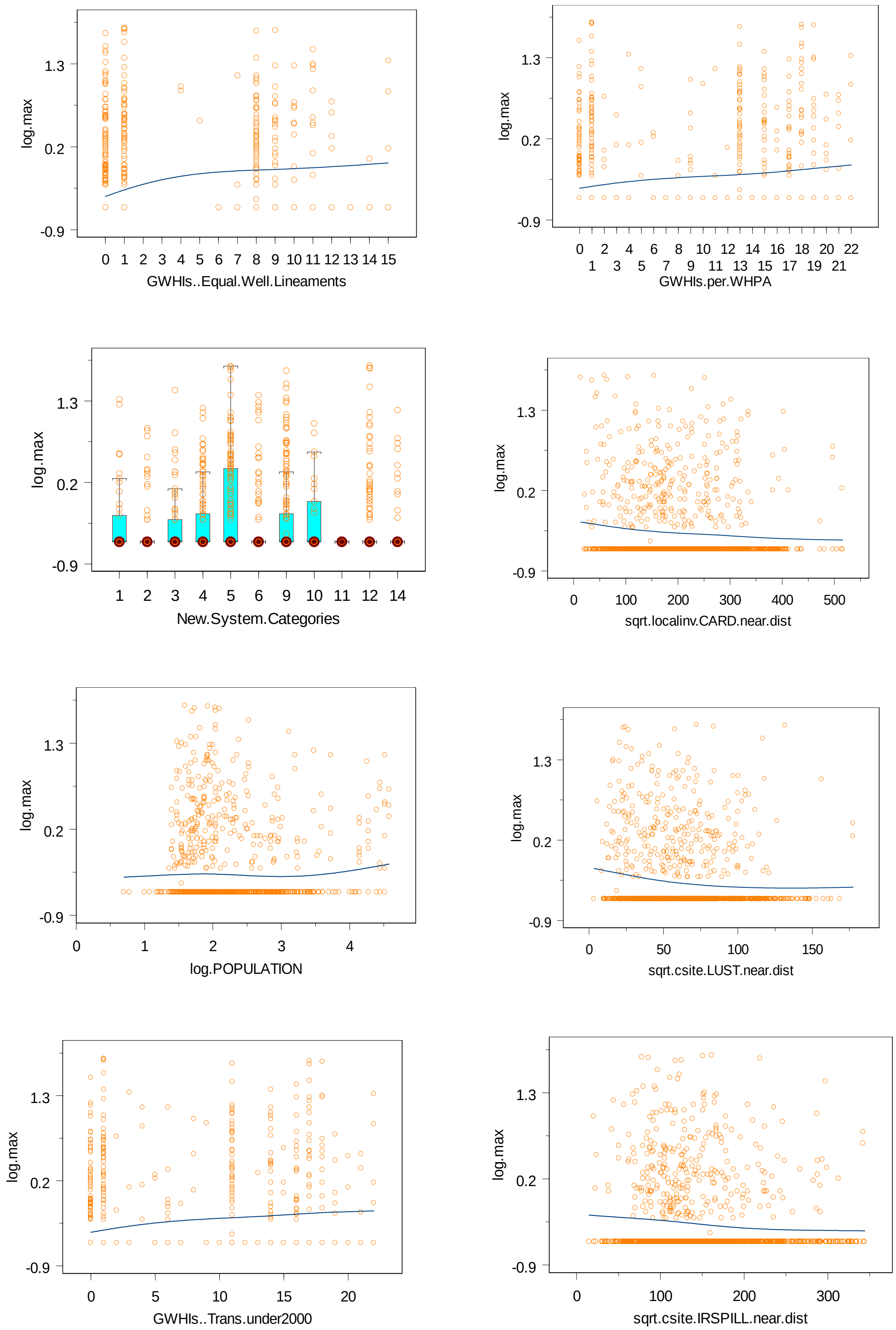
The second most important risk factor was the number of GWHI sites (also referred to as remediation sites) within the WHPA of a well that shared the same nearest lineament with the well. Lineaments were also identified as a potential preferential pathway in the detailed study of the Franklin Pierce College wells. The third most important risk factor was the total number of GWHI sites in the WHPA, regardless of whether the GWHI sites and the well shared the same nearest lineament. This is not surprising since GWHI sites are generally sites that involve some type of documented or permitted release of hazardous materials, petroleum products, or waste materials either in a controlled manner, such as an UIC site or a septic system, or uncontrolled manner, such as an IRSPILL or a LUST site.

