Health Consultation

Follow-Up Evaluation on Outdoor Use of
Private Well Data in the Fairmount Neighborhood (2010-2013)

HAZEN RESEARCH INC.

GOLDEN, JEFFERSON COUNTY, COLORADO

Prepared by
Colorado Department of Public Health and Environment

DECEMBER 10, 2015

Prepared under a Cooperative Agreement with the
U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Agency for Toxic Substances and Disease Registry
Division of Community Health Investigations
Atlanta, Georgia 30333

Health Consultation: A Note of Explanation

A health consultation is a verbal or written response from ATSDR or ATSDR's Cooperative Agreement Partners to a specific request for information about health risks related to a specific site, a chemical release, or the presence of hazardous material. In order to prevent or mitigate exposures, a consultation may lead to specific actions, such as restricting use of or replacing water supplies; intensifying environmental sampling; restricting site access; or removing the contaminated material.

In addition, consultations may recommend additional public health actions, such as conducting health surveillance activities to evaluate exposure or trends in adverse health outcomes; conducting biological indicators of exposure studies to assess exposure; and providing health education for health care providers and community members. This concludes the health consultation process for this site, unless additional information is obtained by ATSDR or ATSDR's Cooperative Agreement Partner which, in the Agency's opinion, indicates a need to revise or append the conclusions previously issued.

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Foreword

The Colorado Department of Public Health and Environment's (CDPHE) Colorado Cooperative Program for Environmental Health Assessments (CCPEHA) has prepared this health consultation under a cooperative agreement with the Agency for Toxic Substances and Disease Registry (ATSDR). ATSDR is part of the United States Department of Health and Human Services and is the principal federal public health agency responsible for the health issues related to hazardous waste. This health consultation was prepared in accordance with the methodologies and guidelines developed by ATSDR.

The purpose of this health consultation is to identify and prevent harmful health effects resulting from exposure to hazardous substances in the environment. Health consultations focus on health issues associated with specific exposures so that the state or local department of public health can respond quickly to requests from concerned citizens or agencies regarding health information on hazardous substances. The CCPEHA evaluates sampling data collected from a hazardous waste site, determines whether exposures have occurred or could occur in the future, reports any potential harmful effects, and then recommends actions to protect public health.

The findings in this report are relevant to conditions at the site during the time this health consultation was conducted and should not necessarily be relied upon if site conditions or land use changes in the future.

For additional information or questions regarding the contents of this health consultation, please contact the author of this document or the Principal Investigator/Program Manager of the CCPEHA:

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List of Abbreviations and Acronyms

ATSDR	Agency for Toxic Substances and Disease Registry
CCPEHA	Colorado Cooperative Program for Environmental Health Assessments
CDC	Centers for Disease Control and Prevention
CDPHE	Colorado Department of Public Health and Environment
COPC	Contaminant of Potential Concern
CV	Comparison Value
EPA	(United States) Environmental Protection Agency
EPC	Exposure Point Concentration
ft.	foot or feet
HI	Hazard Index
HQ	Hazard Quotient
LOAEL	Lowest Observed Adverse Effect Level
NOAEL	No Observed Adverse Effect Level
µg/L	microgram per liter
UCL	Upper Confidence Limit

List of Tables and Figures in Appendices

Statement and Summary of Issues

Introduction

The Colorado Cooperative Program for Environmental Health Assessments (CCPEHA) and the Agency for Toxic Substances and Disease Registry's (ATSDR) top priority at this site is to ensure that all stakeholders have the best health information possible to protect the community from current and future health hazards associated with groundwater contamination in the Fairmount neighborhood in Jefferson County, Colorado. CCPEHA was asked by the Hazardous Materials and Waste Management Division at the Colorado Department of Public Health and Environment to review additional groundwater data that has been collected since a previous health consultation on the site conducted in 2010. This is a follow-up activity to determine if the same level of risk is still present from using groundwater for alternate outdoor uses such as filling a hot tub or child pool with contaminated groundwater. Other pathways of exposure such as household have been evaluated in previous health consultations that are cited later in this document

Hazen Research, Incorporated is an industrial research and development firm, located approximately 10 miles west of downtown Denver in Golden, Colorado. In March 2007, Hazen officials identified a possible leak in a concrete floor drain in the commercial laboratory of their facility. This discovery led to an investigation which revealed that shallow groundwater beneath the facility and the adjacent Fairmount neighborhood was contaminated with Volatile Organic Compounds (VOCs), including tetrachloroethene and trichloroethene.

CCPEHA initially became involved with the site to assist the Hazardous Waste and Waste Management Division of the Colorado Department of Public Health and Environment with community health concerns related to the contaminated groundwater. To date, CCPEHA has conducted three health consultations to address community health concerns related to groundwater and indoor air in the Fairmount neighborhood.

Since 2008, Hazen has been conducting semi-annual groundwater sampling events at six private wells in the Fairmount neighborhood. The six private wells were selected for monitoring due to their history of elevated VOC concentrations. In March 2008, all homes in the Fairmount neighborhood were connected to the municipal water supply, which eliminated the major pathways of exposure. The main exposure pathway evaluated in this health

consultation is alternative use of contaminated groundwater such as filling child pools and/or hot tubs.

Overview

CCPEHA and ATSDR have reached one conclusion regarding the public health implications of residents using contaminated groundwater for outdoor uses in the Fairmount neighborhood.

Conclusion 1

Chronic exposure to VOCs present in private wells is not expected to harm the health of current and future residents if groundwater is used to fill child pools and/or hot tubs.

Basis for Decision

This conclusion was reached because the estimated non-cancer health hazards are below a level of concern and the estimated cancer risks are below the EPA target cancer risk range. This indicates that there is a very low increased risk of developing cancer and non-cancer health effects from exposure to contaminated water in hot tubs and swimming pools.

Next Steps

Remediation and monitoring of groundwater at the Hazen facility will continue to mitigate potential impacts to groundwater in the Fairmount neighborhood. In particular, private wells #5 and #6 where the concentration of PCE has been reduced, but does not yet meet the CDPHE long-term risk management goals for groundwater (i.e., Colorado Basic Groundwater Standard) remain a concern.

For More Information

If you have immediate concerns about your health, you should contact your health care provider. Please call Thomas Simmons at 303-692-2961 or Dr. Raj Goyal at 303-692-2634 for more information on the materials contained in this health consultation.

Purpose

The Hazardous Materials and Waste Management Division (HWWMD) of the Colorado Department of Public Health and Environment (CDPHE) requested that the Colorado Cooperative Program for Environmental Health Assessments (CCPEHA) evaluate the public health implications associated with outdoor use of six private groundwater wells located in the Fairmount neighborhood of Golden, Colorado. This document continues the evaluation of groundwater contamination at the six private wells.

In 2011, CCPEHA evaluated the public health implications associated with outdoor use of the six private groundwater wells and found a potential health concern from using the wells to fill child pools and hot tubs. However, CCPEHA could not draw definitive conclusions due to the need for more data. Therefore, recommendations were made to continue groundwater remediation and to collect more groundwater data from the six private wells.

The purpose of this evaluation is to examine the current groundwater data collected since the previous health consultation (2010 to 2013) to determine if there is a health concern from using groundwater from the six private wells to fill child pools and hot tubs.

Background

Hazen Research, Incorporated (Hazen) is an industrial research and development firm that was founded in 1961. Hazen currently offers a variety of services for clients in the mineral, chemical, energy, and environmental fields including the development of hydrometallurgical, pyrometallurgical, and mineral benefication processes for most commercial metals, industrial minerals, and inorganic compounds [HWS 2007]. In March 2007, Hazen personnel identified a possible floor leak in a concrete drain trench located in the commercial laboratory. The floor trench conveyed wastewater from laboratory sinks to a treatment sump prior to discharge to the sanitary sewer. Hazen contacted the Colorado Department of Public Health and Environment's Hazardous Materials and Waste Management Division (HMWMD) to inform them of the incident and seek further guidance. HMWMD officials recommended the installation of onsite groundwater monitoring wells to identify any potential contaminant releases from the leaking floor drain. Initially, the HMWMD of CDPHE required Hazen to also analyze for VOCs in addition to inorganics. The analytical results adjacent to the lab showed that inorganics were at background levels, but PCE was found as the potential contaminant of concern in the VOC analyses. So the follow up testing was focused on PCE and breakdown products.

PCE, trichloroethene, and chloroform were identified in the onsite monitoring wells with PCE being the most prominent contaminant. Further investigation of the underlying aquifer revealed that contamination was also present in the Fairmount neighborhood, which lies east-southeast of the Hazen facility (Figure A1).

Initially, the HMWMD contacted CCPEHA in July 2007 to examine the potential public health hazards associated with the groundwater contamination in the Fairmount

neighborhood. At the time, some residents in the Fairmount neighborhood were using private wells for household use. CCPEHA's initial evaluation examined household use of groundwater, indoor air, and homegrown produce that had been irrigated with contaminated groundwater [ATSDR 2008]. Because it was unknown how long the contamination had been present, and what the concentration of contaminants was over time, it could not be determined if the contamination presented a past public health hazard (prior to July 2007). However, it was clear that the levels of contamination in some private wells were not suitable for household use (drinking, showering, etc.) because of estimated cancer risks above the cancer risk threshold. In March 2008, all residents (11 properties) that were using a contaminated groundwater well for household purposes were connected to city water, which eliminated the major pathways of exposure.

In September 2008, Hazen began remediating the groundwater contamination onsite at their facility. Hazen has been regularly monitoring groundwater contamination in the Fairmount neighborhood since 2007. Six private groundwater wells in the Fairmount neighborhood were selected in Hazen's groundwater monitoring plan. These wells were selected because of their history of elevated contaminant levels, relative to Colorado's Basic Groundwater Standards, and their location. In 2009, CCPEHA conducted a health consultation to evaluate the potential health hazards at one of the wells in the groundwater monitoring regime for new owners of the property that had concerns beyond household use of the contaminated groundwater [ATSDR 2009]. In addition to unacceptable health risks from using the well for household use, it was found that alternative uses of the contaminated water (filling hot tubs and child pools) could pose a potential health hazard due to estimated cancer risks above the high-end of EPA's target cancer risk range (i.e. above 100 excess cancer cases per million people exposed).

Based on these findings, CCPEHA examined this scenario for all private groundwater wells in the monitoring program in 2011 [CDPHE 2011]. In that health consultation, no public health harm was expected from using groundwater from wells #1-4 to fill child pools and hot tubs. However at wells #5 and #6, it could not be determined if the levels of contaminants in those wells would pose a public health hazard to residents using their well water to fill child pools and hot tubs. At the time, the levels of PCE were increasing in the latest groundwater samples collected from the wells. The results of the 2011 evaluation indicated that cancer risks were a potential concern if the concentration of PCE continued to increase. At the time, the estimated cancer risks based on the latest available data were slightly above the EPA's target cancer risk range (i.e. above 100 excess cancer cases per million people exposed).

Since the previous health consultation was conducted, Hazen has continued to remediate groundwater in the Fairmount neighborhood and levels of contaminants have shown a decreasing trend. Therefore, the focus of this evaluation is to review the additional groundwater data that has been collected since the last health consultation was conducted to determine if health hazards still exist from current outdoor uses such as filling child pools and hot tubs with groundwater from the six private wells.

It should be noted that the evaluation of the exact source of VOC contamination is not the focus of this health consultation. The data indicates that VOCs are migrating off of the Hazen property. However, it is unknown if Hazen is the only source of groundwater contamination in the Fairmount neighborhood or if the contamination in all private wells originated at the Hazen property. Rather, the focus of this health consultation is to evaluate public health implications of groundwater contamination that exists in private wells. In no way should this information be construed as a determination of the source of contamination in each well.

Demographics

According to U.S. Census data (2010), there are 1,913 individuals occupying 820 homes within a one mile buffer surrounding the Hazen facility (Figure A1). Fairmount is a middle-class neighborhood located in northeastern Golden. Approximately 6% of this population is under the age of six years and approximately 16% is over the age of 65 years. Language data is not available at this resolution. However, the data does show a small Hispanic/Latino (5%) and Asian (0.5%) subpopulation indicating that some individuals may need materials in languages other than English.

Community Health Concerns

Community health concerns have been collected by CDPHE through phone conversations, visits to community members at their residence, and public meetings. The primary health-related community concerns are: the general health effects of exposure to PCE; how to identify exposure; the likelihood of PCE exposure resulting in miscarriages; if it was safe to eat fruits and vegetables; and the carcinogenic risk of PCE exposure. General health effects of PCE are provided as ATSDR Public Health Statement in Appendix C. These community concerns have been evaluated in a series of previous health consultations [ATSDR 2008 and 2009; CDPHE 2011]. This follow-up health consultation evaluates both non-cancer health effects and the potential for cancer from exposure to PCE-related contaminants during outdoor use of private well water in the Fairmount neighborhood.

Discussion

The overall goal of this public health consultation is to determine if contaminants in private wells pose a public health hazard and to make recommendations to protect residents. The first step includes an examination of the currently available environmental data to determine if contaminants of potential concern (COPCs) exist. If COPCs exist, the next step is to determine if and how people may come into contact with the contamination. If complete or potential exposure pathways exist, exposure doses are estimated and compared to health-based guidelines established by the ATSDR and EPA. This is followed by an in-depth health effects evaluation if the estimated exposure doses exceed health-based guidelines.

Exposure Assessment

Environmental Data

Historically, the first groundwater samples from private wells were collected in the summer of 2007. Hazen identified approximately forty private groundwater wells in the

Fairmount neighborhood through well surveys and community outreach. All of the wells have been sampled in the past and PCE was not detected, or was detected at very low concentrations (<1ppb), in over ½ of the private wells. During subsequent sampling events, the number of wells that were sampled was pared down and focused primarily on the private wells that showed evidence of contamination. Six private wells have been sampled on a regular basis since 2007 (Figure A2). In addition to the six private wells Hazen monitors on a routine basis, they are also routinely monitoring four groundwater monitoring wells that Hazen installed in the neighborhood, to keep an eye on the plume. Data from private wells and groundwater wells both indicate that the concentrations of PCE in the neighborhood are decreasing. The plume is collapsing, not migrating or expanding, so the HMWMD doesn't believe that additional monitoring locations are necessary.

The data utilized for this health consultation includes all groundwater data collected since the spring of 2010, when the last health consultation was conducted. This includes the time period October 2010 through September 2013. Private groundwater data is collected on a semi-annual basis from the six private wells and sampling events typically occur in the spring and fall. Groundwater samples are sent to ESC analytical laboratory in Evergreen, Colorado for analysis of volatile organic (VOCs) by EPA method 8260B.

