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Abstract

Tetrachloroethylene (PCE) is a known volatile carcinogen that has been found in many groundwater plumes. This study investigates the levels of PCE in air samples taken from inside well casings on Cape Cod. Results show that there are traceable levels of this chemical in the collected air samples which could potentially pose a threat to those exposed.

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Acknowledgements

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1.0 - Introduction

Tetrachloroethylene (PCE) has been established as a known volatile, carcinogen. There are many contaminated groundwater plumes that result from multiple different sources of PCE. PCE has been studied extensively and there are currently many remediation systems in place. Due to the high volatility of PCE, the presence of this carcinogenic compound in water may remain a threat because it can volatilize and result in human exposure through air pathways. For example, the residents in Niagara Falls, NY (Love Canal) were exposed to hazardous chemicals that were dumped into landfills. On Cape Cod, air samples have been collected and tested by Silent Spring Institute for levels of PCE in Falmouth, MA, but only in the physical upper levels of homes and thus, resulting in suggested, unclear results (Silent Spring Institute, 2010).

Since there has not been much research on the volatility of PCE, especially pertaining to testing in basements of homes or inside well casings, it is hypothesized that there are levels of PCE present through air pathways from groundwater contaminated with PCE. This report describes a study of the volatility of PCE in well casings in Falmouth, MA that are intended to provide an initial step towards addressing this question.

In an attempt to correlate water concentration of PCE to PCE in gas samples, airborne samples were obtained from inside the well casing above ground water in ten monitoring wells in Massachusetts Military Reservation (MMR) Chemical Spill "Plumes" CS-20 and CS-21. The samples were analyzed in accordance with US Environmental Protection Agency's approved procedures by Alpha Analytical Laboratories of Westborough Massachusetts. The sample results indicated detectable levels of PCE. Although there are trace levels of PCE in the air, there is not enough data to make the correlation between PCE levels and increased cancer rates on Cape Cod.

2.0 - Background

This chapter includes a description of the history, health implications, and relevance of PCE in this study. Case studies are summarized showing the relevance and effects of contamination from volatile organic compounds (VOC's). Location information and significance of the study of the volatility of PCE in groundwater in Falmouth, MA is presented.

2.1 - Regulation of Chemicals

"Federal water legislation dates back to the nineteenth century, when Congress enacted the River and Harbor Act of 1886," which regulated the pollution of existing ground water (Environmental Protection Agency , 2011). In 1948, the Water Pollution Control Act was passed. This act set out the basic legal authority for federal regulation of water pollution and contamination. Amended several times, this act eventually became the Clean Water Act which gave the Environmental Protection Agency the right to regulate pollutant discharge into public waters (Environmental Protection Agency , 2011).

It was not until 1976 when the EPA enacted the Safe Drinking Water Act which, for the first time, regulated known contaminants in drinking water. Current drinking water standards regulate chemicals known to be contaminants. Although regulations are strict, many of these pollutants are still finding their way into drinking water though corrosion of pipe lining, diffusion of groundwater through piping, chemical and fuel spills, etc. (Environmental Protection Agency , 2011).

During this study, levels of tetrachloroethylene were evaluated. EPA has set a Maximum Contaminant Level Goal (MCLG) for PCE in drinking water and air as zero because this is the level which ensures that there will be no potential health affects to people. Although the MCLG for PCE is zero, EPA has set a standard for drinking water utilities to detect and remove PCE using suitable treatment technologies. This standard, called the Maximum Contaminant Level (MCL) is 5 parts per billion (ppb). All public water suppliers must remove PCE to 5 ppb as set by the National Primary Drinking Water Regulations (US EPA, Consumer Factsheet on Tetrachloroethylene). In air The US Occupational Safety and Health Administration (OSHA) set the Permissible Exposure Limit (PEL) for PCE to 100 parts per million (ppm) for an 8 hour day (time weighted average) with a maximum exposure level of 200 ppm, except that an exposure of 300 ppm (peak) is allowed for 5 minutes in any 3 hour period (Regulatory Context, 2009).

2.2 - Carcinogenic Compounds

Many chemicals that are sometimes found in drinking water can be extremely hazardous to your health. In the mid 1970's, high levels of tetrachloroethylene were discovered in drinking water in specific cities and towns in Massachusetts (Christopher Paulu A. A., 1999). Tetrachloroethylene is a chemical used for dry cleaning fabrics, operations involving degreasing metal, and also is a resultant product caused by the curing of vinyl lining in asbestos cement pipes. PCE is a volatile organic compound which is a dense, non-flammable, colorless liquid and can be transmitted into the air due to its high volatility (Ten Carcinogens in Toronto: Tetrachloroethylene). The main route of exposure to humans is through inhalation, although it can be consumed as well. Inhaling PCE can result in upper respiratory problems, impairments in neuro-behavioral functioning, cardiac arrhythmia, liver damage, and possible kidney effects.