Less expected was the fourth most important variable identified by the statistical modeling. This variable was the distance to the nearest car dealership. Upon review of the database, it was determined that the listing of car dealerships obtained from the OneStop database was incomplete. It was based on the "Local Inventory of Potential Contaminant Sites" provided by local towns and municipalities. Because of the small data set (only 34 dealerships listed in the statewide database), this result was driven by a small number of sites and is not considered to be very reliable.

The fifth most important variable was the log of population served by the well (not to be confused with population density). The significance of the log of the population variable could be interpreted as the larger the population served by a well would mean a greater demand on that well. This may consequently result in more frequent pumping and possibly an expanded capture zone for the well. The sixth most important variable was the distance to nearest LUST. The GWHI sites appeared again as the seventh most important variable, this time the number of GWHI sites in the WHPA in locations with low aquifer transmissivities was an indicator of higher risk. The eighth most important variable was identified as distance to nearest initial spill response site. Figure 8-3 shows plots of the data for the eight risk factors discussed above. Thirty-seven additional variables and the conditions that are likely to create increased risk of MtBE contamination are listed in Table 8-8.

Figure 8-3
Summary of Average Overall Effects of Eight Most Important Risk Factors

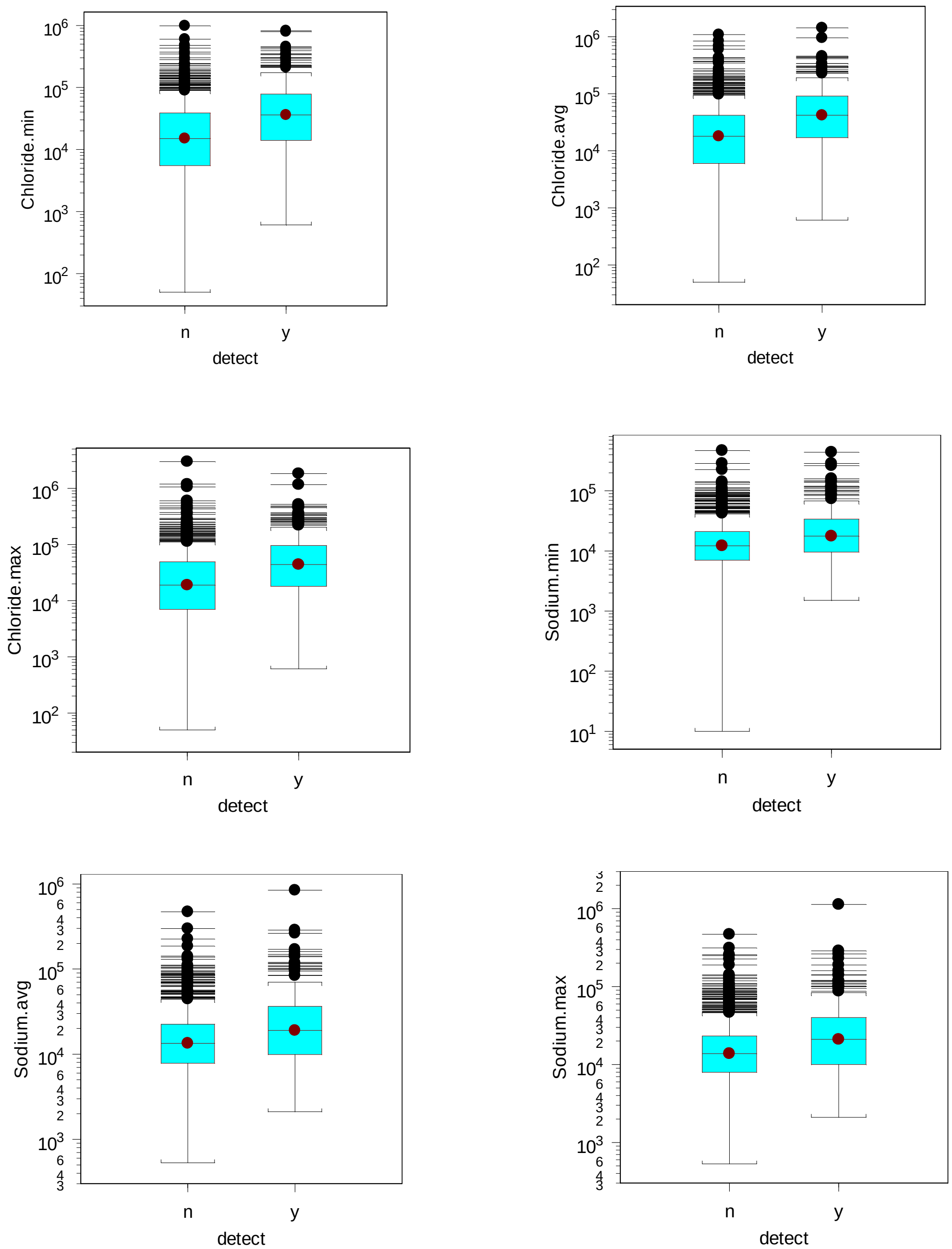
X-axis: risk factor, y-axis: logarithm (base 10) of maximum MtBE. Nondetects are included.