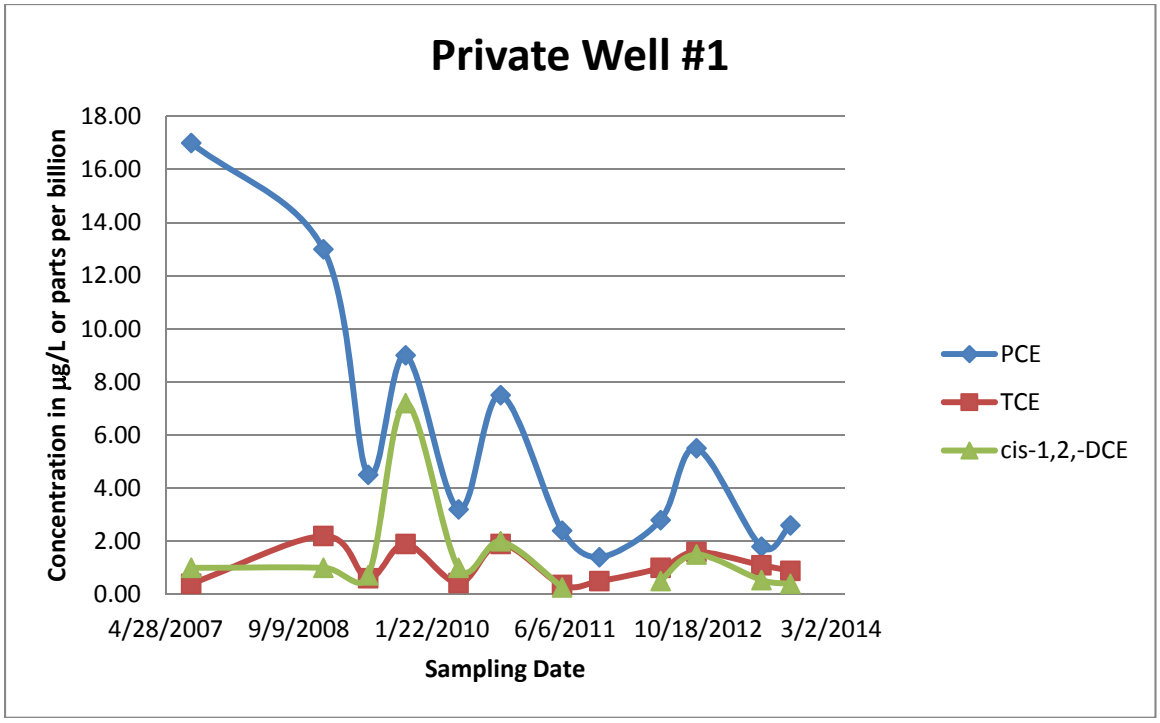
In September 2008, Hazen began remediating the groundwater contamination onsite at their facility. As a result the concentration of VOCs in the aquifer appears to be decreasing. PCE has always been the major contaminant of concern, and it is still found at the highest levels. For instance, in private well #5, the concentration of PCE has decreased from a maximum of 70 ppb (parts per billion or micrograms per liter) to 7.6 ppb in the latest sample collected from the well. In private well #6, the concentration of PCE has reduced from a maximum of 95 ppb down to 15 ppb in the latest sample collected. The other three VOCs (trichloroethene, cis-1,2-dichloroethene, and chloroform) are found at fairly low and stable concentrations. Vinyl chloride has never been detected in any of the six private groundwater wells. The groundwater data collected from each private well is presented in more detail below. Table A1 is a summary of the groundwater data collected from the six private wells in the Fairmount neighborhood since the time of the last health consultation. Table A2 contains the complete data set.

Private Well #1

Private well #1 is located in the western portion of the Fairmount neighborhood, closest to the Hazen facility. Seven groundwater samples have been collected from this well since the last health consultation was completed. The groundwater data was collected between October 2010 and September 2013. During this time, the levels of PCE in private well #1 have decreased from a maximum of 7.5 ppb to 2.6 ppb. Methylene chloride, TCE, and *cis*-1,2-DCE were also detected, but all were found at less than 2 ppb. Chloroform was only detected one time at a concentration of 1 ppb (Table A2).

The graph below shows the concentration of the major contaminants in private well #1 since PCE was first discovered in groundwater in 2007. Since groundwater sampling began at private well #1 in August 2007, the concentration of PCE has decreased from 17

ppb to 2.6 ppb (September 2013). The concentration of TCE has fluctuated slightly over this same time period with a maximum concentration of 2.2 ppb (December 2008) and a minimum concentration of 0.4 ppb. The latest sampling data (September 2013) showed that TCE was detected at a concentration of 0.9ppb in Private well #1. Similarly, the concentration of cis-1,2,-DCE has fluctuated since the initial sample was collected in 2007 from a high of 7.2 ppb in October 2009 to non-detectable levels in the latest groundwater sample from the well.

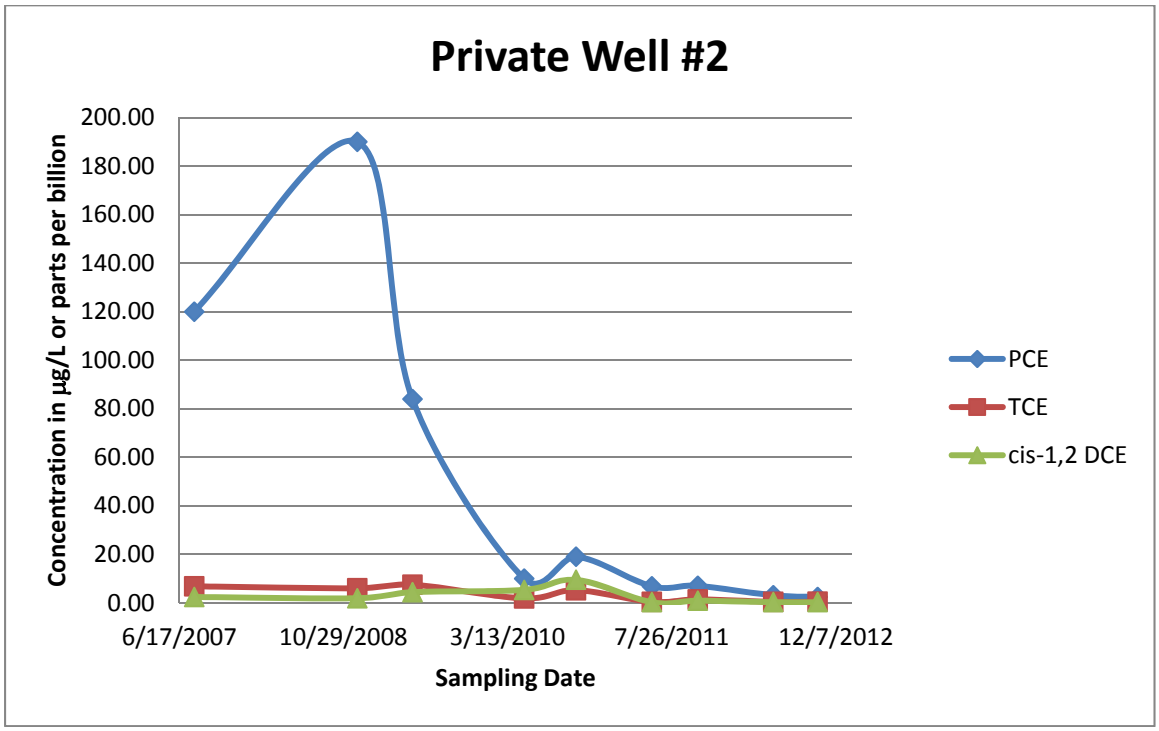


Private Well #2

Private well #2 is located approximately 300 feet east of private well #1 in the western portion of the Fairmount neighborhood. PCE contamination in private well #2 has decreased from 19 ppb in October 2010 to 2.4 ppb in the latest sampling round conducted in October 2012. This value is below CDPHE's Basic Standards for Groundwater of 5 ppb (CDPHE 2013) and the well is no longer part of the semi-annual groundwater monitoring plan for the site. TCE was detected in 3 of the 5 samples collected since the last evaluation and was last detected at 0.47 ppb, which is nearly equivalent to the detection limit of the analytical method (0.40 ppb). Cis-1,2,-DCE was detected in 2 of the 5 samples collected since the last evaluation, but was not detected in either sample collected in 2012.

The graph below shows the concentration of the major contaminants in private well #2 since PCE was first discovered in groundwater in 2007. Since groundwater sampling began at private well #2, the concentration of PCE has decreased from a high of 190 ppb

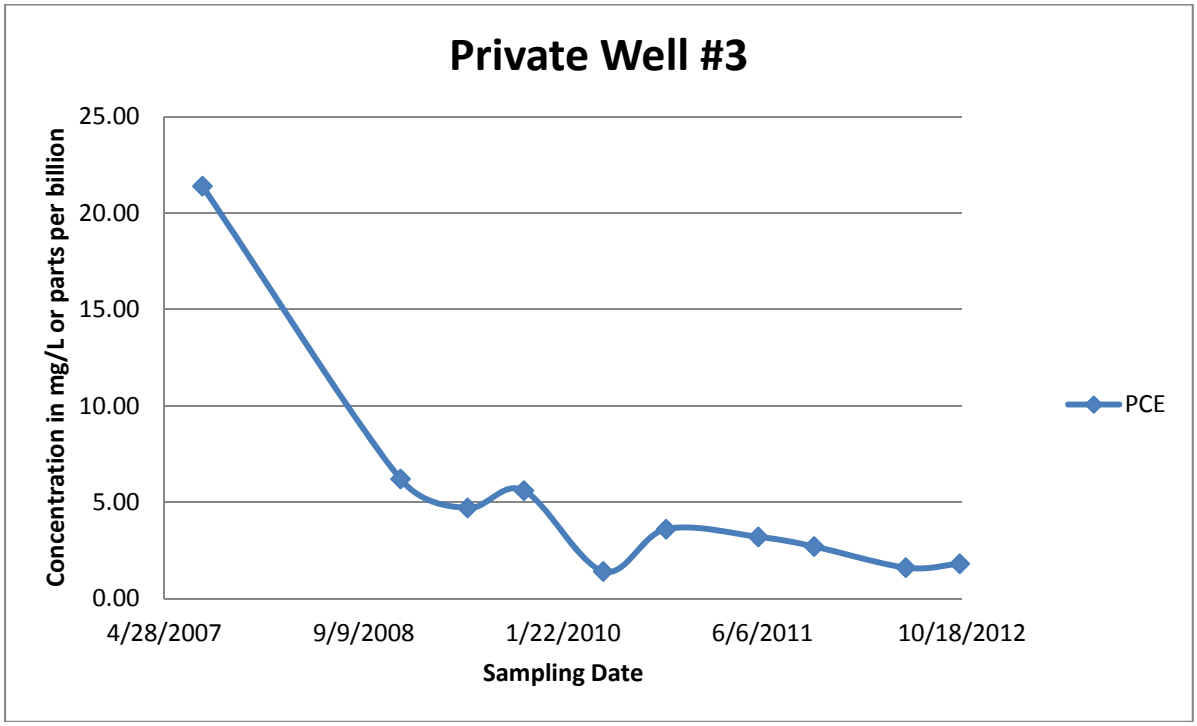
to 2.4 ppb in the latest sampling round collected in October 2012. TCE reached a maximum concentration of 7.5 ppb in May 2009 and has since decreased to virtually non-detectable levels. The same is true for cis-1,2-DCE, which reached a maximum concentration of 9.5 ppb in October 2010 and was not detected in either sample collected in 2012, the latest year the sampling data was collected.



Private Well #3

Private well #3 is located east of private wells 1 and 2 in the Fairmount neighborhood. PCE is the only contaminant that has ever been reliably detected in private well #3. Since the last evaluation, the concentration of PCE has decreased from 3.6 ppb to 1.8 ppb in October 2012. Since 2012, the concentration of PCE in private well #3 has been consistently below the CDPHE Basic Standards for Groundwater and is no longer part of the semi-annual groundwater monitoring plan for the site. TCE and *cis*-1,2-DCE have not been detected in any of the samples collected since the previous evaluation was conducted.

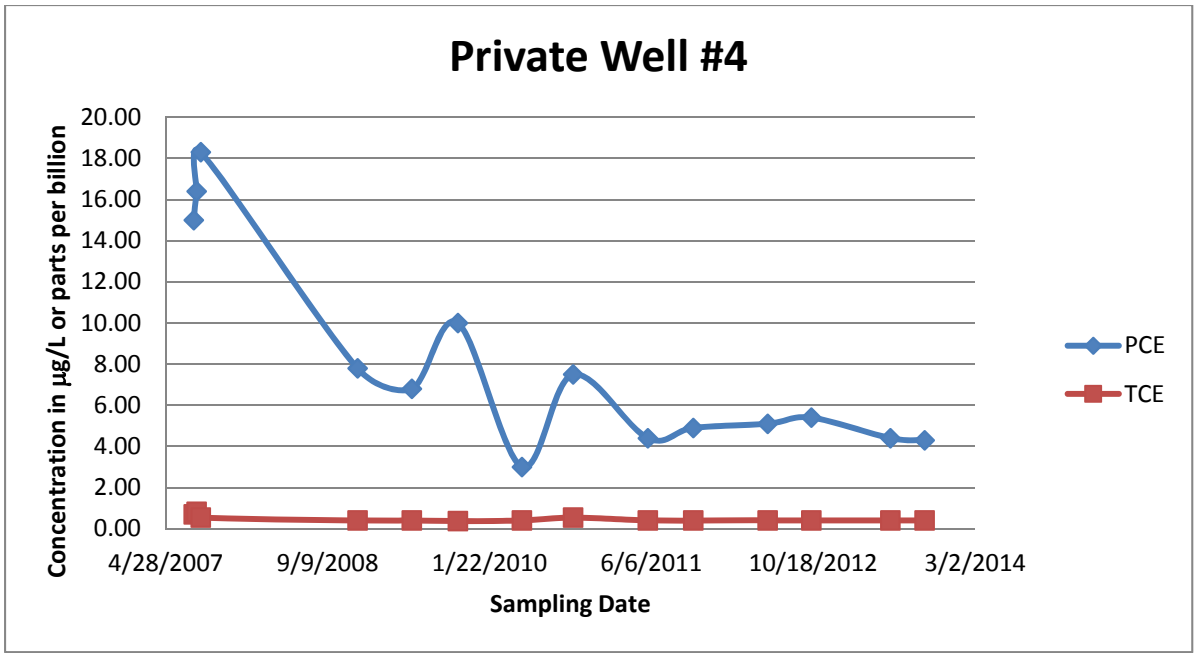
The graph below shows the concentration of PCE in private well #3 since the initial discovery in 2007. The initial sampling results for private well #3, collected in 2007, indicated the concentration of PCE at 21.4 ppb and the latest sampling results from the well showed a PCE concentration of 1.8 ppb. TCE was only detected in the initial sample collected from this well at a concentration of 0.7 ppb (August 2007). Since that time TCE has not been detected in groundwater sampling. *Cis*-1,2-DCE has never been detected in private well #3.



Private Well #4

Private well #4 is located in the far eastern portion of the Fairmount neighborhood, near the distal extent of the contaminant plume (Figure A2). PCE has been detected in private well #4 at fairly low levels since the last evaluation. In October 2010, the concentration of PCE was 7.4 ppb, which decreased to 4.3 ppb in the latest sample collected from the well in September 2013. TCE was also detected in the well in October 2010 at a maximum concentration of 0.54 ppb. For all other samples collected from the well during this time period, TCE was been not detected. *Cis*-1,2-DCE has never been detected in private well #4.