PCE can be released into the environment from contaminated groundwater and be sustained in the atmosphere for several months. This is further supported by Henry's law which depicts the equilibrium distribution of dilute concentrations of volatile, soluble chemicals between a gas and water (US EPA, Estimated Henry's Law Constants, 2011). "[PCE]'s high vapor pressure and Henry's law constant usually result in its rapid volatilization to the atmosphere. Tetrachloroethylene has relatively low solubility in water and has medium-to-high mobility in soil, thus its resistance time in surface environments is not expected to be more than a few days… Because of its pervasiveness and ability to persist under certain conditions, the potential for human exposure may be substantial" (Tetrachloroethylene, 1996).

In the mid-1980s, EPA considered the epidemiological and animal evidence on tetrachloroethylene as intermediate between a probable and possible human carcinogen (Environmental Protection Agency, 2007). According to the American Cancer Society, a carcinogen is defined as "any substance that causes cancer or helps cancer grow" (American Cancer Society, 2011). Even though PCE is a known carcinogen, it was not until 1991 that it was regulated under the Safe Drinking Water Act by EPA.

2.3 - Study of PCE in Drycleaners

Because of its degreasing efficiency, PCE is used in the dry cleaning industry and is a widespread commonality between dry cleaners. The everyday use of PCE allows for the volatile substance to be exposed to numerous people within a dry-cleaning facility. Using cleaning material that contains the PCE allows for it to evaporate into the air thus entering the lungs which ultimately leads to the blood stream.

Epidemiological studies of drycleaners exposed to tetrachloroethylene vapor have shown increased susceptibility to cancer (Tucker et al., 2011). "In humans, perc [PCE] is readily absorbed into the bloodstream both after inhalation and after oral exposure" (Ten Carcinogens in Toronto: Tetrachloroethylene). The drycleaner's study showed that PCE levels were severely increased in dry cleaners' blood and respiratory tracts after working three days in a dry cleaning facility. "In addition to breathing contaminated air, infants can also be exposed to PCE in breast milk" (Tetrachloroethylene, 1996). Because these studies have already shown a correlation between PCE and increased cancer rates, there is a great possibility that chronic exposure of PCE in air can be directly related to increased cancer rates.

2.4 - Standard Incidence Ratio (SIR)

Standard Incidence Ratio (SIR) relates the actual number of diagnosed cases to the expected number of cases. Using the SIR, Silent Springs Institute compared breast cancer rates in Cape Cod to the rest of Massachusetts. After a 13 year study, their results showed that, overall, residents living on Cape Cod have a 20% higher risk of breast cancer diagnosis than the rest of Massachusetts (Silent Spring Institute, 2008). This 20% value does not specify the causes of the higher risk but just that it is more likely to be diagnosed with breast cancer in Cape Cod than other areas of Massachusetts. The SIR value is statistically significant and, therefore, elevated incidences did not occur by chance. During the years 1995-1999, fifteen towns on Cape Cod were tested and although not all showed high cancer rates, eight towns showed SIR values that were statistically significant (Breast Cancer Incidence in Cape Cod towns 1995-1999, 2008). The Massachusetts Department of Public Health confirmed the finding of Silent Spring

Institute in 1999 that breast cancer incidences were statistically significant, and much higher than the rest of Massachusetts with an SIR of 110 (10% higher than the rest of Massachusetts) (Unit, 1999). The cause of increased cancer rates on Cape Cod is unknown and currently being studied.

2.5 - Cranberry Bogs as Source of Airborne Contamination

Since PCE is a volatile chemical, health effects from airborne contamination may present a problem. A variety of everyday chemicals have been thought to be the cause of increased breast cancer rates on Cape Cod. It was thought that one of Cape Cod's unique attributes, having many large cranberry bogs, were the cause of increased cancer rates. These bogs are sprayed with pesticides that can be harmful and become airborne during the spraying process. Silent Spring found insignificant information to make a correlation between cancer rates and residents living near cranberry bogs (Silent Spring Institute). Further, researchers have verified that there is no correlation between cranberry bog treatment chemicals and increased cancer rates (Ann Aschengrau P. D., 2006). Since the cranberry bogs are not the cause of increased cancer rates, there must be other factors playing a role. It is thought that if PCE is present in the air, that it could be one of the factors leading to increased cancer rates.

2.6 - Massachusetts Military Reservation (MMR)

Groundwater has been repeatedly tested and found to be contaminated from well identified "plumes" from Massachusetts Military Reservation (MMR). As a result of this and possibly additional factors, most affected residents living in Falmouth, Massachusetts currently use town water instead of well water. Because most of the affected people in Falmouth, MA are using town water, it is hoped that their level of exposure to PCE from drinking, cooking, bathing, etc. with groundwater is decreased.

MMR was chosen as the research site for a variety of reasons. A Superfund site and home to various United States military branches, MMR covers approximately 22,000 acres including parts of the towns of Bourne, Mashpee, Sandwich and Falmouth (Massachusetts Military Reservation). Numerous, well-documented, contaminated plumes are located within MMR and volumes of public data are available as resources. Fuel and chemical spills, fire training activities, landfills, and drainage structures have led to multiple contaminated areas in and around MMR. The ground above the plumes in MMR is generally composed of sandy soil, which makes it easier for chemicals to reach the surface.