Average, maximum, and minimum sodium and chloride concentrations per well were included as variables in the predictive modeling, but they were also evaluated individually for correlations with MtBE contamination. Figure 8-4 shows boxplots of the log concentrations verses detection of MtBE. Higher average concentrations of both sodium and chloride are observed for the population of wells with MtBE detections as opposed to those wells with no detections. Chloride is somewhat more related to MtBE detections than sodium. However, the differences between the two populations (detect wells verse non-detect) are not sufficient to make either sodium or chloride a good predictor of MtBE contamination.

Figure 8-4

Comparison of Distributions of Chloride and Sodium of Wells with no MtBE-detected (n) and of Wells with MtBE-detected (y)



Concentrations shown are in µg/L

SECTION 9

PHASE I CONCLUSIONS

9. PHASE I CONCLUSIONS

The detailed studies of selected PWS sources, the focused evaluations of surface water supply sources and remediation sites, and the statistical modeling all provided consistent and complementary results with respect to the types of risk factors identified. Many of the factors associated with increased risk of MtBE contamination were not surprising. In fact, the remediation sites identified as GWHI sites in NHDES OneStop database were the parameters that were most highly correlated with MtBE contamination in PWS sources by the statistical modeling, and were most frequently noted at contaminated PWS sources during the detailed studies.

The GWHI sites are typically sites that involve some type of documented release of hazardous materials or petroleum products, or permitted release of waste materials. The GWHI sites include leaking bulk fuel oil storage facilities, initial response spills, landfills, LAST, LUST, wastewater lagoons, leaking motor oil storage tanks, leaking residential or commercial heating oil tanks (OPUF), large septic systems, oil spills or releases, transfer stations, and underground injection control sites. Several of the types of GWHI sites were evaluated separately in the statistical modeling. The LUST, OPUF, and initial response spills appeared to be the types of GWHI sites that were most highly correlated with MtBE contamination. Both the detailed studies and the statistical modeling indicated that heating oil leaks and spills were a risk factor.

The focused evaluations of remediation sites examined the remedial activities performed at some of the GWHI sites where uncontrolled releases occurred. It appears that better characterization of groundwater contamination and active groundwater remediation at these sites might have prevented MtBE contamination from reaching nearby PWS wells or diminished the extent of that contamination. Interestingly, the remedial activities that were performed appeared to be adequate to protect the nearby PWS wells from becoming contaminated with other BTEX constituents, but were not adequate to protect them from MtBE contamination.