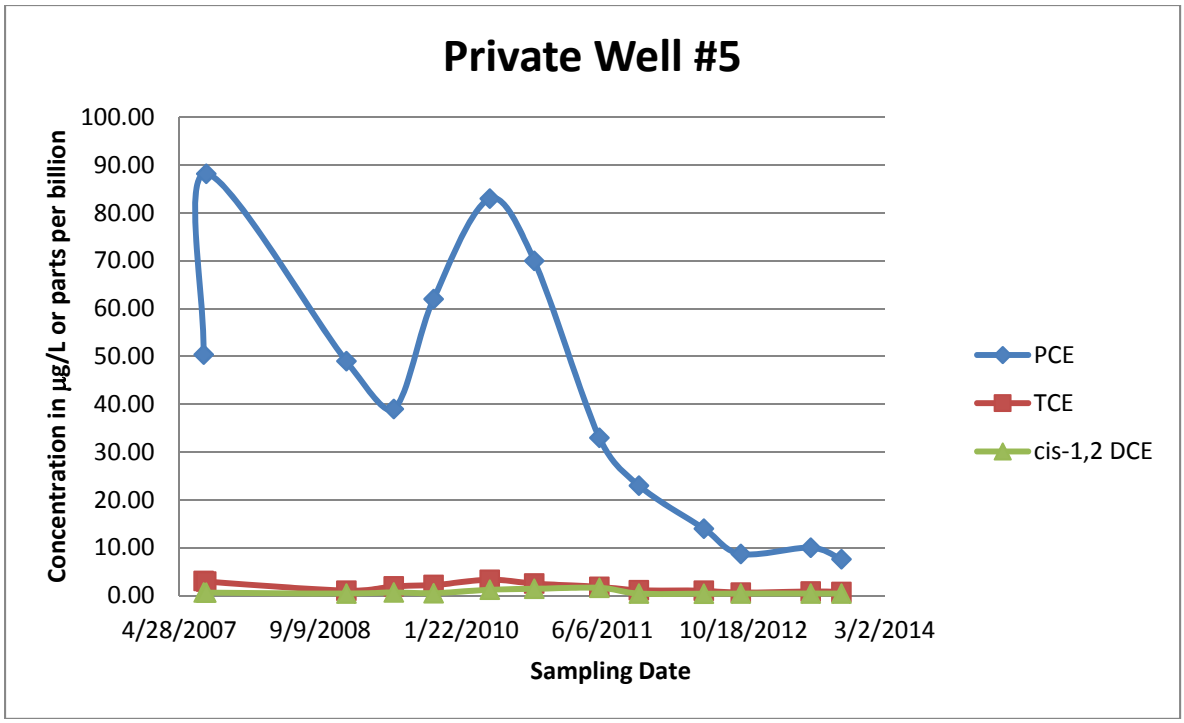
The graph below shows the concentration of PCE and TCE in private well #4 since the initial discovery in 2007. The initial sampling results for private well #4 indicated the concentration of PCE at 15 ppb, which increased slightly over the next two sampling rounds to a high concentration of 18ppb. Then the concentration of PCE began to decrease to a concentration of 4.3 ppb in the latest sample collected in September 2013. TCE was detected in private well #4 at low concentrations (below 1 ppb) in all samples collected from 2007 to 2010. TCE has not been detected in private well #4 since October 2010 and *cis*-1,2-DCE has never been detected in private well #4.



Private Well #5

Private well #5 is also located in the far eastern portion of the Fairmount neighborhood (Figure A2). Since the last evaluation, the concentration of contaminants in private well #5 has decreased dramatically. For instance in private well #5, the levels of PCE have decreased from 83 ppb (May 2010) to 7.6 ppb in the latest sampling data collected in September 2013. The concentration of TCE decreased from 3.3 ppb to 0.7 ppb and *cis*-1,2-DCE decreased from 1.2 ppb to non-detectable levels in the latest sampling rounds.

The graph below shows the concentration of the major contaminants in private well #5 since PCE was first discovered in groundwater in 2007. Prior to October 2010, the concentration of contaminants fluctuated, but ended up at relatively equivalent concentrations in the last sampling round included in the previous evaluation. Thus, there was no major movement in contaminant concentrations before the previous evaluation commenced. However, from October 2010 to May 2011, the concentration of PCE decreased in private well #5 from 70 ppb to 33 ppb. PCE continues to decline in the well and the last sampling period (September 2013) indicated a concentration of 7.6 ppb. To a lesser degree, TCE and cis-1,2-DCE mimic this decline. TCE was found at a maximum concentration of 3.3 ppb in May 2010 and has since decreased to 0.73 ppb. *Cis*-1,2-DCE was found at a maximum concentration of 1.6 ppb in May 2011 and is currently not detectable in groundwater sampling. It should be noted that the latest concentration of PCE in private well #5 is above the Colorado Basic Groundwater Standard of 5 ppb.

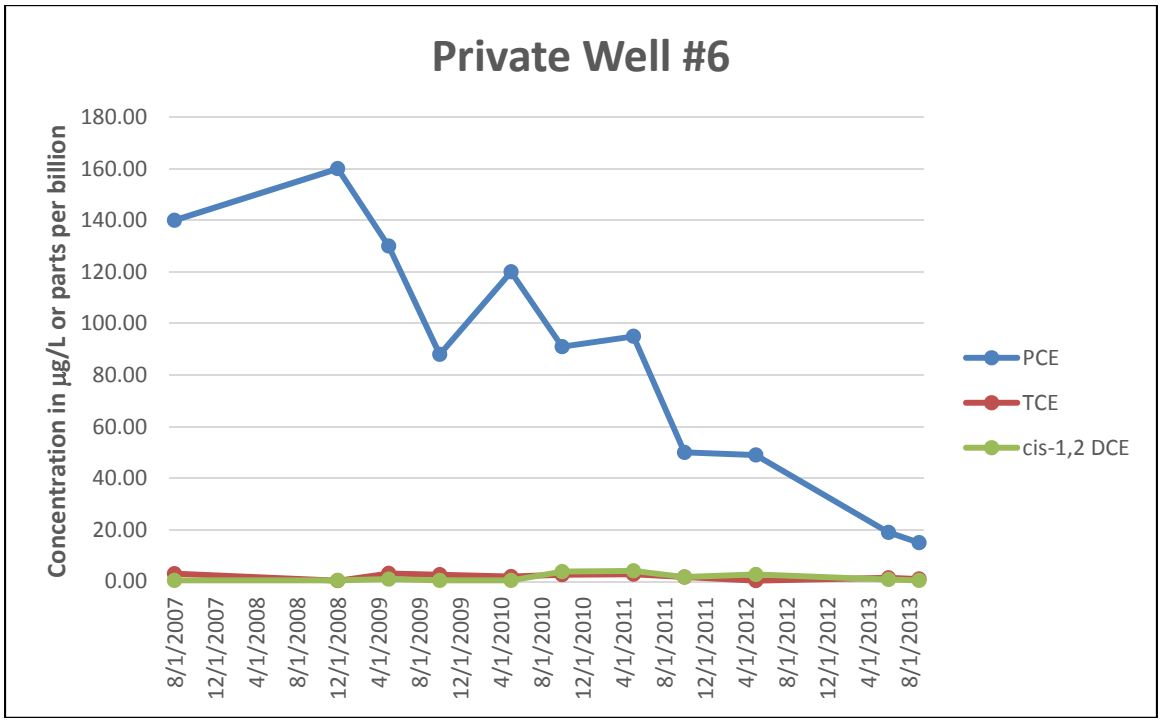


Private Well #6

Private well #6 is also located in the far eastern portion of the neighborhood, just south of private well #5 (Figure A2). In private well #6, the levels of PCE have decreased from 120 ppb to 15 ppb since the last evaluation was conducted. The most substantial reduction occurred between May and October 2011 when the concentration of PCE decreased by a factor of 2 from 95 ppb to 50 ppb. From 2012 to 2013, the PCE concentration dropped from 49 ppb to 19 ppb. Since the last evaluation was conducted, the concentration of TCE dropped from 2.6 ppb to 0.9 ppb in the latest sample. Over the same period of time, *cis*-1,2-DCE decreased from 4.1 ppb to 0.4 ppb. This sampling data indicates that the concentration of contaminants in private well #6 is continually decreasing as shown in the graph below.

Prior to October 2010, the concentration of contaminants in private well #6 fluctuated. At the time of the last evaluation, the concentration of PCE had increased from 88 ppb to 120 ppb. At this level, the estimated cancer risks from using the well to fill hot tubs and child pools were above the EPA's target cancer risk range. However, from October 2010 to May 2011, the concentration of PCE began to decrease from 120 ppb to 91 ppb. The next sampling period in May 2011 had nearly equivalent concentration of PCE and then began the downward trend discussed above. The last sampling period (September 2013) indicated a PCE concentration of 15 ppb. To a lesser degree, TCE and *cis*-1,2-DCE follow this trend. TCE was found at a maximum concentration of 3.1 ppb in May 2009 and has since decreased to 0.94 ppb. *Cis*-1,2-DCE was found at a maximum concentration of 4.1 ppb in May 2011 and was last detected at a concentration of 0.39 ppb. *Cis*-1,2-DCE was not detected in the sampling data used in the previous evaluation.

It should be noted that the latest concentration of PCE found in private well #6 is above the Colorado Basic Groundwater Standard of 5 ppb



Selection of Contaminants of Potential Concern

To identify COPCs, the available groundwater data that was collected from the 6 private wells, was screened with comparison values established by the ATSDR and EPA. The comparison values (CVs) from both agencies were reviewed and the most conservative value was selected for the screening process (Table A3). The CVs used in this evaluation are derived for residential water use. Residential CVs are based on 350 days exposure per year over a period of 30 year and include drinking water, dermal contact, and inhalation of volatile organic compounds such as those found in this assessment. Using these CVs is considered conservative and protective of residents in the Fairmount neighborhood based on what is currently known about the use of contaminated groundwater. Therefore, if the maximum concentration of a particular contaminant is below the CV, it is dropped from further evaluation. If the maximum concentration of the contaminant is above the CV, it is generally retained for further analysis as a COPC. However, exceeding the CV does not indicate that a health hazard exists, only that additional evaluation is warranted.

Table 1 below summarizes the contaminants that exceeded the screening value in the latest two sampling rounds. A more detailed table of the screening process is presented in Table A3. Overall, three COPCs were selected based on the residential CVs: PCE, TCE, and chloroform. PCE is the most prominent contaminant since it was detected in each well and also has the highest concentration of all contaminants. However, PCE exceeded

the screening value in only one well (private well #6). Chloroform was selected as a COPC in each private well. In many cases, chloroform was not detected in the well, but the detection limit of the analytical method is equal to the screening value and chloroform was retained as a COPC. Trichloroethene was selected as a COPC in three of the six private wells evaluated in this consultation. *Cis*-1,2-DCE was detected in some private wells, but was below the CV and was not carried further in the evaluation.

It should be noted that PCE, TCE, and chloroform were all selected as COPCs in the previous evaluation. For comparison purposes, exposure doses were calculated for each of these contaminants based on the latest two sampling rounds conducted in 2012 or 2013.

Table 1. COPC Summary

Private well Location	Tetrachloroethene	Trichloroethene	*cis*-1,2-Dichloroethene	Chloroform
#1		X		X
#2				X
#3				X
#4				X
#5		X		X
#6	X	X		X

Conceptual Site Model

A conceptual site model helps people to visualize how contaminants of potential concern move in the environment at the site and how people might come into contact with these contaminants. A conceptual site model identifies the five components of a completed exposure pathway, which include:

- A *source* of contamination.
- A *release mechanism* into water, soil, air, food chain or transfer between media (i.e., the fate and transport of environmental contamination).
- An *exposure point* or area (e.g., drinking water well, residential yard).
- An *exposure route* (e.g., ingestion, dermal contact, inhalation).
- A *potentially exposed population* (e.g., residents; adults and children).

Exposure pathways are classified as complete, potential or incomplete based on the available information and the likelihood of a particular pathway actually occurring. Since COPCs exist in private wells in the Fairmont neighborhood, the next step is to determine if people are coming into contact with these contaminants. The exposure evaluation examines current and future use of private wells to develop a conceptual site model that describes how people could come into contact with groundwater-related

contaminants in the Fairmont neighborhood. Simply having contamination in the environment does not indicate there is a public health hazard. Therefore, it is necessary to determine if and how individuals can be exposed to the contamination.

As mentioned before, previous health consultations conducted on the Fairmount neighborhood have addressed other types of environmental data such as indoor air and fruit and vegetable data. The limited available data from home-grown fruits and vegetables in the Fairmount neighborhood was evaluated in ATSDR 2008 and did not show any contaminants thought to be related to the groundwater contamination under investigation. Indoor air sampling data was also evaluated in ATSDR 2008 and ATSDR 2009. The estimated cancer risks from inhalation of PCE in indoor air were around the mid-point of the EPA's target cancer risk range for this pathway based on the limited available data.

Exposure Scenarios/Receptors

Aside from household use of groundwater, which ceased in March 2008, the remaining potential exposure pathways include irrigation and other typical outdoor household uses of water. This includes filling child pools and hot tubs with the groundwater and outdoor cleaning activities that would result in short-term dermal (skin) contact. The main exposure pathways considered in this evaluation are dermal contact and incidental ingestion of contaminated groundwater while wading/bathing in child pools and/or hot tubs. Short-term contact with contaminated groundwater during other potential uses of private wells including outdoor cleaning, connecting hoses, rinsing hands, etc. are considered inconsequential exposure pathways at the contaminant levels found in these wells and the limited amount of time that people would be in contact with the water. Therefore, these exposures were not considered further in this evaluation.

The primary exposure assumption is that residents will use their private well to fill child pools and/or hot tubs. Two primary pathways of exposure exist in this scenario including dermal contact and incidental ingestion. In addition, people could inhale vapors off-gassing from the contaminated groundwater used to fill the hot tubs and child pools. However, this exposure is likely to be minimal for the following reasons: 1) low concentration of VOCs found in private wells, 2) dilution of vapors in the open air atmosphere, and 3) the amount of water and the surface area in hot tubs and child pools is much less than in a swimming pool. Therefore, this pathway is not quantitatively evaluated in this consultation, but is addressed qualitatively in the Uncertainty Analysis: To estimate exposure doses, assumptions must be made to describe the exposure scenario over a certain period of time. These assumptions, or exposure factors, can be based on scientific literature, site-specific information, or professional judgment. As shown in Table B1, the recreational exposure factors used in this evaluation are based on professional judgment and assume that residents of the Fairmount neighborhood could use a child pool, hot tub, etc. approximately 3 hours per week during the warmer months of the year or 1 hour per week throughout the year (hot tubs) for a period of 6 yrs. (children) or 30 years (adult). These are the same exposure factors that were used to evaluate health risks in the previous health consultation published in 2011. It is possible that people could be exposed more or less frequently, which could result in an under- or over-estimation of health risks. More information regarding the exposure factors used in

this evaluation is available in Appendix B. The major exposure pathway information is summarized below in the conceptual site model.

Table 2. Conceptual Site Model

Source	Affected Environmental Medium	Point of Exposure	Potentially Exposed Populations	Timeframe of Exposure	Route of Exposure
Contaminated groundwater	Private groundwater wells	Child Pools and Hot tubs	Child and Adult Residents	Current and Future	1) Dermal Exposure and 2) Incidental Ingestion of groundwater in child pools and hot tubs

Note: Ingestion of home-grown fruits/vegetables irrigated with contaminated groundwater is considered a complete, but inconsequential pathway, based on the limited available historical data. No new data are available for further evaluation. In addition, indoor air contaminated with PCE (vapor intrusion and/or indoor sources) is also a complete pathway, but not evaluated here because no new data are available. For the results of previous evaluations on these pathways, see ATSDR (2008) and ATSDR (2009).