The method approved by EPA for public drinking water suppliers to use when PCE is above 5 ppb is a combination of granular activated carbon and packed tower aeration (US EPA, Consumer Factsheet on Tetrachloroethylene).Remediation projects have been implemented since the 1990s in an effort to treat the contaminated soil and groundwater at MMR (Environmental Protection Agency, 2010). Extraction wells have been placed within plumes around Upper Cape Cod "to pump the contaminated groundwater from the aquifer to a treatment plant where the water is treated" removing PCE. Treated water is then returned to the aquifer using reinjection wells (Groundwater Plume Maps & Information Booklet, 2010).

2.7 - Remediation

Most VOC's can be removed in water by numerous types of remediation. Pump and treat is the most common type of removal of VOC's from water. This method involves pumping contaminated water from a well and treating it above ground, sending it to a wastewater treatment plant or other approved location, and discharging it back into the aquifer. Another type of remediation is phytoremediation, which uses plants that absorb and filter VOC's. During this process, plants absorb VOC's and store the chemicals, which can be changed into less harmful chemicals and released into the air as a harmless gas. Bioremediation is another process of removal where microorganisms consume VOC's and use them for food and energy. The chemicals are transformed into harmless chemicals by the microorganisms. One more way to remove VOC's is by a permeable reactive barrier. This barrier reacts with the VOC's and creates a less harmful chemical that is released into the water (Hazardous Substance Fact Sheet PCE, 2001).

2.8 - Case Studies

2.8.1 - Love Canal, NY

VOC's have been discovered in many different areas across the country, but one example that is more widely known is the tragedy that occurred in the area of New York known as the "Love Canal." In Niagara Falls, NY, the Love Canal was originally constructed by William T Love in the 1890's to be a "dream community." However, technology being created for a hydroelectric power system was never completed and in the 1920's, the canal was turned into a municipal and industrial dumping site (Beck, 1979). Beginning in 1942, the landfill was used by Hooker Chemicals and Plastics [now Occidental Chemical Corporation (OCC)] for the disposal of over 21,000 tons of various chemical wastes, including halogenated organics, pesticides, chlorobenzenes and dioxin. In 1953, the Hooker Chemical Company, then the owners and operators of the property, covered the canal with earth and sold it to the city for one dollar. During the latter part of the 1950's, nearly 100 homes and a school were built on the site (Beck, 1979).

In the late 1970's, there was a record amount of rainfall causing the leaching of hazardous chemicals through the topsoil and exposure of these chemicals to the people living on the canal. The people of the Love Canal that were exposed to these harmful chemicals developed many precursors to cancer and also saw an elevation of miscarriages and birth defects. Approximately 950 families were evacuated from a 10-square-block area surrounding the landfill (Beck, 1979).

To clean up the Love Canal, the site was addressed in seven stages: initial actions and six major long-term remedial action phases, focusing on 1) landfill containment with leachate collection, treatment and disposal; 2) excavation and interim storage of the sewer and creek sediments; 3) final treatment and disposal of the sewer and creek sediments and other Love Canal wastes; 4) remediation of the 93rd Street School soils; 5) EDA home maintenance and technical assistance by the Love Canal Area Revitalization Agency (LCARA), the agency implementing the Love Canal Land Use Master Plan; and, 6) buyout of homes and other properties in the EDA by LCARA. In 1988, EPA issued the Love Canal EDA Habitability Study (LCHS), a comprehensive sampling study of the EDA to evaluate the risk posed by the site (Love Canal, New York, 2010).

New homeowners have repopulated the habitable areas of the Love Canal EDA. More than 260 formerly abandoned homes in the EDA were rehabilitated and sold to new residents, thus creating a viable new neighborhood. The vacant property in the EDA was developed and deemed complete on September 29, 1999. The Love Canal was then deleted from the National Priorities List on September 30, 2004. The contamination problem discovered at the Love Canal ultimately led to the passage of Federal legislation governing abandoned hazardous waste sites (Love Canal, New York, 2010).

2.8.2 - Times Beach, Missouri

Around the same time that the EPA was dealing with the VOC contamination at the Love Canal, they were also trying to contain an equally damaging exposure of harmful chemicals in Times Beach, Missouri. In years previous to 1982, Times Beach regularly had waste oil sprayed on its streets and parking lots to control dust. Some of the oil used in dust control was contaminated with dioxin, an unwanted chemical byproduct of certain manufacturing processes. In 1982, the EPA discovered extremely dangerous levels of dioxin and was forced to close down all roads leading into the town and placed security guards to patrol the site around the clock. The EPA had to permanently relocate more than 2,000 people and destroy all of the homes and businesses at a cost of approximately $30 million (Times Beach One-Page Summary).

The remedy involved the placement of a transportable incinerator at the Times Beach site to provide thermal destruction for 25,600 cubic yards of dioxin-contaminated soil. In addition, the incinerator provided capacity for thermal destruction of an additional 66,500 cubic yards of dioxin-contaminated soil from 24 other sites in eastern Missouri (Times Beach Record of Decision Signed, 1988).

To protect the cleanup activities from the danger of flooding from the Meramec River, EPA first had to build a 15 foot high barrier around the incinerator. Contaminated soils were then dug up, burned, and the resulting waste ash was buried on site (Times Beach One-Page Summary).