The statistical modeling indicated that some local hydrogeologic factors, such as proximity to lineaments and low transmissivity overburden aquifers increased the risks posed by GWHI sites. If the nearest lineament to a PWS well was also the nearest lineament to a GWHI site in the WHPA, that well was at a particularly high risk of becoming contaminated with MtBE. This type of relationship was observed during the detailed study of the wells at Franklin Pierce College. The focused evaluations of remediation sites indicated that PWS wells in highly transmissive aquifers appeared to be less at risk for MtBE contamination, even when in close proximity to a release.

The sites identified in the "Local Inventory of Potential Contaminant Sites" in NHDES OneStop database were also evaluated as potential risk factors. The PCS are not documented release sites, but rather types of facilities or industries identified by local municipalities that would be likely to use or produce hazardous materials or petroleum products. The PCS in areas of low transmissivity were identified as the 26th most important risk factor in the statistical modeling. Vehicle repairs were identified as a potential risk factor in the detailed studies, particularly backyard mechanic activities. Unfortunately, the undocumented backyard mechanic activities could not be evaluated in the statistical modeling. However, commercial vehicle service and repair facilities were identified as the 27th most important risk factor in the predictive modeling. Car dealerships were identified as the fourth most important parameter in the statistical modeling, However, upon further review, it was determined that this result was based on the locations of only 34 dealerships throughout the state, a very small and incomplete data set . Also, the distances between the wells and the dealerships for which the statistically significant relationship was identified were greater than what MtBE could reasonably be assumed to migrate. Therefore, the importance of this variable is suspect. Since the car dealerships identified in the database were predominantly in the southern more populated portion of the state, the statistical results are more likely to be related to higher population density than the car dealerships locations.

The focused evaluations of nine surface water sources revealed a consistent pattern of seasonal MtBE contamination in lakes and ponds with motorized watercraft activities. Some, but not all wells located near lakes or ponds with boating activity were found to also have a seasonal pattern of MtBE contamination. However, the maximum detected MtBE concentrations in surface water never exceeded the MCL.

Potential contaminant sources and risk factors in the SPA (also referred to as the sanitary radii) of wells were evaluated during the detailed studies. The SPA are circles with a radius of 75 to 400 ft around the wellhead. Several types of potential risk factors were found to be present in the SPA, including use and storage of petroleum products, poor housekeeping, wellhead deficiencies, and road runoff. However, there was no method of statistically evaluating whether these were likely to be the sources of MtBE contamination in the wells.

Another parameter that appeared near the top of the list of the 45 most important risk factors in the predictive modeling was the number of people served by the PWS system (more people = higher risk), although this factor was interdependent with the type of community served by the PWS system. Distance to nearest RCRA site, AST, road, jun

kyard, NPDES outfalls, waste and scrap processing and storage facility, and mapped trails were also in the list of the top 45 risk factors. This list also included larger WHPA, location in an RFG county verses a non-RFG county, higher average chloride concentration, and lower well yield as risk factors associated with MtBE contamination. The presence of a greater number USTs in the WHPA, particularly those without secondary containment, was another factor associated with a high risk of MtBE contamination.

Well depth was identified as the 15th most important parameter in the statistical modeling. Its "main" effect was to decrease risk with greater depth, but this parameter interacted with other variables and on less frequent occasions, greater depth was associated with increased risk. These findings contradict those of the USGS study in Rockingham County performed by Ayotte et al. in 2005 which found that MtBE occurrence in PWS wells correlated positively with greater well depth. The results of the detailed studies indicated that shallower overburden wells tended to be more at risk of MtBE contamination. The percent of bedrock wells with MtBE detections in the WSEB Analytical Database was slightly lower than the percent for overburden wells. However, the frequency of MtBE MCL exceedances was higher for bedrock wells than for overburden wells.