Exposure Point Concentrations

Exposure Point Concentration (EPC) for each of the contaminants is selected based on the higher value of the latest 2 sampling rounds (2012 and 2013). This approach is consistent with the recent EPA directive on estimating groundwater exposure point concentrations [EPA 2014a]. This EPA directive recommends using data from the latest two rounds collected within the last year so that the data is representative of current conditions.

Public Health Implications

Evaluating the public health implications of exposure to groundwater contaminants is a multi-step process. For all contaminants that exceed the CV, exposure doses are estimated for non-cancer and cancer endpoints (if the COPC is a carcinogen) for each exposure pathway identified in the exposure assessment. To assess the public health implications of exposure to contaminants of potential concern, the estimated doses for non-cancer health effects are divided by the appropriate health-based guidelines to calculate the Hazard Quotient (HQ). The health-based guidelines used in this evaluation are shown in Appendix C, Table C1. The cumulative non-cancer hazard, or hazard index (HI) of multiple contaminants is estimated by adding all HQs together. A HQ or HI greater than one indicates the estimated exposure exceeds the non-cancer health-based guideline and requires further evaluation by comparison of estimated exposure doses or concentrations with reference levels observed in animal and/or human studies (see Appendix C for more details). These non-cancer levels are referred to as the No-Observed-Adverse-Effect Level (NOAEL) and the Lowest-Observed-Adverse-Effect Level (LOAEL). The in-depth analysis serves as a means of gaining a better perspective on how strongly the available toxicological information in the scientific literature suggests potential for harmful exposures (i.e., could harm people's health). However, it

should be noted that because of the uncertainties regarding exposure conditions and adverse health effects associated with environmental levels of exposure, definitive answers on whether health effects actually will or will not occur are not possible.

The estimated doses for cancer health effects are calculated in a similar manner to non-cancer health effects; however, cancer doses are averaged over a lifetime and the results of the exposure dose estimation are multiplied by the Oral Slope Factors established by EPA or state health agencies (Table C3). This calculation estimates the cancer risk, which is compared to EPA's target cancer risk range of 1 excess cancer case per million people exposed to 100 excess cancer cases per million people exposed (1×10^{-6} to 1×10^{-4}).

Exposure doses were calculated for both children and adults based on the COPCs found at each private well in the 2011 health consultation. The concentration of many of the previously identified COPCs no longer exceeded the screening value per the latest sampling rounds. However, exposure doses were calculated on these contaminants for comparison to the potential health hazards identified in the previous report [ATSDR 2011]. The exposure doses for dermal contact and incidental ingestion are combined to produce a total estimated dose while wading/bathing in a child pool and hot tub filled with well water. Please refer to Appendix B for additional information on the exposure doses calculated for this evaluation. Appendix C contains additional information on the toxicological evaluation and toxicity values used in this evaluation. In addition, Appendix C includes an update on changes in the toxicity values for chloroform, PCE and TCE that have occurred since the 2011 health consultation (Table C2).

Private Well #1

TCE and chloroform exceeded the CV in the latest two sampling rounds conducted in June and September 2013. TCE slightly exceeded the screening value of 0.76 ppb at a concentration of 1.1 ppb. Chloroform was not detected in the latest sampling rounds; however, the detection limit of the analytical method was equivalent to the screening value of 0.32 ppb. Therefore, chloroform was carried forward as a COPC. PCE was not selected as a COPC, but doses were estimated in this evaluation in order to provide comparison to the previous 2011 health consultation. In the 2011 health consultation, PCE, TCE, and chloroform were selected as COPCs with respective concentrations of 17 ppb, 2.2 ppb, and 2.8 ppb [CDPHE 2011]. As such, doses were estimated for PCE, TCE, and chloroform in this evaluation.

The child and adult estimated non-cancer doses of PCE, TCE, and chloroform are all well below the associated health-based guideline for these contaminants (Tables A4 and A5). The largest hazard quotient for child exposure to TCE (incidental ingestion and dermal contact), which is the ratio of the estimated dose to the health-based guideline, indicates that the estimated exposure for TCE is nearly 400 times lower than the health-based guideline. This indicates that the estimated exposure to PCE, TCE, and chloroform in child pools and hot tubs filled with groundwater from private well #1 is not likely to result in adverse non-cancer health effects. In the 2011 health consultation, non-cancer health hazards were also below a level of concern at private well #1. However, the potential for developing non-cancer health effects is much lower now due to the

decreased concentration of all contaminants despite the lower (or more conservative) health-based guidelines for PCE and TCE.

The estimated cancer risks are also well below a level of concern based on the latest groundwater samples collected from private well #1 (Table A6). The total age-adjusted cancer risk, which takes into account exposures occurring from childhood to the age of 30 years, is 4.4×10^{-8}. This analysis indicates that out of one million people exposed, less than one (0.04) excess cancer case might occur. The estimated cancer risk indicates a very low increased risk of developing cancer from exposure to contaminants in a child pool or hot tub. In comparison, the previous 2011 health consultation estimated that out of one million people exposed, 15 excess cancer cases might occur [CDPHE 2011]. The estimated cancer risk based on the latest sampling rounds is approximately 300 times lower than the risk estimated in the previous 2011 health consultation report.

Overall, the estimated dermal and incidental ingestion exposure to contaminants in private well #1 is not likely to result in adverse non-cancer health effects based on the assumptions made in this evaluation. In addition, the estimated risk of developing cancer from exposure to contaminants in private well #1 is also very low.

Private Well #2

Chloroform was the only contaminant that exceeded the CV in the latest sampling rounds from private well #2 that were conducted in May and October 2012. Once again chloroform was not detected, but the detection limit of the analytical method (0.3 ppb) is equivalent to the screening value. The concentrations of PCE and TCE are so low that the well is no longer monitored regularly. PCE and TCE were detected in the well water, but at low concentrations of 2.6 ppb and 1.1 ppb, respectively. In comparison, the maximum levels of PCE, TCE, and chloroform found in the previous 2011 health consultation were 190 ppb, 7.5 ppb, and 10 ppb, respectively.

The child and adult estimated non-cancer exposure doses for PCE, TCE, and chloroform are all well below the associated health-based guidelines (Table A4 and A5). The largest HQ is 0.003 from children's exposure to PCE while swimming/bathing. This indicates that the estimated exposure dose to PCE is approximately 300 times lower than EPA's Reference Dose for PCE. No adverse non-cancer health effects are expected at this exposure level. In addition, no adverse health effects from exposure to TCE and chloroform are likely to occur since the combined non-cancer HQ for both contaminants is much lower than 1. The total hazard index (HI) for children from exposure to all contaminants is 0.005 and the total HI for adults is 0.003. This indicates that exposure to all contaminants of concern while swimming/wading in child pools and hot tubs filled with water from private well #2 is not likely to result in non-cancer adverse health effects. In the 2011 health consultation, non-cancer health hazards were also below a level of concern at private well #2. However, the potential for developing non-cancer health effects is much lower now due to the decreased concentration of all contaminants despite the lower health-based guidelines for PCE and TCE.

The estimated cancer risks are also well below a level of concern based on the latest groundwater samples collected from private well #2 (Table A6). The total age-adjusted cancer risk is 3.0×10^{-8}, which takes into account exposures occurring from childhood to the age of 30 years. This indicates that out of one million people exposed, less than one (0.03) excess cancer case might occur. The estimated cancer risk indicates a very low increased risk of developing cancer from exposure to contaminants in a child pool or hot tub filled with water from private well #2. In comparison, the previous 2011 health consultation estimated that out of one million people exposed, 168 excess cancer cases might occur [CDPHE 2011]. The estimated cancer risk based on the latest sampling rounds is approximately 5,600 times lower than the risk estimated in the previous 2011 health consultation report.

Overall, the estimated dermal and incidental ingestion exposure to contaminants in private well #2 is not likely to result in adverse non-cancer health effects based on the assumptions made in this evaluation. In addition, the estimated risk of developing cancer from exposure to contaminants in private well #2 is also very low.

Private Well #3

The only contaminant that exceeded the CV in private well #3 was chloroform at a concentration of 0.40 ppb, which is only slightly higher than the screening value of 0.3 ppb. The maximum detected concentration of PCE in the latest two sampling periods in May and October of 2012 was 1.8 ppb. TCE was not detected in the latest two sampling events. In comparison, the maximum levels of PCE, TCE, and chloroform found in the previous 2011 evaluation were 21.4 ppb, 0.7 ppb, and 1.0 ppb, respectively [CDPHE 2011].

The child and adult estimated non-cancer doses for PCE, TCE, and chloroform are all well below the associated health-based guideline for these contaminants (Tables A4 and A5). The largest hazard quotient of 0.002 for children indicates that the estimated exposure to PCE is over 500 times lower than the health-based guideline for PCE (oral and dermal exposure). The hazard quotients for TCE and chloroform are the same or even lower at 0.002 and 0.000, respectively. This indicates that the estimated exposure to PCE, TCE, and chloroform in child pools and hot tubs filled with groundwater from private well #3 is not likely to result in adverse non-cancer health effects. Although the estimated non-cancer hazards in the previous evaluation were higher (e.g., PCE HQ was 0.01), the potential for developing non-cancer health effects were also below a level of concern at that time [CDPHE 2011].

The estimated cancer risks are also well below a level of concern based on the latest groundwater samples collected from private well #3 (Table A6). The total age-adjusted cancer risk is 2.2×10^{-8}. This indicates that out of one million people exposed, less than one (0.02) excess cancer case might occur. This level of estimated cancer risk is associated with a very low increased risk of developing cancer from exposure to contaminants in a child pool or hot tub filled with water from private well #3. In comparison, the 2011 health consultation estimated that out of one million exposed, 19 excess cancer cases might occur [CDPHE 2011]. The estimated cancer risk based on the

latest sampling rounds is approximately 600 times lower than the risk estimated in the previous 2011 health consultation report.

Overall, the estimated dermal and incidental ingestion exposure to contaminants in private well #3 is not likely to result in adverse non-cancer health effects based on the assumptions made in this evaluation. In addition, the estimated risk of developing cancer from exposure to contaminants in private well #3 is also very low.

Private Well #4

TCE and chloroform were the only contaminants that exceeded the CV in the latest two sampling rounds conducted in June and September 2013 and were selected as COPCs. The child and adult estimated non-cancer doses for PCE, TCE, and chloroform are all well below the associated health-based guideline for these contaminants (Tables A4 and A5). The largest hazard quotient of 0.004 for children indicates that the estimated exposure via incidental ingestion and dermal contact to PCE is over 200 times lower than the health-based guideline for PCE. The hazard quotients for TCE and chloroform are even lower at 0.002 and 0.000, respectively. This indicates that the estimated exposure to PCE, TCE, and chloroform in child pools and hot tubs filled with groundwater from private well #4 is not likely to result in adverse non-cancer health effects. Although the estimates in the 2011 evaluation were higher (e.g., PCE HQ for children was 0.01), non-cancer health hazards were also below a level of concern at private well #4 [CDPHE 2011].

The estimated cancer risks are also well below a level of concern based on the latest groundwater samples collected from private well #4 (Table A6). The total age-adjusted cancer risk is 3.0×10^{-8}. This indicates that out of one million people exposed, less than one (0.03) excess cancer case might occur. The estimated cancer risk indicates an extremely low increased risk of developing cancer from exposure to contaminants in a child pool or hot tub filled with water from private well #4. In comparison, the 2011 health consultation estimated that out of one million people exposed, 16 excess cancer cases might occur [CDPHE 2011]. The estimated cancer risk based on the latest sampling rounds is approximately 500 times lower than the risk estimated in the previous 2011 health consultation report.

Overall, the estimated dermal and incidental ingestion exposure to contaminants in private well #4 is not likely to result in adverse non-cancer health effects based on the assumptions made in this evaluation. In addition, the estimated risk of developing cancer from exposure to contaminants in private well #4 is also negligible.

Private Well #5

In private well #5, TCE and chloroform exceeded the CVs and were selected as COPCs. Again, PCE was also retained as a COPC for dose and risk estimation for comparison purposes. However, the non-cancer health hazards are well below a level of concern (Tables A4 and A5). As shown in Table A4, the largest hazard quotient of 0.01 for children indicates that the estimated exposure via incidental ingestion and dermal contact to PCE is over 100 times lower than the health-based guideline for PCE. In addition, the

combined non-cancer child HI from exposure to all contaminants is 0.01, which is approximately 75 times lower than the acceptable level of 1. Therefore, non-cancer health effects are not likely to occur following exposure to contaminants in child pools and hot tubs at private well #5.

The estimated cancer risks are also well below a level of concern based on the latest groundwater samples collected from private well #5 (Table A6). The total age-adjusted cancer risk is 6.8×10^{-8}. This indicates that out of one million people exposed, less than one (0.07) excess cancer case might occur. This estimated cancer risk is associated with a very low increased risk of developing cancer from exposure to contaminants in a child pool or hot tub filled with water from private well #5. In comparison, it was estimated in the 2011 health consultation that out of one million people exposed, 78 excess cancer cases might occur [CDPHE 2011]. The estimated cancer risk based on the latest sampling rounds is approximately 1,000 times lower than the risk estimated in the previous 2011 health consultation report.

Overall, the estimated dermal and incidental ingestion exposure to contaminants in private well #5 is not likely to result in adverse non-cancer health effects based on the assumptions made in this evaluation. In addition, the estimated risk of developing cancer from exposure to contaminants in private well #5 is also very low. It should be noted that the estimated cancer risks in private well #5 have fallen below the EPA target cancer risk range based on the latest sampling results. However, the concentration of PCE is still greater CDPHE's risk management goal (i.e., Colorado Basic Standards for Groundwater).

Private Well #6

In private well #6, PCE, TCE, and chloroform all exceeded the CVs and were selected as COPCs. PCE was detected at the highest concentration of all the wells considered in this evaluation. However, the non-cancer health hazards from using groundwater to fill child pools and hot tubs are still well below a level of concern as shown in Tables A4 and A5. As shown in Table A4, the largest hazard quotient of 0.019 for children indicates that the estimated exposure via incidental ingestion and dermal contact to PCE is over 50 times lower than the health-based guideline for PCE. In addition, the combined non-cancer HI for children from exposure to all contaminants is 0.025, which is approximately 40 times lower than the acceptable level of 1. Therefore, non-cancer health effects are not likely to occur following exposure to contaminants in child pools and hot tubs at private well #6. Non-cancer health hazards were also below a level of concern in the previous 2011 health consultation report [CDPHE 2011].

The estimated cancer risks are also well below a level of concern based on the latest groundwater samples collected from private well #5 (Table A6). The total age-adjusted estimated cancer risk is 1.2×10^{-7}. This indicates that out of one million exposures, less than one (0.1) excess cancer case might occur. The estimated cancer risk indicates a very low level of increased risk of developing cancer from exposure to contaminants in a child pool or hot tub filled with water from private well #6. In comparison, it was estimated in the 2011 health consultation that out of one million people exposed, 141 excess cancer

cases might occur [CDPHE 2011]. The estimated cancer risk based on the latest sampling rounds is over 1,400 times lower than the risk estimated in the previous 2011 health consultation report.

Overall, the estimated dermal and incidental ingestion exposure to contaminants in private well #6 is not likely to result in adverse non-cancer health effects based on the assumptions made in this evaluation. In addition, the estimated risk of developing cancer from exposure to contaminants in private well #6 is also very low. It should be noted that the estimated cancer risks in private well #6 have fallen below the EPA target cancer risk range based on the latest sampling results. However, the concentration of PCE in the well is still greater than CDPHE's risk management goal (i.e., Colorado Basic Standards for Groundwater).