The Center for Disease Control (CDC) completed analysis of extensive soil sampling in the area and advised that the hazard posed by dioxin contamination is a continuing threat to the health of citizens in the community. Laboratory analysis of post-flood sampling along roadways (including the shoulders and ditches), houses and yards in Times Beach was completed. Of some 255 samples, levels of dioxin in a few yards and in one home showed levels of greater than 1 ppb and less than 5 ppb. Sample locations in streets, on shoulders and in ditches showed levels from non-detectable up to 100 ppb (Joint Federal/State Action Taken To Relocate Times Beach Residents, 1983).

A park to commemorate Route 66 is now covering 500 acres, some of which includes the area where Times Beach once was (Times Beach One-Page Summary).

2.8.3 - Valley Park, Missouri

Just down the road from Times Beach, similar to the Love Canal, is another town that has had to deal with the presence of VOC's in their lives. In Valley Park, MO, 1982, the Missouri Department of Natural Resources (DNR) detected a number of VOCs including trichloroethylene (TCE), tetrachloroethylene (PCE), and trichloroethane (TCA) in the three municipal water supply wells serving the community due to a plume of contaminated ground water in the Meramec River alluvial aquifer. Also, many private wells within the area of the site have been contaminated with VOC's. It was estimated that approximately 3,000 people in the community had obtained drinking water from the affected ground water (Valley Park, Missouri, 2010).

In 1986, Valley Park installed aeration equipment at its water treatment plant to remove the VOC's that had been detected in the drinking water. In 1989, Valley Park was connected to the St. Louis County public water system to supplies its drinking water. In 1990, 331 cubic yards of PCE- and TCE-contaminated soil were removed and the area was backfilled. This effort, however, was not enough to reach predetermined clean up levels (Valley Park, Missouri, 2010).

The site was then divided into two operable units for cleanup. For operable unit one, clean up began in 1994 and the remedy included limited soil excavation; soil vapor extraction (SVE) and after 5 years, additional soil excavation if needed; ground water extraction and treatment by air stripping; discharge of treated ground water into a public storm sewer; and ground water monitoring. In 1997, for operable unit two, the remedy included limited soil excavation followed by offsite disposal of contaminated soils; in-situ SVE at the second source area; ground water extraction and treatment; and discharge of treated ground water to a storm sewer; and, finally, installation of air stripping systems on two industrial wells located within the contaminated aquifer (Valley Park, Missouri, 2010).

By connecting the public water supply to the county water system, the potential for exposure to contaminated drinking water was reduced at the Valley Park TCE site while final cleanup remedies were planned. Most of the clean-up activities for operable unit one were completed in 1998, whereas for operable unit two, most activities were completed by 2005. Two reviews of the site were completed in 2003 and 2008, which identified several operational issues that could affect the long-term protectiveness of the remedies for both areas. Although this may become an issue, the review concluded that the remedy is currently protective (Valley Park, Missouri, 2010).

2.8.5 - The CS20 and CS 21 Plumes on Cape Cod

Cape Cod contains numerous contaminated groundwater sites, or plumes. There are over 100 recorded contaminated spills, including fuel and chemical spills. The two spills studied in this paper are Chemical Spill-20 (CS-20) and Chemical Spill- 21 (CS-21). These spills were discovered in the late 1990s (Groundwater Plume Maps & Information Booklet, 2010). Both spills are located mostly above Route 151 in Falmouth, MA as seen in Figure 1.