Uncertainty and Limitations

In general, the uncertainties associated with any risk-based health consultation are likely to over- or underestimate environmental exposures and the associated health hazards because all aspects of the exposure are typically unknown. This section of the discussion is not intended to be an in-depth description of all the uncertainties associated with this evaluation. Rather, the focus is to highlight the major assumptions and limitations that are specific to this evaluation and result in uncertainty.

- Exposure assumptions for activities related to child pools and hot tubs may result in over- or under-estimation of risk based on the actual use of contaminated well water.

- The default exposure factors (e.g., body weight, lifetime, incidental water ingestion rate, and exposure duration) used in this health consultation are EPA's and/or ATSDR default values that were recommended for use until late 2014. In January 2015, ATSDR recommended new default exposure factors, which included an increase in the incidental ingestion rate for Reasonable Maximum Exposure (RME) children and adults, an increase in body weight for adults, an increase in the exposure duration for residential adults, and an increase in life expectancy (Appendix Table B7). The impact of these new ATSDR default exposure factors is evaluated in Section B2 of Appendix B. Tables B9 to B12 show that the estimated cancer and non-cancer risks based on the new ATSDR default parameters remain well below levels of health concern and do not change the conclusions drawn in this health consultation based on the 2014 ATSDR exposure parameters (old defaults).

- All of the contaminants considered in this evaluation are volatile compounds. Therefore, it is likely that the contaminants would evaporate into the atmosphere after filling a child pool or hot tub, which would reduce the exposure to contaminants. This is particularly true in the case of hot tubs where the water is heated. Unfortunately, this loss cannot be accurately accounted for because too many variables exist. In addition, volatilization of compounds from pools filled with groundwater could potentially result in inhalation exposures. . However, this

exposure is likely to be minimal under for the following reasons: 1) low concentration of VOCs found in private wells, 2) dilution of vapors in the open air atmosphere, and 3) the amount of water and the surface area in hot tubs and child pools is much less than in a swimming pool. Therefore, this pathway is not quantitatively evaluated in this consultation. Furthermore, the conclusions drawn in this health consultation are not likely to be impacted by quantitatively evaluating the inhalation pathway because the estimated cancer and non-cancer risks (from dermal and ingestion pathway) are considerable lower (about 100-fold) than levels of concern.

- Both carcinogenic and non-carcinogenic risks for multiple contaminants are assumed to be additive. This assumption, however, is associated with limitations and, therefore, there is potential for under- or over-estimation of risk. For example, the assumption of additive risk for estimating cumulative cancer and non-cancer risks does not account for synergistic and antagonistic chemical interactions, which are known to occur for some chemical combinations.

Child Health Considerations

In communities faced with air, water, or food contamination, the many physical and behavioral differences between children and adults demand special emphasis. Children could be at greater risk than are adults from certain kinds of exposure to hazardous substances. Children play outdoors and sometimes engage in hand-to-mouth behaviors that increase their exposure potential. Children are shorter than are adults; this means they breathe dust, soil, and vapors close to the ground. A child's lower body weight and higher intake rate results in a greater dose of hazardous substance per unit of body weight. If toxic exposure levels are high enough during critical growth stages, the developing body systems of children can sustain permanent damage. Finally, children are dependent on adults for access to housing, for access to medical care, and for risk identification. Thus adults need as much information as possible to make informed decisions regarding their children's health.

In this evaluation, child health concerns were evaluated and no special health concerns were identified for children. As expected, child residents are the most sensitive exposure group evaluated in this health consultation. However, the results indicate that there is little chance that children would experience adverse non-cancer health effects from wading in child pools and/or bathing in hot tubs filled with groundwater in the Fairmount neighborhood. The estimated cancer risks include children in the age-adjusted equation. As discussed in the Public Health Implication section, the overall estimated increased risk for children of developing cancer appears to be very low.

Conclusion

CCPEHA and ATSDR have reached one conclusion regarding current and future exposures to groundwater in the Fairmount neighborhood:

Chronic exposure to VOCs in private well water is not expected to harm the health of current and future residents when used to fill child pools and/or hot tubs at the currently

available concentrations. This conclusion was reached because 1) the non cancer health hazards are well below the health-based guidelines for each contaminant indicating an extremely low increased risk of developing non-cancer adverse health effects, and 2) the estimated cancer risks from exposure to detected contaminants are well below the EPA target cancer risk range. This indicates a very low increased risk of developing cancer from exposure to contaminants in hot tubs and swimming pools. Please note that this conclusion remains the same based on the new 2015 ATSDR recommended exposure factors. It is, however, important to note that PCE levels in private well #5 and #6 have not yet reached CDPHE risk management goal of meeting the Colorado state standard for groundwater of 5 ppb.

Recommendations

Based upon CCPEHA's review of the environmental data, exposure pathways, and potential public health implications of exposure to groundwater contaminants located in the Fairmount neighborhood, the following recommendations are appropriate and protective of current and future residents.

- Continue remediation and monitoring of groundwater onsite at the Hazen facility to eliminate potential impacts to groundwater in the Fairmount neighborhood.

- Do not use private wells (#5 and #6) for household purposes until contaminant levels in the wells have consistently decreased (to meet Colorado state standards) or filter the well water to reduce contaminant levels prior to groundwater entering the house.

Public Health Action Plan

The public health action plan for the site contains a description of actions that have been or will be taken by CCPEHA and other governmental agencies at the site. The purpose of the public health action plan is to ensure that this public health consultation both identifies public health hazards and provides a plan of action designed to mitigate and prevent harmful human health effects resulting from breathing, drinking, eating, or touching hazardous substances in the environment. Included is a commitment on the part of CCPEHA to follow up on this plan to be sure that it is implemented.

Public health actions that will be implemented include:

- Continuing monitoring groundwater contaminant levels at the Hazen facility and the Fairmount neighborhood.

- Providing additional health consultations as needed or requested. However, it is not necessary to re-evaluate alternate outdoor uses of contaminated groundwater unless contaminant levels begin to rise again.

- Providing the appropriate level of health education on the findings of this health consultation to stakeholders and the community.

Report Preparation

This Health Consultation for the Fairmont Neighborhood (Hazen Research Inc.) was prepared by the Colorado Department of Public Health and Environment under a cooperative agreement with the federal Agency for Toxic Substances and Disease Registry. It is in accordance with approved agency methodology and the procedures existing at the time the health consultation was initiated. Editorial review was completed by the cooperative agreement partner. The Agency for Toxic Substances and Disease Registry has reviewed this health consultation and concurs with its findings based on the information presented in this report. ATSDR's approval of this document has been captured in an electronic database, and the approving reviewers are listed below.

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Appendix A. Additional Tables and Figures

Figure A1. Hazen Research Site Demographic Map

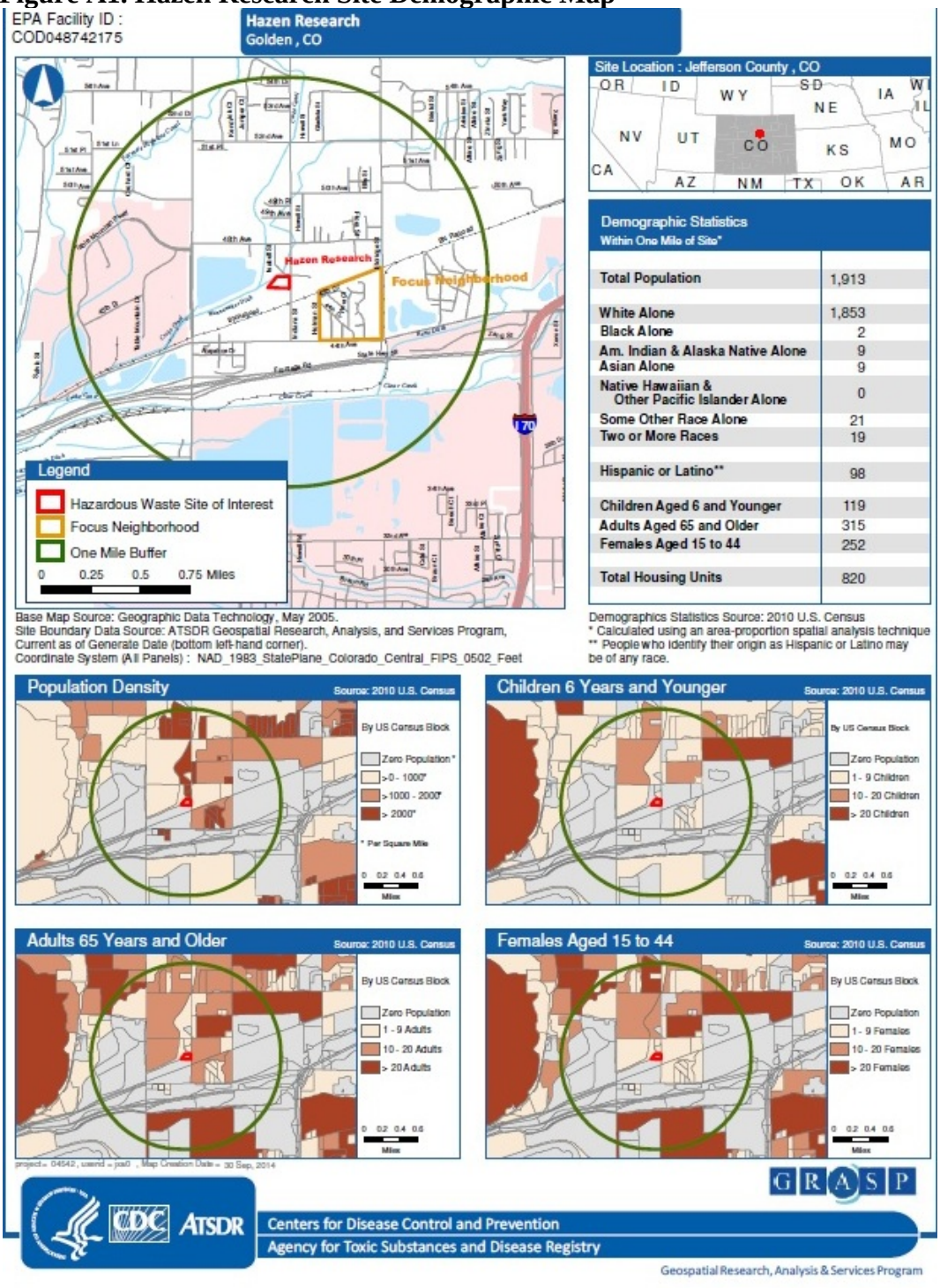
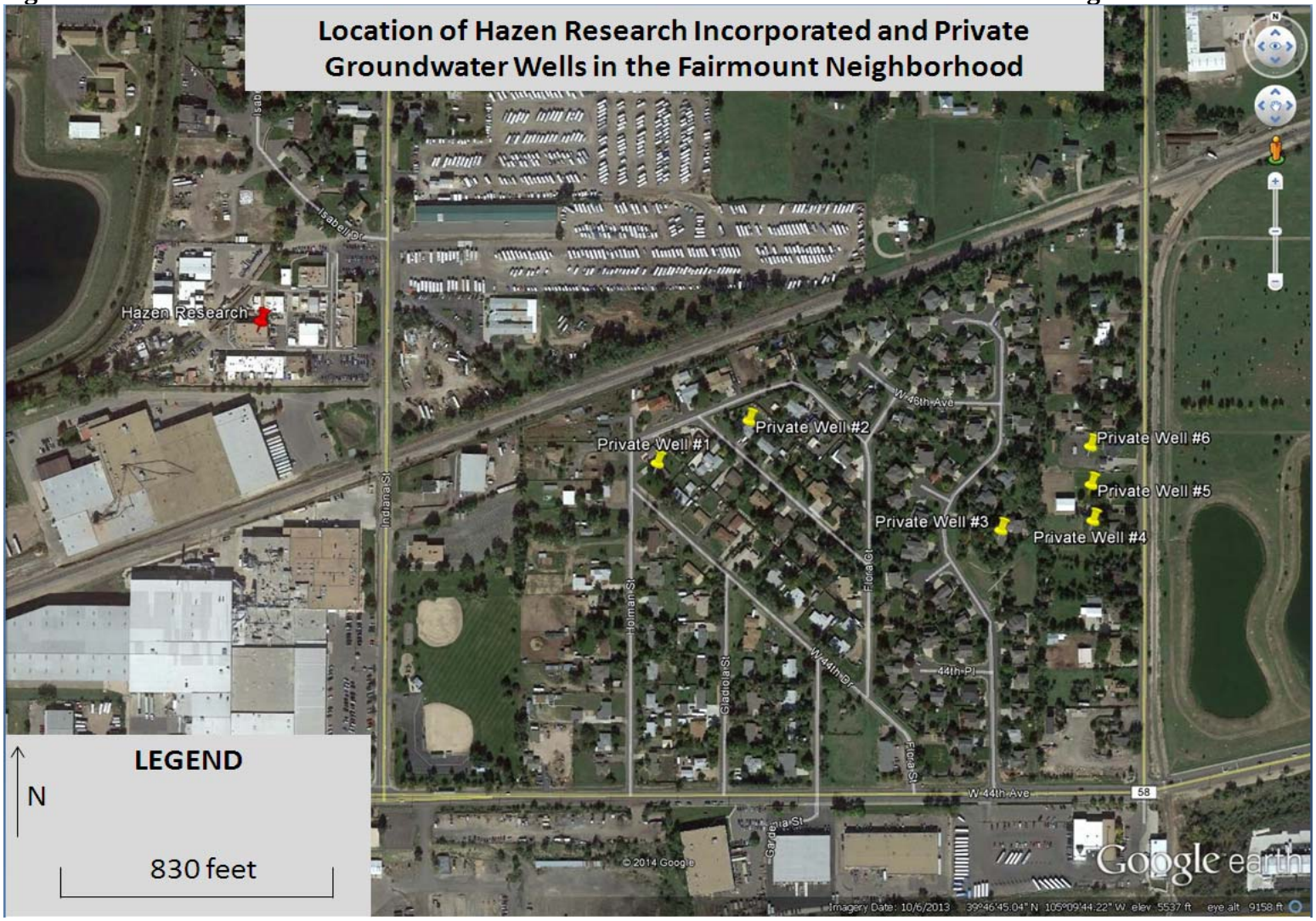


Figure A2. Location of Hazen Research and Private Groundwater Wells in the Fairmount Neighborhood



SOURCE: Google Earth (Imagery Dated October 2013)

Table A1. Summary of Residential Groundwater Monitoring Results (October 2010 through September 2013)

Residential Well Number	Number of Samples (*n*)	Chloroform (in µg/L)	1,1-Dichloroethane (in µg/L)	*cis*-1,2-Dichloroethene (in µg/L)	Methylene Chloride (in µg/L)	Tetrachloroethene (in µg/L)	Trichloroethene (in µg/L)	Vinyl Chloride (in µg/L)
Private well #1	7	ND (0.32) – 1.0	ND (0.26)	ND (0.26) – 1.5	ND (1.0) – 1.3	1.4 – 7.5	0.36 – 1.9	ND (0.26)
Private well #2	5	ND (0.32) – 2.7	ND (0.26)	ND (0.26) – 9.5	ND (1.0) – 3.1	2.4 – 19	ND (0.40) – 5.2	ND (0.26)
Private well #3	7	ND (0.32) – 0.66	ND (0.26)	ND (0.26)	ND (1.0) – 1.1	4.3 – 7.5	ND (0.40) – 0.54	ND (0.26)
Private well #4	7	0.37 – 3.7	ND (0.26)	ND (0.26) – 1.6	ND (0.84) – 1.3	1.6 – 70	0.61 – 2.5	ND (0.26)
Private well #5	6	0.94 – 5.3	ND (0.26)	0.39 – 4.1	ND (1.0) – 1.2	3.8 – 95	ND (0.40) – 91	ND (0.26)
Private well #6	5	ND (0.32) – 0.58	ND (0.26)	ND (0.26)	ND (0.84)	1.6 – 3.6	ND (0.40)	ND (0.26)

NOTE: ND = Not Detected (Detection Limit), µg/L = micrograms per liter

Table A2. Private Groundwater Well Results

Residential Well Location	Date Sampled	Chloroform (µg/L)	*cis*-1,2-Dichloroethene (µg/L)	Methylene Chloride (µg/L)	Tetrachloroethene (µg/L)	Trichloroethene (µg/L)
Private well #1	10/7/2010	1	2	ND (1.0)	7.5	1.9
	5/26/2011	ND (0.32)	ND (0.26)	ND (1.0)	2.4	0.36 J
	10/13/2011	ND (0.32)	ND (0.26)	ND (1.0)	1.4	0.5
	5/30/2012	ND (0.32)	0.5 J	ND (1.0)	2.8	1
	10/12/2012	ND (0.32)	1.5	ND (0.84)	5.5	1.6
	6/13/2013	ND (0.32)	0.54 J	ND (1.0)	1.8	1.1
	9/30/2013	ND (0.32)	0.4 J	1.3 J	2.6	0.89 J
Private well #2	10/7/2010	2.7 J	9.5	ND (1.0)	19	5.2
	5/26/2011	0.68 J	ND (0.26)	ND (1.0)	6.8	ND (0.40)
	10/13/2011	0.51 J	0.86	3.1	7	1.4
	5/30/2012	ND (0.32)	ND (0.26)	ND (1.0)	3.1	ND (0.40)
	10/12/2012	ND (0.32)	ND (0.26)	ND (0.84)	2.4	0.47
Private well #3	10/7/2010	ND (0.32)	ND (0.26)	ND (1.0)	3.6	ND (0.40)
	5/26/2011	ND (0.32)	ND (0.26)	ND (1.0)	3.2	ND (0.40)
	10/13/2011	0.58	ND (0.26)	ND (1.0)	2.7	ND (0.40)
	5/30/2012	0.36 J	ND (0.26)	ND (1.0)	1.6	ND (0.40)
	10/12/2012	0.4 J	ND (0.26)	ND (0.84)	1.8	ND (0.40)
Private well #4	10/7/2010	0.66 J	ND (0.26)	ND (1.0)	7.5	0.54 J
	5/26/2011	0.44 J	ND (0.26)	ND (1.0)	4.4	ND (0.40)
	10/13/2011	0.44	ND (0.26)	ND (1.0)	4.9	ND (0.40)
	5/30/2012	ND (0.32)	ND (0.26)	ND (1.0)	5.1	ND (0.40)
	10/12/2012	ND (0.32)	ND (0.26)	ND (0.84)	5.4	ND (0.40)
	6/13/2013	ND (0.32)	ND (0.26)	ND (1.0)	4.4	ND (0.40)
	9/27/2013	ND (0.32)	ND (0.26)	1.1 J	4.3	ND (0.40)
Private well #5	10/7/2010	3.7	1.4	ND (1.0)	70	2.5
	5/26/2011	1.6 J	1.6	ND (1.0)	33	1.8
	10/13/2011	0.95	0.41	ND (1.0)	23	1.1
	5/30/2012	0.6 J	0.38 J	ND (1.0)	14	1 J
	10/8/2012	0.42 J	ND (0.26)	ND (0.84)	8.7	0.61 J
	6/13/2013	0.37 J	ND (0.26)	1.3 J	10	0.85 J
	9/30/2013	0.46 J	ND (0.26)	1.3 J	7.6	0.73 J
Private well #6	10/7/2010	5.3	3.8	ND (1.0)	3.8	91
	5/26/2011	4.7 J	4.1	ND (1.0)	95	2.8
	10/13/2011	2.1	1.7	ND (1.0)	50	1.7
	5/30/2012	1.9 J	2.7	ND (1.0)	49	ND (0.40)
	6/13/2013	1.1 J	0.73 J	ND (1.0)	19	1.4
	9/27/2013	0.94 J	0.39 J	1.2 J	15	0.93 J

NOTE: µg/L = micrograms per liter, ND = Not Detected (detection limit), J = indicates that the value is an estimate

Table A3. Comparison Values and Selection of Contaminants of Potential Concern

Private well	Contaminant	Maximum of the latest 2 samplings (in µg/L)	EPA Regional Screening Level (in µg/L)	ATSDR Comparison Value (in µg/L)	COPC
#1	Tetrachloroethene	2.6	24	17[1]	
	Trichloroethene	1.1	0.94	0.76[1]	X
	Chloroform	ND (0.32)	0.32	70[2]	X
	cis-1,2-Dichloroethene	0.54	160	10[2]	
	Methylene Chloride	1.3	57	18[1]	
#2	Tetrachloroethene	3.1	24	17[1]	
	Trichloroethene	0.47	0.94	0.76[1]	
	Chloroform	ND (0.32)	0.32	70[2]	X
	cis-1,2-Dichloroethene	ND (0.26)	160	10[2]	
	Methylene Chloride	ND (1.0)	57	18[1]	
#3	Tetrachloroethene	1.8	24	17[1]	
	Trichloroethene	ND (0.40)	0.94	0.76[1]	
	Chloroform	0.4	0.32	70[2]	X
	cis-1,2-Dichloroethene	ND (0.26)	160	10[2]	
	Methylene Chloride	ND (1.0)	57	18[1]	
#4	Tetrachloroethene	4.4	24	17[1]	
	Trichloroethene	ND (0.40)	0.94	0.76[1]	
	Chloroform	ND (0.32)	0.32	70[2]	X
	cis-1,2-Dichloroethene	ND (0.26)	160	10[2]	
	Methylene Chloride	1.1	57	18[1]	
#5	Tetrachloroethene	10	24	17[1]	
	Trichloroethene	0.85	0.94	0.76[1]	X
	Chloroform	0.46	0.32	70[2]	X
	cis-1,2-Dichloroethene	ND (0.26)	160	10[2]	
	Methylene Chloride	1.3	57	18[1]	
#6	Tetrachloroethene	19	24	17[1]	X
	Trichloroethene	1.4	0.94	0.76[1]	X
	Chloroform	1.1	0.32	70[2]	X
	cis-1,2-Dichloroethene	0.73	160	10[2]	
	Methylene Chloride	1.2	57	18[1]	

NOTE: µg/L = micrograms per liter, Bolded comparison values were selected for use in screening, [1] CREG, [2] Lifetime Health Advisory, ND = Not Detected (Detection Limit)

Table A4. Non-cancer Hazard Quotients for Children

Well Number	Exposure Pathway	Tetrachloroethene Hazard Quotient	Trichloroethene Hazard Quotient	Chloroform Hazard Quotient	Total Hazard Index
Private well #1	Dermal	2.36E-03	3.48E-03	2.67E-05	--
	Incidental Ingestion	2.06E-04	1.04E-03	1.52E-05	--
	Combined Pool Exposure	**2.57E-03**	**4.52E-03**	**4.19E-05**	**7.13E-03**
Private well #2	Dermal	2.82E-03	1.49E-03	2.67E-05	--
	Incidental Ingestion	2.45E-04	4.46E-04	1.52E-05	--
	Combined Pool Exposure	**3.07E-03**	**1.94E-03**	**4.19E-05**	**5.05E-03**
Private well #3	Dermal	1.64E-03	1.27E-03	3.33E-05	--
	Incidental Ingestion	1.42E-04	3.80E-04	1.90E-05	--
	Combined Pool Exposure	**1.78E-03**	**1.65E-03**	**5.23E-05**	**3.48E-03**
Private well #4	Dermal	4.00E-03	1.27E-03	2.67E-05	--
	Incidental Ingestion	3.48E-04	3.80E-04	1.52E-05	--
	Combined Pool Exposure	**4.35E-03**	**1.65E-03**	**4.19E-05**	**6.04E-03**
Private well #5	Dermal	9.09E-03	2.69E-03	3.83E-05	--
	Incidental Ingestion	7.91E-04	8.07E-04	2.18E-05	--
	Combined Pool Exposure	**9.88E-03**	**3.50E-03**	**6.01E-05**	**1.34E-02**
Private well #6	Dermal	1.73E-02	4.43E-03	9.16E-05	--
	Incidental Ingestion	1.50E-03	1.33E-03	5.22E-05	--
	Combined Pool Exposure	**1.88E-02**	**5.76E-03**	**1.44E-04**	**2.47E-02**

Table A5. Non-cancer Hazard Quotients for Adults

Well Number	Exposure Pathway	Tetrachloroethene Hazard Quotient	Trichloroethene Hazard Quotient	Chloroform Hazard Quotient	Total Hazard Index
Private well #1	Dermal	1.38E-03	2.04E-03	1.56E-05	--
	Incidental Ingestion	4.41E-05	2.24E-04	3.26E-06	--
	Combined Pool Exposure	**1.42E-03**	**2.26E-03**	**1.89E-05**	**3.70E-03**
Private well #2	Dermal	1.65E-03	8.70E-04	1.56E-05	--
	Incidental Ingestion	5.26E-05	9.57E-05	3.26E-06	--
	Combined Pool Exposure	**1.70E-03**	**9.66E-04**	**1.89E-05**	**2.68E-03**
Private well #3	Dermal	9.56E-04	7.40E-04	1.95E-05	--
	Incidental Ingestion	3.05E-05	8.14E-05	4.07E-06	--
	Combined Pool Exposure	**9.86E-04**	**8.21E-04**	**2.36E-05**	**1.83E-03**
Private well #4	Dermal	2.34E-03	7.40E-04	1.56E-05	--
	Incidental Ingestion	7.46E-05	8.14E-05	3.26E-06	--
	Combined Pool Exposure	**2.41E-03**	**8.21E-04**	**1.89E-05**	**6.04E-03**
Private well #5	Dermal	5.31E-03	1.57E-03	2.24E-05	--
	Incidental Ingestion	1.70E-04	1.73E-04	4.68E-06	--
	Combined Pool Exposure	**5.48E-03**	**1.74E-03**	**2.71E-05**	**3.25E-03**
Private well #6	Dermal	1.01E-02	2.59E-03	5.36E-05	--
	Incidental Ingestion	3.22E-04	2.85E-04	1.12E-05	--
	Combined Pool Exposure	**1.04E-02**	**2.88E-03**	**6.48E-05**	**1.33E-02**

Table A6. Age-Adjusted Estimated Cancer Risks

Well Number	Exposure Pathway	Tetrachloroethene Estimated Cancer Risks	Trichloroethene Estimated Cancer Risks	Chloroform Estimated Cancer Risks	Total Estimated Cancer Risks
Private well #1	Dermal	8.52E-09	3.18E-08	2.36E-09	---
	Incidental Ingestion	4.11E-10	5.67E-10	7.47E-10	---
	Combined Pool Exposure	**8.93E-09**	**3.24E-08**	**3.11E-09**	***4.39E-08***
Private well #2	Dermal	1.02E-08	1.36E-08	2.36E-09	---
	Incidental Ingestion	4.90E-10	2.42E-10	7.47E-10	---
	Combined Pool Exposure	**1.07E-08**	**1.38E-08**	**3.11E-09**	***2.76E-08***
Private well #3	Dermal	5.90E-09	1.16E-08	2.96E-09	---
	Incidental Ingestion	2.85E-10	2.06E-10	9.34E-10	---
	Combined Pool Exposure	**6.18E-09**	**1.18E-08**	**3.89E-09**	***2.19E-08***
Private well #4	Dermal	1.44E-08	1.16E-08	2.36E-09	---
	Incidental Ingestion	6.96E-10	2.06E-10	7.47E-10	---
	Combined Pool Exposure	**1.51E-08**	**1.18E-08**	**3.11E-09**	***3.00E-08***
Private well #5	Dermal	3.28E-08	2.45E-08	3.40E-09	---
	Incidental Ingestion	1.58E-09	4.38E-10	1.07E-09	---
	Combined Pool Exposure	**3.44E-08**	**2.91E-08**	**4.47E-09**	***6.80E-08***
Private well #6	Dermal	6.23E-08	4.05E-08	8.13E-09	---
	Incidental Ingestion	3.00E-09	7.21E-10	2.57E-09	---
	Combined Pool Exposure	**6.53E-08**	**4.12E-08**	**1.07E-08**	***1.17E-07***

NOTE: 4.39E-08 is equal to 4.39×10^{-8} or less than 1 excess cancer case per million people exposed (0.04)

Appendix B. Additional Exposure Dose Information

B1. Exposure Dose Estimations based on the Exposure Factors used in this Health Consultation

The first step to determine if adverse health effects are likely to occur from exposure to contamination found in the Fairmount neighborhood site is to estimate exposure doses for the people that are likely to come into contact with site-related contamination. The estimated exposure doses are designed to be conservative estimations of actual contaminant intake, accounting for the majority of potential exposures at the site. As mentioned previously in the document, exposure doses are only estimated for Contaminants of Potential Concern (COPC), which have exceeded the comparison values (CVs). Estimating the exposure dose requires assumptions to made regarding various exposure parameters such as the frequency of a particular activity, duration of exposure to site-related contamination, and the amount of a particular substance that is taken in by an individual during a given activity. Site-specific exposure information is always preferable when estimating exposure doses. However, site-specific information is rarely available due to time and financial constraints. In lieu of site-specific information, default exposure parameters that are established by the U.S. Environmental Protection Agency (EPA) and Agency for Toxic Substances and Disease (ATSDR) are used in the exposure dose estimation. At times, professional judgment is used when default values are not available or seem unreasonable for the site exposures.

Two primary receptors were identified in this evaluation that are likely to come into contact with site-related contamination now or in the future, child and adult residents. The major exposure factors used are listed below in Table B1. The primary exposure pathway evaluated in this health consultation is exposure from secondary uses of contaminated groundwater (child pools, hot tubs, etc.). Overall, the main dose estimations calculated in this evaluation assume exposure to contaminated groundwater in hot tubs and child pools for 52 hours per year over a period of 6 yrs. (children) or 30 yrs. (adults). Two routes of exposure exist in this exposure pathway scenario: 1) dermal exposure to water containing VOCs and 2) incidental ingestion of water containing VOCs. Since both routes of exposure occur at the same time, the estimated doses for each exposure route are combined to form a total dose for each contaminant. Non-cancer and cancer exposure doses are estimated for both pathways. The major difference between estimating non-cancer and cancer doses are that non-cancer doses are averaged over the exposure duration and cancer doses are averaged over a lifetime.