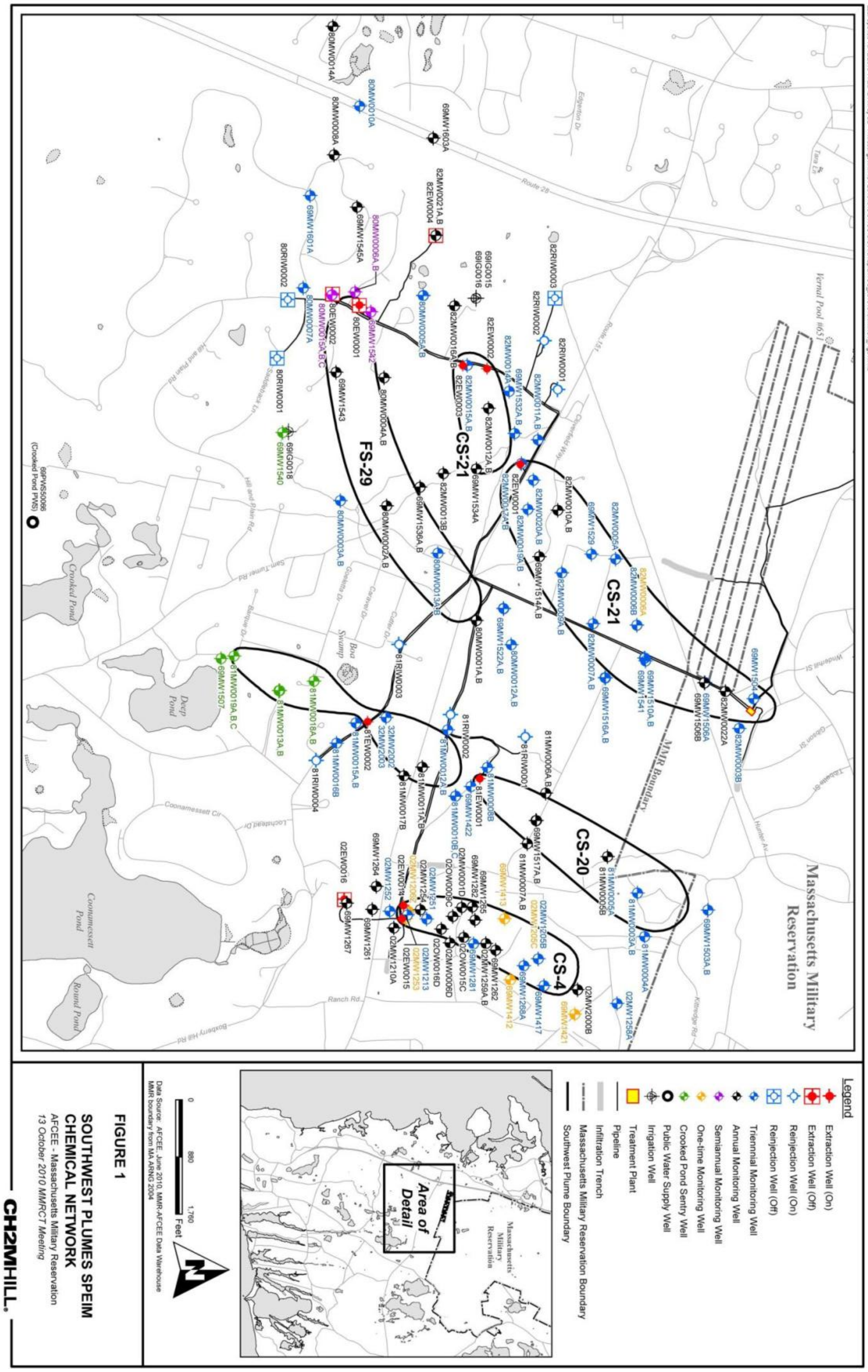

Figure 1: Southwest Plumes SPEIM Chemical Network (CH2MHill)

Starting in the early 1900s, MMR has used "… petroleum products, solvents, and other hazardous materials. It was common practice for many years at the MMR… to dispose of wastes in unlined landfills and drywells, to dump and burn them at firefighter-training areas, or to rinse them down drains" (Groundwater Plume Maps & Information Booklet, 2010). The dumping of those materials has led to the many plumes on Cape Cod. The CS-20 and CS-21 plumes currently contain volatile chlorinated compounds that are known carcinogens. Of these known carcinogens, PCE and trichloroethylene (TCE) are known to be present in highest concentrations.

In 2000, a Record of Decision (ROD) was signed for both CS-20 and CS-21 in order to design and build an extraction and treatment system to remove contaminants in the groundwater. CS-20 contains two extraction wells and CS-21 contains three extraction wells. As of December 2010, the CS-20 extraction wells are operating at a combined flow rate of 773 gallons per minute (GPM) and the CS-21 extraction wells are operating at a combined flow rate of 1395 GPM (Massachusetts Military Reservation).

There are numerous monitoring wells within each plume of which most are tested biannually for contaminants in the groundwater. In this study, gas and water samples were taken at various locations in Cape Cod to test for volatile organic compounds.

3.0 - Methodology

Since PCE is a known carcinogenic it is important to test for it in the atmosphere to limit human exposure. In this study, the gas above the water in the casing of seven monitoring wells was sampled for air contaminants within CS-20 and CS-21 in MMR. One monitoring well and one bleeder were also sampled outside of the boundaries of CS-20 and CS-21 as control samples. The wells are opened once a year to collect water samples. An environmental scientist hired by CH2M Hill is responsible for conducting water quality tests from the monitoring wells. This is done by using thin wall plastic bags that allow the chemical contaminants to permeate into the solution in the narrow casing.

In general, each well has an “A” and “B” drill casing. The “A” casing provides access to water at the bottom/base of the plume while the “B” casing provides access to water at the top of the plume. The location of the “A” and “B” sample points correspond to the plume depth not the thickness/depth of the aquifer. The actual height of the aquifer is above the top of the plume. This would be anticipated since the specific gravity of trichloroethylene (TCE) is about 1.46 times that of water (MSDS, 2005) and the specific gravity of PCE is about 1.62 times that of water (MSDS, 2007).

The well casing for the “A” and “B” wells are 2 ½ inch PVC. A loose fitting connection is provided at the top of each well casing for access during sampling. A section of heavy duty twine is connected to the fixture at the top of the casing, connected to the diffusive sampling device located at the midpoint of the well casing perforated section at the top (or bottom) of the plume. MMR contract personnel provided access to each well sampled.

For testing purposes, a steel chamber was used for gas samples, which came with a pressure gauge, a rubber stopper, and a stainless steel section of tubing. For each well the procedure was the same. The WPI sample device consisted of a four foot section of ¼ inch Series 316 Stainless Steel tubing. A #13 one-hole rubber stopper (silicone material) was employed. The tubing was pushed through the rubber stopper such that about 24 inches of tubing extended down into the well casing during sampling. The #13 rubber stopper provided a tight seal in the top of the well casing with about 3/8 inch engagement. The ¼ inch tubing was connected to a 3.4 liter 316L Stainless Steel evaluated sample vessel. A 316L stainless Steel needle valve, positioned between the sample fitting connected to the ¼ inch tubing and the sample vessel maintained the vacuum condition in the sample chamber. Once physically positioned on the top of the casing, the sample valve was opened. A compound-type pressure gauge (pressure/vacuum), located between the sample valve and sample tubing, verified the initial full vacuum condition upon opening the sample valve and completion of air intake by reading 0 psig (14.696 psia). Upon noting the 0 psig reading, the sample valve was closed and the sampling device was removed.

Water samples were taken on Camelot Drive to ensure that those houses using town water were indeed using water that was PCE-free. Testing for water samples differed slightly. Instead of the steel chamber, a 10mL vial was used to take the water samples. Two water samples were taken from houses on Camelot Drive that use town water. For water tests, the vial was placed under the flowing water until it over flowed to prevent air bubbles from entering. After water was collected, the cap was sealed and the vial was turned upside down to assure there was no space left in the vial.

Sample date, location, and time were recorded on a tag attached to each sample container. The testing took place over two days. On the first day, Thursday March 24, 2011, five wells were tested for gas. On Friday, March 25, 2011, three wells were tested for gas, a bleeder was tested for gas and water, and two additional water tests were performed. The wells with their specific dates and times are shown below in Table 1. The containers were brought to Alpha Analytical in Westborough Massachusetts. Tetrachloroethylene and trichloroethylene analysis were performed using EPA methodology. A blank and spiked sample of known tetrachloroethylene and trichloroethylene concentration were also analyzed as control variables and in conformance with EPA criteria.

Table 1: Date and Time of Sample Acquirement

Sample	Date & Time
69MW1603A (gas)	03/25/11 10:25
82MW0012A (gas)	03/25/11 09:55
82MW0010A (gas)	03/25/11 09:15
CAMELOT DR. (water)	03/25/11 12:25
81MW0011B (gas)	03/24/11 12:35
81MW003B (gas)	03/24/11 11:20
81MW003B (gas)	03/24/11 11:15
69MW1517A (gas)	03/24/11 10:24
81MW006A (gas)	03/24/11 10:00
69MW1506B (gas)	03/24/11 09:45

4.0 - Results

Chemical Spill-20 and Chemical Spill-21 are both located in the North Falmouth/Hatchville Area of Falmouth, MA and originated from the Massachusetts Military Reservation (MMR). These plumes are known to contain carcinogenic contaminants such as tetrachloroethylene (PCE) and trichloroethylene (TCE). Remediation systems have since been put in place to contain the spills and reduce aqueous concentrations. The gaseous space above contaminated water in monitoring wells for eight wells in and around CS-20 and CS-21 was sampled for these volatile contaminants. Table 2 shows each well number and well depth, along with a description of the well location. Column 4 shows results obtained in 2010 from MMR for the concentration of PCE in water. Columns 5 and 6 show the results obtained in March 2011 for the concentration of PCE and TCE in air within the well casing above water.

The data showed insignificant levels of PCE in air samples from monitoring wells 69MW1603A, 82MW0012A, and 82ME0010A. These three wells are located within or around CS-21. Monitoring well 69MW1506B showed small amounts of PCE in air at 0.590 µg/l of air. This well is located up gradient of the trailing edge of CS-21 plume.

Small amounts of PCE were also detected in monitoring wells 69MW1517A and 81MW006A, which are both located on the boundary of CS-20. Monitoring well 81MW0011B showed significantly high levels of PCE at 19.7 µg/l of air. Monitoring well 81MW003B showed even higher levels of PCE at 83.8 µg/l of air. These two wells are located within the main body of the CS-20 plume.

TCE showed insignificant levels in air in monitoring wells 69MW1603A, 81MW0011B, 81MW003B, 69MW1517A, and 81MW006A. 69MW1603A, located down gradient of CS-21 and the other four monitoring wells are located within and around CS-20. Small amounts of TCE were detected in monitoring wells 82MW0012A and 69MW1506B, both of which are located within and around CS-21. Monitoring well 82MW0010A showed high levels of TCE at 10.3 µg/l in air. This monitoring well is located within the main body of the CS-21 plume.

These results suggest that the CS-20 plume's major volatile contaminant is tetrachloroethylene while CS-21 is contaminated with both tetrachloroethylene and trichloroethylene. This observation is verified by published MMR data (Massachusetts Military Reservation).