Table B1. Exposure Factors

Receptor	Body Weight (BW)	Exposure Frequency (EF)	Exposure Duration (ED)	Incidental Water Ingestion Rate* (IRW)	Skin Surface Area** (SA)	Time per Event (t_{ev})	Non-cancer Averaging Time (AT_{NC})	Cancer Averaging Time (AT_C)	Conversion Factor (CF)
Child Residents	15 kg. (EPA 1997)	52 days per year (professional judgment)	6 years (EPA 1997)	50 ml. Per hour or event (EPA 1997)	6600 cm^2 (EPA RAGS, Part E 2004)	1 hr. (professional judgment)	2,190 days (EPA RAGS A, 1989)	25550 days (EPA RAGS A, 1989)	10^{-3} mg/µg
Adult Residents	70 kg. (EPA 1997)	52 days per year (professional judgment)	30 year (non-cancer) 24 years (cancer) (EPA 1997)	50 ml. per hour or event (EPA 1997)	18000 cm^2 (EPA RAGS, Part E 2004)	1 hr. (professional judgment)	10,950 days (EPA RAGS A, 1989)	25550 days (EPA RAGS A, 1989)	10^{-3} mg/µg

Notes:

*Age-adjusted water ingestion rate (IRW_{adj}) equals 0.037 L-yr/kg based on the exposure duration of 6 years as a child and 24 years as an adult

**Age-adjusted dermal exposure factor (SA_{adj}) 8811.43 cm^2-yr/kg-event (EPA RAGS, Part E 2004)

$cm.^2$ = square centimeters

kg. = kilogram

mg. = milligram

µg. = microgram

EPA (1997) = Environmental Protection Agency, Exposure Factors Handbook

EPA (2004) = Environmental Protection Agency, Risk Assessment Guidance for Superfund, Part E. Supplemental Guidance for Dermal Exposure

Table B2. Chemical-Specific Dermal Exposure Factors (EPA RAGS, Part E 2004)

Contaminant of Potential Concern	Fraction Absorbed FA (dimensionless)	Dermal Permeability Coefficient of Compound in Water K_p (cm./hr.)	Lag Time per event τ_{event} (hour/event)	Time to reach steady-state t^* (in hours)
Tetrachloroethene	1.0	3.3E-02	0.91	2.18
Trichloroethene	1.0	1.2E-02	0.58	1.39
Cis-1,2-Dichloroethene	NA	NA	NA	NA
Chloroform	1.0	6.8E-03	0.50	1.19

NOTE: cm./hr. = centimeters per hour

Another critical component of the exposure dose estimation is the concentration of chemicals of potential concern that individuals are likely to be exposed to in a particular medium, which is referred to as the Exposure Point Concentration (EPC). The EPA has established guidelines for determining the EPC. In Region 8, if there are less than 10 samples available for a contaminant, the maximum detected concentration is used as the EPC since there is a limited amount of information about the actual concentration in a particular medium and area. In this health consultation, there were less than 10 samples available for each private well. Therefore, the maximum concentration was used as the high-end exposure point concentration. Because the concentrations of groundwater contaminants appear to be fluctuating up and down over time, a low-end value was also selected to provide a range of potential risk to private wells owners. The EPCs used in this evaluation are presented in Table B3.

Table B3. Exposure Point Concentrations used in Dose Calculations

Well Location	Contaminant	Exposure Point Concentration (μg/L)
Private well #1	Tetrachloroethene	2.6
	Trichloroethene	1.1
	Chloroform	ND (0.32)
Private well #2	Tetrachloroethene	3.1
	Trichloroethene	0.47
	Chloroform	ND (0.32)
Private well #3	Tetrachloroethene	1.8
	Trichloroethene	ND (0.40)
	Chloroform	0.4
Private well #4	Tetrachloroethene	4.4
	Trichloroethene	ND (0.40)
	Chloroform	ND (0.32)
Private well #5	Tetrachloroethene	10
	Trichloroethene	0.85
	Chloroform	0.46
Private wells #6	Tetrachloroethene	19
	Trichloroethene	1.4
	Chloroform	1.1

NOTE: μg/L = microgram per liter, ND = Not Detected (Detection Limit)

Non-cancer and cancer health endpoints are evaluated differently so the estimation of exposure dose also differs slightly (non-cancer doses are averaged over the timeframe of exposure and cancer doses are averaged over a lifetime). The exposure dose equations used in this evaluation are presented below. Use the equations below and the values presented above in Tables B1-B3 to reproduce the output Tables B4-B7.

Dose Equations (See Tables B1, B2, and B3 for equation parameters)

Non-Cancer Incidental Ingestion Dose

Non-Cancer Dose = $(C_w * IRW * CF * ET * EF * ED) / (BW * AT_{NC})$

Where:
C_w = Chemical Concentration in Water (in µg /L or micrograms contaminant per liter of water)
IRW = Ingestion Rate of Water (in liters of water per hour)
CF = Conversion Factor (in milligrams per microgram)
ET = Exposure Time (hours per event)
EF = Exposure Frequency (in days per year)
ED = Exposure Duration (in years)
BW = Body Weight (in kilograms)
AT_{NC} = Non-Cancer Averaging Time (in days)

Example: Non-cancer child ingestion dose for PCE at Private well #1 =
$(2.6\ \mu g/L * 0.050L * 10^{-3}\ mg/\mu g * 1\ hour * 52\ days * 6\ years)/(15kg * 2190\ days) = 1.23 * 10^{-6}\ mg/kg\text{-}day$

Age-Adjusted Water Ingestion Cancer Dose

Cancer Dose = $(C_w * CF * IRW_{adj} * EF) / AT_C$

Where:
C_w = Chemical Concentration in Water (in ug/L or micrograms contaminant per liter of water)
IRW_{adj} = Age adjusted Ingestion Rate of Water (in Liter-years per kilogram)
CF = Conversion Factor (in milligrams per microgram)
EF = Exposure Frequency (in days per year)
BW = Body Weight (in kilograms)
AT_C = Cancer Averaging Time (in days)

Example: Age-adjusted cancer ingestion dose for maximum level PCE at Private well #1=
$(2.6\ \mu g/L * 10^{-3}\ mg/\mu g * 0.037\ L\text{-}year/kg * 52\ days)/(25550\ days) = 1.96 * 10^{-7} mg/kg\text{-}day$

Non-Cancer Dermal Absorbed Dose

DA event (mg/cm^2-event) = 2 FA * K_p * C_w * CF $\sqrt{(6\tau ev * tev \div \pi)}$ (EPA 2004, Equation 3-2)

$$DAD\ (mg/kg\text{-}day) = \frac{DAev * EV * EF * ED * SA}{BW * AT_{NC}}$$ (EPA 2004, Equation 3-1)

Where:
DAev = Absorbed dose per event (in milligrams per square centimeter event)
FA = Fraction Absorbed Water (dimensionless)
K_p = Dermal permeability coefficient of compound in water (in centimeters per hour)
C_w = Chemical concentration in water (in micrograms per liter)
CF = Conversion factor (in milligrams contaminant per milliliter water)
τev = Lag time per event (in hours)
tev = Event Duration (in hours)
EV = Events per day (one event assumed here)
EF = Exposure Frequency (in days per year)
ED = Exposure Duration (in years)
SA = Skin Surface Area (in square centimeters)
BW = Body Weight (in kilograms)
AT_{NC} = Non-Cancer Averaging Time (in days)

Example: Non-cancer child dermal absorbed dose for PCE at Private well#1 =

DA_{ev} = 2 * 1 * 3.3x10^{-2}cm/hr * 2.6 μg/L * 10^{-3}mg/μg * 10^{-3} L/mL $\sqrt{(6 * 0.91 * 1 \div \pi)}$ = 2.26 * 10^{-7} mg/cm^2-event

DAD = (2.26 * 10^{-7} mg/cm^2-event * 1 event * 52 days * 6 years * 6600cm^2)/ (15kg * 2190 days)= 1.42 * 10^{-5}mg/kg-day

Age-Adjusted Cancer Dermal Absorbed Dose

$$DAD\ (mg/cm^2\text{-event}) = \frac{DAev * IRW_{adj} * EF}{AT_C}$$

Where:
DAev = Absorbed dose per event (in milligrams per square centimeter event)
IRW_{adj} = Age-adjusted dermal absorption factor (in square centimeter-year per kilogram)
EF = Exposure Frequency (in days)
AT_C = Cancer Averaging Time (in days)

NOTE: The DA event calculation for non-cancer and cancer dermal absorbed dose equations is the same (EPA 2004, Equation 3-2).

Example: $(2.26 * 10^{-7}$ mg/cm^2-event * 8811.43cm^2-year/kg * 52 days)/25550 days = $4.06*10^{-6}$ mg/kg-day

Table B4. Dermal Absorbed Dose per Event for Children and Adults

Well Number	Tetrachloroethene Dermal Absorbed Dose per Event (in mg/cm^2-event)	Trichloroethene Dermal Absorbed Dose per Event (in mg/cm^2-event)	Chloroform Dermal Absorbed Dose per Event (in mg/cm^2-event)
Private well #1	2.26E-07	2.78E-08	4.25E-09
Private well #2	2.70E-07	1.19E-08	4.25E-09
Private well #3	1.57E-07	1.01E-08	5.32E-09
Private well #4	3.83E-07	1.01E-08	4.25E-09
Private well #5	8.70E-07	2.15E-08	6.11E-09
Private well #6	1.65E-06	3.54E-08	1.46E-08

NOTE: mg/cm^2-event = milligram per square centimeter of skin per event

Table B5. Estimated Non-cancer Exposure Doses for Children

Well Number	Exposure Pathway	Tetrachloroethene Non-Cancer Dose (in mg/kg-day)	Trichloroethene Non-Cancer Dose (in mg/kg-day)	Chloroform Non-Cancer Dose (in mg/kg-day)
Private well #1	Dermal	1.42E-05	1.74E-06	2.67E-07
	Incidental Ingestion	1.23E-06	5.22E-07	1.52E-07
	Combined Pool Exposure	**1.54E-05**	**2.26E-06**	**4.19E-07**
Private well #2	Dermal	1.69E-05	7.44E-07	2.67E-07
	Incidental Ingestion	1.47E-06	2.23E-07	1.52E-07
	Combined Pool Exposure	**1.84E-05**	**9.67E-07**	**4.19E-07**
Private well #3	Dermal	9.82E-06	6.33E-07	3.33E-07
	Incidental Ingestion	8.55E-07	1.90E-07	1.90E-07
	Combined Pool Exposure	**1.07E-05**	**8.23E-07**	**5.23E-07**
Private well #4	Dermal	2.40E-05	6.33E-07	2.67E-07
	Incidental Ingestion	2.09E-06	1.90E-07	1.52E-07
	Combined Pool Exposure	**2.61E-05**	**8.23E-07**	**4.19E-07**
Private well #5	Dermal	5.45E-05	1.35E-06	3.83E-07
	Incidental Ingestion	4.75E-06	4.04E-07	2.18E-07
	Combined Pool Exposure	**5.93E-05**	**1.75E-06**	**6.01E-07**
Private well #6	Dermal	1.04E-04	2.22E-06	9.16E-07
	Incidental Ingestion	9.02E-06	6.65E-07	5.22E-07
	Combined Pool Exposure	**1.13E-04**	**2.89E-06**	**1.44E-06**

NOTE: mg/kg-day = milligram per kilogram body weight per day

Table B6. Estimated Non-cancer Exposure Doses for Adults

Well Number	Exposure Pathway	Tetrachloroethene Non-Cancer Dose (in mg/kg-day)	Trichloroethene Non-Cancer Dose (in mg/kg-day)	Chloroform Non-Cancer Dose (in mg/kg-day)
Private well #1	Dermal	8.29E-06	1.02E-06	1.56E-07
	Incidental Ingestion	2.65E-07	1.12E-07	3.26E-08
	Combined Pool Exposure	**8.56E-06**	**1.13E-06**	**1.89E-07**
Private well #2	Dermal	9.88E-06	4.35E-07	1.56E-07
	Incidental Ingestion	3.15E-07	4.78E-08	3.26E-08
	Combined Pool Exposure	**1.02E-05**	**4.83E-07**	**1.89E-07**
Private well #3	Dermal	5.74E-06	3.70E-07	1.95E-07
	Incidental Ingestion	1.83E-07	4.07E-08	4.07E-08
	Combined Pool Exposure	**5.92E-06**	**4.11E-07**	**2.36E-07**
Private well #4	Dermal	1.40E-05	3.70E-07	1.56E-07
	Incidental Ingestion	4.48E-07	4.07E-08	3.26E-08
	Combined Pool Exposure	**1.44E-05**	**4.11E-07**	**1.89E-07**
Private well #5	Dermal	3.19E-05	7.87E-07	2.24E-07
	Incidental Ingestion	1.02E-06	8.65E-08	4.68E-08
	Combined Pool Exposure	**3.29E-05**	**8.74E-07**	**2.71E-07**
Private well #6	Dermal	6.06E-05	1.30E-06	5.36E-07
	Incidental Ingestion	1.93E-06	1.42E-07	1.12E-07
	Combined Pool Exposure	**6.25E-05**	**1.44E-06**	**6.48E-07**

NOTE: mg/kg-day = milligram per kilogram body weight per day

B2. Comparison of Exposure Doses using the New ATSDR Default Exposure Factors

It should be noted that updated exposure factors were released by ATSDR after the completion of this document while it was under independent review. These changes include an increase in the incidental ingestion rate for Reasonable Maximum Exposure (RME) children and adults from 50 milliliter per event (mL/event) to 120 mL/event and 71 mL/event, respectively. Other changes include an increase in the body weight for adults (from 70 to 80 kilograms) and an increase in the exposure duration for the RME adult resident (from 30 to 33 years). However these changes do not impact the conclusions drawn in this health consultation. To address this uncertainty, the exposure dose estimations were performed at the private well # 6, which showed the highest estimated cancer and non-cancer risk in this health consultation. As shown in Appendix Table B11, the lifetime excess cancer risk at private well #6 would change from 1.2×10^{-7} to 1.3×10^{-7} if the new default exposure parameters were used in the calculation. Both results are well below the EPA target cancer risk level, which indicates a very low increased risk of developing cancer. In addition, the total non-cancer hazard index would change from 0.0247 to 0.0291. Again both the non-cancer hazard indices are well below the acceptable level of 1, which indicates that people are not likely to develop non-cancer health effects.