Table 2: Chemical Concentrations in water (2010) and Gas (2011) at Each Well

MMR Monitoring Well Number	Monitoring Well Description	Monitoring Well Depth (Feet)	Plume Tetrachloroethylene Concentration (µg/l of water) (Data from 2010)	Gaseous Tetrachloroethylene Concentration (µg/l of air) (Data from 2011)	Henry's Law: Expected Gaseous Concentration of Tetrachloroethylene (µg/l of air)	Gaseous Trichloroethylene Concentration (µg/l of air) (Data from 2011)
69MW1603A	Down gradient of plume – CS-21	238.38	0.19	<0.200	0.13509	<0.200
82MW0012A	Main body of plume – CS-21	312.5	22	<0.200	15.642	0.378
82MW0010A	Main body of plume – CS-21	343.7	57	<0.200	40.527	10.3
81MW0011B	Main body of plume – CS-20	152.3	26	19.7	18.486	<0.200
81MW003B	Main body of plume – CS-20	72.3	19	83.8	13.509	<0.200
69MW1517A	Plume boundary – CS-20	232.7	0.79	0.641	0.56169	<0.200
81MW006A	Plume boundary – CS-20	242.5	0.59	0.346	0.41949	<0.200
69MW1506B	Up gradient of trailing edge of plume – CS-21	137.4	74	0.590	52.614	0.278

Using Henry's Law with a Henry's Law constant for PCE of 0.711, the expected concentration of the air is calculated to equal the concentration of the water times the Henry's Law constant (H). In this study, most of the calculated gaseous concentrations for each well differed greatly. There is no direct correlation to the experimental gaseous results compared to the calculated gaseous results for PCE.

Remediation projects have been implemented since the early 1990s in an effort to treat the contaminated soil and groundwater associated with the plumes in Cape Cod (Massachusetts Military Reservation). Monitoring wells are sampled annually (or at a frequency determined by the nature of contaminants and concentration level) by MMR for levels of PCE in the water. Table 3 shows the water results for PCE contamination of each monitoring well from 2009 and 2010. Remediation is a long process and no significant changes can be seen between 2009 and 2010 data, although the levels of this volatile contaminant vary slightly each year. Data from 2011 is not yet available for comparison.

Table 3: 2009 and 2010 Water Concentrations of Tetrachloroethylene

MMR Monitoring Well Number	Monitoring Well Depth (Feet)	Plume Tetrachloroethylene Concentration (µg/l of water) (2009)	Plume Tetrachloroethylene Concentration (µg/l of water) (2010)
69MW1603A	238.38	ND	0.19
82MW0012A	312.5	20.9	22
82MW0010A	343.7	48.8	57
81MW0011B	152.3	20.5	26
81MW003B	72.3	14.5	19
69MW1517A	232.7	0.37	0.79
81MW006A	242.5	0.64	0.59
69MW1506B	137.4	87.4	74

To determine if there is a correlation between high water levels of PCE and high gaseous levels of PCE in the well casings, the MMR water results from 2010 were compared to the 2011 air sampling results for each monitoring well. There does not seem to be a correlation between high water levels of PCE and high gaseous levels of PCE in the well casing above the plume. Monitoring wells showing the highest water concentration of PCE show low concentrations of PCE in monitoring well casing air samples. Monitoring wells showing the highest gaseous concentrations of PCE does not reflect the highest water concentration of PCE. While there is no apparent correlation between the liquid concentration of PCE and the gaseous concentration of PCE above the water in individual well casings, the transfer mechanism is complex. The level of water in each well casing reflects the level of water in the aquifer. Since the perforated casing sections are positioned at the top and bottom of the plumes, contaminated water was forced into the well casings by the pressure of water in the aquifer above the screens in the casings. While this could explain an initial introduction of contaminated water during well casing installation, it is suggested that the PCE in the vapor phase associated with the water in the well casing would have been depleted several years ago since the cap of each well casings is not air tight. The sample results indicate that PCE is being continuously transferred from the screen section of the casing to the top of the water level in the casing. Diffusion, equilibrium, and volatilization of PCE are possible methods of transfer. The nature and type of the transfer mechanism is beyond the scope of this project. However, the fact that the concentration of PCE in the air space of the well casing is significant requires further investigation.

To determine if the gaseous concentration of PCE is related to the well depth, these values were compared in Table 4 and Figure 2. As shown in Figure 2, the monitoring well with the highest concentration of PCE, at 83.8 (µg/l of air), had the shallowest well depth, at 72.3 (feet). Monitoring wells with the three deepest well depths showed insignificant levels of PCE in air. These results indicated that shallower wells result in higher gas phase concentration within the well casing.

Table 4: Gaseous Concentration of Tetrachloroethylene vs. Well Depth

MMR Monitoring Well Number	Gaseous Tetrachloroethylene Concentration (µg/l of air) (2011)	Monitoring Well Depth (Feet)
69MW1603A	<0.2	238.38
82MW0012A	<0.2	312.5
82MW0010A	<0.2	343.7
81MW0011B	19.7	152.3
81MW003B	83.8	72.3
69MW1517A	0.641	232.7
81MW006A	0.346	242.5
69MW1506B	0.59	137.4