Table B7. Comparison of the Old ATSDR Exposure Factors with the Newly Revised ATSDR Exposure Factors

Receptor	Body Weight (BW)	Exposure Frequency (EF)	Exposure Duration (ED)	Incidental Water Ingestion Rate* (IRW)	Skin Surface Area** (SA)	Time per Event (t_{ev})	Non-cancer Averaging Time (AT_{NC})	Cancer Averaging Time (AT_C)	Conversion Factor (CF)
Child Residents 0-6 years (Old ATSDR Parameters)	15 kg. (EPA 1997)	52 days per year (professional judgment)	6 years (EPA 1997)	50 ml. per hour or event (EPA 1997)	6,600 cm^2 (EPA RAGS, Part E 2004)	1 hr. (professional judgment)	2,190 days (ATSDR 2005)	25,550 days (ATSDR 2005)	10^{-3} mg/μg
RME Child Residents 0-6 years (New ATSDR Parameters)	14.8 kg. (ATSDR 2014a)	52 days per year (professional judgment)	6 years (EPA 1997)	120 ml. per hour or event ATSDR 2014b)	6,600 cm^2 (EPA RAGS, Part E 2004)	1 hr. (professional judgment)	2,190 days (ATSDR 2005)	25,550 days (ATSDR 2005)	10^{-3} mg/μg
Adult Residents 6-30 years (Old ATSDR Parameters)	70 kg. (EPA 1997)	52 days per year (professional judgment)	30 year (non-cancer) 24 years (cancer) (EPA 1997)	50 ml. per hour or event (EPA 1997)	18,000 cm^2 (EPA RAGS, Part E 2004)	1 hr. (professional judgment)	10,950 days (ATSDR 2005)	25,550 days (ATSDR 2005)	10^{-3} mg/μg
RME Adult Residents 6-33 years (New ATSDR Parameters)	80 kg. (ATSDR 2014a)	52 days per year (professional judgment)	33 years (ATSDR 2014c)	71 ml. per hour or event (ATSDR 2014b)	18,000 cm^2 (EPA RAGS, Part E 2004)	1 hr. (professional judgment)	12,045 days (ATSDR 2014c)	28,470 days (ATSDR 2014c)	10^{-3} mg/μg

Notes (Notes Continued on the Next Page):

*Old ATSDR Age-adjusted water ingestion rate (IRW_{adj}) equals 0.037 L-yr/kg based on the exposure duration of 6 years as a child and 24 years as an adult

**Old ATSDR Age-adjusted dermal exposure factor (SA_{adj}) 8811.43 cm^2-yr/kg-event (EPA RAGS, Part E 2004)

*New ATSDR Age-adjusted water ingestion rate (IRW_{adj}) equals 0.073 L-yr/kg based on the exposure duration of 6 years as a child and 27years as an adult

**New ATSDR Age-adjusted dermal exposure factor (SA_{adj}) 8750.68 cm^2-yr/kg-event (EPA RAGS, Part E 2004)

$cm.^2$ = square centimeters, kg. = kilogram, mg. = milligram, μg. = microgram

EPA (1997) = Environmental Protection Agency, Exposure Factors Handbook

EPA (2004) = Environmental Protection Agency, Risk Assessment Guidance for Superfund, Part E. Supplemental Guidance for Dermal Exposure

Continued Notes from Previous Page:
ATSDR (2005) = Agency for Toxic Substances and Disease Registry, Public Health Assessment Guidance Manual
ATSDR 2014 a,b,c = Exposure Dose Guidance for Body Weight, EDG for Water Ingestion, EDG for Life Expectancy, respectively

Table B8. Dermal Absorbed Dose per Event for Children and Adults (No Change in ATSDR Exposure Parameter Values)

Well Number	Tetrachloroethene Dermal Absorbed Dose per Event (in mg/cm^2-event)	Trichloroethene Dermal Absorbed Dose per Event (in mg/cm^2-event)	Chloroform Dermal Absorbed Dose per Event (in mg/cm^2-event)
Private well #6	1.65E-06	3.54E-08	1.46E-08

NOTE: mg/cm^2-event = milligram per square centimeter of skin per event

Table B9. Estimated Non-cancer Exposure Doses and Hazard Quotients for RME Children (0-6 years of age)

Well Number	Exposure Pathway	PCE Non-Cancer Dose (in mg/kg-day)	PCE Hazard Quotient	TCE Non-Cancer Dose (in mg/kg-day)	TCE Hazard Quotient	Chloroform Non-Cancer Dose (in mg/kg-day)	Chloroform Hazard Quotient
Private well #6 (Old ATSDR RME; used in current health consultation)	Dermal	1.04E-04	*1.73E-02*	2.22E-06	*4.43E-03*	9.16E-07	*9.16E-05*
	Incidental Ingestion	9.02E-06	*1.50E-03*	6.65E-07	*1.33E-03*	5.22E-07	*5.22E-05*
	Combined Pool Exposure	**1.13E-04**	***1.88E-02***	**2.89E-06**	***5.76E-03***	**1.44E-06**	***1.44E-04***
Private well #6 (New ATSDR RME)	Dermal	1.05E-04	*1.75E-02*	2.25E-06	*4.49E-03*	9.29E-07	*9.29E-05*
	Incidental Ingestion	2.19E-05	*3.66E-03*	1.62E-06	*3.23E-03*	1.27E-06	*1.27E-04*
	Combined Pool Exposure	**1.27E-04**	***2.12E-02***	**3.87E-06**	***7.72E-03***	**2.20E-06**	***2.20E-04***

NOTE: PCE = Tetrachloroethene, TCE = Trichloroethene, RME = Reasonable Maximum Exposure, ATSDR = Agency for Toxic Substances and Disease Registry, mg/kg-day = milligram per kilogram body weight per day

Table B10. Estimated Non-cancer Exposure Doses and Hazard Quotients for RME Adults

Well Number	Exposure Pathway	PCE Non-Cancer Dose (in mg/kg-day)	PCE Hazard Quotient	TCE Non-Cancer Dose (in mg/kg-day)	TCE Hazard Quotient	Chloroform Non-Cancer Dose (in mg/kg-day)	Chloroform Hazard Quotient
Private well #6* (Old ATSDR RME; used in current health consultation)	Dermal	6.06E-05	*1.01E-02*	1.30E-06	*2.59E-03*	5.36E-07	*5.36E-05*
	Incidental Ingestion	1.93E-06	*3.22E-04*	1.42E-07	*2.85E-04*	1.12E-07	*1.12E-05*
	Combined Pool Exposure	**6.25E-05**	***1.04E-02***	**1.44E-06**	***2.88E-03***	**6.48E-07**	***6.48E-05***
Private well #6** (New ATSDR RME)	Dermal	5.30E-05	*8.83E-03*	1.13E-06	*2.27E-03*	4.69E-07	*4.69E-05*
	Incidental Ingestion	2.40E-06	*4.00E-04*	1.77E-07	*3.54E-04*	1.39E-07	*1.39E-05*
	Combined Pool Exposure	**5.54E-05**	***9.23E-03***	**1.31E-06**	***2.62E-03***	**6.08E-07**	***6.08E-05***

NOTE: * Exposures occurring for a period of 30 years. ** Exposures occurring for a period of 33 years. RME = Reasonable Maximum Exposure, ATSDR = Agency for Toxic Substances and Disease Registry, PCE = Tetrachloroethene, TCE = Trichloroethene, mg/kg-day = milligram per kilogram body weight per day

Table B11. Estimated Age-Adjusted Cancer Risks

Well Number	Exposure Pathway	Tetrachloroethene Estimated Cancer Risks	Trichloroethene Estimated Cancer Risks	Chloroform Estimated Cancer Risks	Total Estimated Cancer Risks
Private well #6* (Old ATSDR RME; used in current health consultation)	Dermal	6.23E-08	4.05E-08	8.13E-09	---
	Incidental Ingestion	3.00E-09	7.58E-09	2.57E-09	---
	Combined Pool Exposure	**6.53E-08**	**4.81E-08**	**1.07E-08**	***1.22E-07***
Private well #6** (New ATSDR RME)	Dermal	5.55E-08	4.15E-08	7.24E-09	---
	Incidental Ingestion	5.29E-09	1.71E-08	4.52E-09	---
	Combined Pool Exposure	**6.08E-08**	**5.86E-08**	**1.18E-08**	***1.31E-07***

NOTE: * Exposures occurring from birth to the age of 30 years. ** Exposures occurring from birth to the age of 33 years. RME = Reasonable Maximum Exposure, ATSDR = Agency for Toxic Substances and Disease Registry, 6.23E-08 is equal to 6.23×10^{-8} or less than 1 excess cancer case per million people exposed (0.06)

Table B12. Estimated Cancer Risks for RME Children (0-6 years) with New ATSDR Defaults

Well Number	Exposure Pathway	Tetrachloroethene Estimated Cancer Risks	Trichloroethene Estimated Cancer Risks	Chloroform Estimated Cancer Risks	Total Estimated Cancer Risks
Private well #6 (New ATSDR RME)	Dermal	1.70E-08	1.74E-08	7.14E-08	---
	Incidental Ingestion	3.55E-09	5.11E-09	3.03E-09	---
	Combined Pool Exposure	**2.06E-08**	**2.25E-08**	**7.44E-08**	***1.17E-07***

NOTE: RME = Reasonable Maximum Exposure, ATSDR = Agency for Toxic Substances and Disease Registry, 1.7E-08 is equal to 1.7×10^{-8} or less than 1 excess cancer case per million people exposed (0.0017)

Appendix C. Toxicological Evaluation

The basic objective of a toxicological evaluation is to identify what adverse health effects a chemical causes, and how the appearance of these adverse effects depends on dose. The toxic effects of a chemical also depend on the route of exposure (oral, inhalation, dermal), the duration of exposure (acute, subchronic, chronic or lifetime), the health condition of the person, the nutritional status of the person, and the life style and family traits of the person.

The U.S. Environmental Protection Agency (EPA) and the Agency for Toxic Substances and Disease (ATSDR) have established oral reference doses (RfD) and minimal risk levels (MRL) for non-cancer effects. An RfD is the daily dose in humans (with uncertainty spanning perhaps an order of magnitude), including sensitive subpopulations, that is likely to be without an appreciable risk of non-cancer adverse health effects during a lifetime of exposure to a particular contaminated substance. An MRL is the dose of a compound that is an estimate of daily human exposure that is likely to be without an appreciable risk of adverse non-cancer effects of a specified duration of exposure. The acute, intermediate, and chronic MRLs address exposures of 14 days or less, 14 days to 365 days, and 1-year to lifetime, respectively. The health-based guidelines for the contaminants of potential concern for this evaluation are listed below.

Table C1. Oral Health-based Guidelines for the Contaminants of Potential Concern

Contaminant Of Potential Concern	Oral Health-based Guideline (mg/kg-day)	Source of Oral Health-based Guideline	Oral Slope Factor ($mg/kg\text{-}day^{-1}$)	Source of Oral Slope Factor
Tetrachloroethene	6.00E-03	EPA IRIS	2.10E-03 Likely to be carcinogenic to humans	EPA IRIS
Trichloroethene	5.00E-04	EPA IRIS and ATSDR Chronic MRL	5.90E-03 Class A or known human carcinogen	EPA IRIS
Chloroform	1.00E-02	EPA IRIS and ATSDR Chronic MRL	3.10E-02 Class B2 Probably carcinogenic to humans	California EPA

Note: mg/kg-day = milligram per kilogram per day, $mg/kg\text{-}day^{-1}$ = per milligram per kilogram per day, ATSDR = Agency for Toxic Substances and Disease Registry, MRL = Minimal Risk Level, EPA = Environmental Protection Agency, IRIS = Integrated Risk Information System, The same values were used for the dermal exposure pathway without adjustment for gastrointestinal absorption in accordance with EPA 2004.

The toxicity assessment process is usually divided into two parts: the first characterizes and quantifies the non-cancer effects of the chemical, while the second addresses the cancer effects of the chemical. This two-part approach is employed because there are typically major differences in the risk assessment methods used to assess cancer and non-cancer effects. For example, cancer risks are expressed as a probability of suffering an adverse effect (cancer) during a lifetime and non-cancer hazards are expressed, semi-quantitatively, in terms of the hazard quotient (HQ), defined as the ratio between an individual's estimated exposure and the health guideline (MRL or RfD). HQs are not an estimate of the likelihood that an effect will occur, but rather an indication of whether there is potential cause for concern for adverse health effects. If the HQ exceeds one, which indicates that the estimated dose is greater than the health-based guideline, the chemical exposure is examined in greater detail using the In-depth approach noted below.

Methodology for in-depth evaluation of potential for non-cancer health Effects

- The estimated non-cancer exposure doses are compared with observed effect levels reported in the **critical toxicological and/or epidemiologic study** used to derive the health-based guideline in the ATSDR Toxicological Profile and/or EPA Integrated Risk Information System (IRIS) database. In addition, the larger toxicological/epidemiological database is also evaluated, especially for critical chemicals with high concentrations in all media in order to gain a better understanding of the range of effect levels rather than focusing on a single dose level, which is used to derive the health-based guideline.

- When the estimated dose approaches or exceeds a Lowest-Observed -Adverse-Effect- Level (LOAEL), it is considered **to cause harm** for longer term exposures, but requires further evaluation for acute exposures based on other factors listed below.

The relevance of the critical study is carefully evaluated in relation to site-specific exposure conditions by taking into consideration the following factors:

- Animal or human study (adults or children)
- Relevance of effects observed in animals to humans
- High bolus dose or low/medium dose levels, dose regimens, and method of dosing
- Bioavailability of metals (arsenic, lead, copper) in the study matrix versus the environmental media evaluated (e.g., soil and water)
- Level of confidence in the critical study and uncertainties/limitations in supporting studies

Toxicity Assessment for Cancer Effects

For cancer effects, the toxicity assessment process has two components. The first is a qualitative evaluation of the weight of evidence that the chemical does or does not cause cancer in humans. Typically, this evaluation is performed by the EPA, using the system summarized in Table C2 below:

Table C2. Cancer Classifications

Category	Meaning	Description
A	Known human carcinogen	Sufficient evidence of cancer in humans.
B1	Probable human carcinogen	Suggestive evidence of cancer incidence in humans.
B2	Probable human carcinogen	Sufficient evidence of cancer in animals, but lack of data or insufficient data from humans.
C	Possible human carcinogen	Suggestive evidence of carcinogenicity in animals.
D	Cannot be evaluated	No evidence or inadequate evidence of cancer in animals or humans.

For chemicals which are classified in Group A, B1, B2, or C, the second part of the toxicity assessment is to describe the carcinogenic potency of the chemical. This is done by quantifying how the number of cancers observed in exposed animals or humans increases as the dose increases. Typically, it is assumed that the dose response curve for cancer has no threshold, arising from the origin and increasing linearly until high doses are reached. Thus, the most convenient descriptor of cancer potency is the slope of the dose-response curve at low dose (where the slope is still linear). This is referred to as the Slope Factor, which has dimensions of risk of cancer per unit dose.

Estimating the cancer SF is often complicated by the fact that observable increases in cancer incidence usually occur only at relatively high doses, frequently in the part of the dose-response curve that is no longer linear. Thus, it is necessary to use mathematical models to extrapolate from the observed high dose data to the desired (but unmeasurable) slope at low dose. In order to account for the uncertainty in this extrapolation process, EPA typically chooses to employ the upper 95th confidence limit of the slope as the SF. That is, there is a 95% probability that the true cancer potency is lower than the value chosen for the SF. This approach ensures that there is a margin of safety in cancer risk estimates. The cancer SFs used in this evaluation are shown below in Table C3.

Previous and Current Oral Health-based Guidelines for Contaminants of Potential Concern

For PCE, the non-cancer health-based guideline and the oral slope factor for carcinogenic risks decreased. The non-cancer health-based guideline for TCE also decreased.

Table C3. Previous and Current Oral Health-based Guidelines for Contaminants of Potential Concern

Contaminant Of Potential Concern	Previous Oral Health-based Guideline (mg/kg-day)	Current Oral Health-based Guideline (mg/kg-day)	Previous Oral Slope Factor ($mg/kg\text{-}day^{-1}$)	Current Oral Slope Factor ($mg/kg\text{-}day^{-1}$)
Chloroform (no change)	1.00E-02	1.00E-02	3.10E-02	3.10E-02
Tetrachloroethene	1.00E-02	6.00E-03	5.40E-01	2.10E-03
Trichloroethene	3.00E-04	5.00E-04	5.90E-03	5.90E-03*

Note: mg/kg-day = milligram per kilogram per day

Greetings,

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Completing the survey should take less than 5 minutes of your time. If possible, please provide your responses within the next two weeks. All information that you provide will remain confidential.

The responses to the survey will help ATSDR determine if we are providing useful and meaningful information to you. ATSDR greatly appreciates your assistance as it is vital to our ability to provide optimal public health information.

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