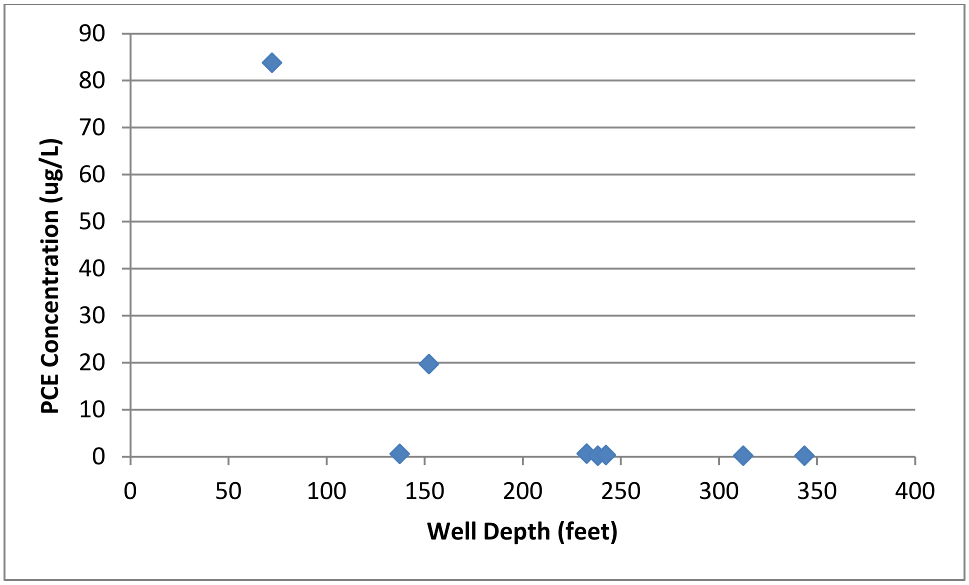

Figure 2: Gaseous Concentration of Tetrachloroethylene vs. Well depth

5.0 - Conclusions

It is well established that plumes CS-20 and CS-21 of MMR are contaminated with volatile organic compounds, tetrachloroethylene and trichloroethylene. In fact, remediation systems have been in place since 2005, which are containing and reducing aqueous concentrations (EPA, 2010). The hypothesis stating that there may also be high levels of PCE present in air pathways prompted this investigation. In an attempt to verify this hypothesis, gas samples were taken from ten wells within CS-20 and CS-21 for tetrachloroethylene and trichloroethylene. The results show that the air within the well casing of CS-20 is mainly contaminated with PCE and that of CS-21 is mainly contaminated with both PCE and TCE. As shown in Table 2, water sample results from public MMR data show slight variation in PCE concentrations. As shown in Figure 2, there seems to be a correlation between well depth and volatile organic levels. Data seems to support the hypothesis that there are high levels of PCE in some well casings; however, there is not enough data to conclusively verify this finding. Although PCE is known to be carcinogenic, there is also not enough evidence to support the notion that existing levels of PCE through air pathways is the reason why Cape Cod suffers from higher cancer rates than the rest of Massachusetts. To investigate the situation further, two tests are suggested. The first series of testing would involve collection of gas samples in the well casings beginning at the top of the casing and proceeding, in 5-10 feet increments to the top of the water level in the well casing. The uniformity of PCE in the gaseous space above the water is critical to understanding the magnitude of this subject. The second series of testing would require drilling and sampling for PCE and TCE in sandy soil above the plume, outside of the well casings.

According to Figure 2, shallower well depths resulted in higher contaminant concentration in air samples. Shallower well depths resulting in higher PCE contaminated air samples could have been because samples were acquired closer to well water levels. Therefore, there is a smaller area inside the well casing for the volatile chemicals to collect. Table 2, however, suggests that there does not seem to be a correlation between the water contamination in the well and the contamination of the air within the well casing. Since only ten wells were tested, additional samples are needed to make a more conclusive statement correlating water and air contaminant concentration.

It is hypothesized that there should be a correlation between the gas and water levels of PCE using Henry's Law. If this hypothesis could be supported with more samples, then the well depth and PCE contamination levels could be related thus verifying the statement regarding the distance from the water level to the sample location.

Through analyzing results taken from ten gas samples from the wells, PCE and TCE are present in the air and therefore volatile chemicals. According to Henry's Law, both PCE and TCE have a high volatility constant and the results support their volatile characteristics (CDC). PCE's volatile properties provide high possibility for ingestion of these chemicals by inhalation. An article by Tucker et al. shows that chronic daily exposure of PCE in dry cleaning establishments lingers in the body over time. This proves that these chemicals can enter the body through inhalation as well as through drinking contaminated water (Tucker et al., 2011).

Research has shown that cancer rates on Cape Cod are 20% higher than the rest of Massachusetts (Silent Spring Institute, 2008). The exposure of these chemicals in the air could be part of the cause of this drastic increase of cancer rates on Cape Cod. More research is needed to look at this.

Further investigation could include testing more wells within CS-20 and CS-21 to better support the results. Since CS-20 and CS-21 are located within residential areas, it would be helpful to test air samples in basements of homes and public establishments. As mentioned in the background, most residents and public buildings in Falmouth have been put on town water, and it would be informative to know which establishments currently use town water and those which still use well water. Cape Cod is known to contain a high retirement population, so it would be informative to find out the ages of residents around the plumes to make the correlation between age and cancer. Numerous other plumes are also located within Falmouth, MA which could also contain volatile organic contaminants. Further testing of these other plumes could also help to provide more conclusive evidence for the link between the health risk of Falmouth residents and volatile organic contaminants. Ultimately, in verifying that these plumes are contaminated, it would be helpful to educate the residents of Falmouth about their everyday exposure to carcinogenic compounds.

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