LETTER HEALTH CONSULTATION

Public Health Implications of Vapor Intrusion of Volatile Organic Compounds Associated with a Former Dry Cleaning Establishment

Cho's Custom Cleaners

Arvada, Jefferson County, Colorado
FACILITY ID:

4/24/2012

Prepared by the Colorado Department of Public Health and Environment under a cooperative agreement with the U.S. Department of Health and Human Services Agency for Toxic Substances and Disease Registry. This document has not been reviewed and cleared by ATSDR

LETTER HEALTH CONSULTATION

TO: ROBERT BEIERLE, PROJECT MANAGER, HMWMD/CDPHE

FROM: THOMAS SIMMONS HEALTH ASSESSOR, CCPEHA/DCEED/CDPHE

SUBJECT: PUBLIC HEALTH IMPLICATIONS OF GROUNDWATER CONTAMINATION AND VAPOR INTRUSION AT THE LAKE ARBOR SHOPPING CENTER IN ARVADA, ADAMS COUNTY, COLORADO

CC: RAJ GOYAL, PH.D, PRICIPAL INVESTIGATOR, CCPEHA/DCEED/CDPHE

DATE: 4/24/2012

This letter health consultation is in response to a request made by The Hazardous Materials and Waste Management Division (HMWMD) of the Colorado Department of Public Health and Environment (CDPHE) for assistance from the Colorado Cooperative Program for Environmental Health Assessments (CCPEHA) to evaluate the potential public health implications of exposure to indoor air contamination in buildings above a groundwater contaminant plume of tetrachloroethene (PCE). The groundwater contaminant plume in question is a result of improper disposal of PCE at Cho's Custom Cleaners, a former dry cleaning facility located in the Lake Arbor Shopping Center of Arvada, Colorado. Since the discovery of PCE in groundwater at the site in 2006, an Integrated Corrective Action Plan (ICAP) has been developed to investigate the extent of contamination and determine the appropriate remedial actions to mitigate the plume (Enviropro, 2007). One component of the ICAP has been indoor and outdoor ambient air sampling to determine if vapor intrusion in buildings overlying the plume is occurring.

Purpose

The purpose of this evaluation is to determine the public health implications of exposure to indoor air contaminants occurring via vapor intrusion in buildings overlying the groundwater contaminant plume.

Site Background

Cho's Custom Cleaners (Cho's) is a former dry cleaning facility that was located in Unit #7533 of the Lake Arbor Shopping Center in Arvada, CO. According to one of the former owners of the business, Cho's Cleaners was in operation since 1981 (Enviropro 2007). However, a city directory search, conducted by Enercon, indicates that Cho's operated at that location since at least 1978 (Enercon 2005). Prior to the development of the Lake Arbor Shopping Center in 1972, the site was undeveloped agricultural land that contained no buildings. The first indication of a release from Cho's was noted in a 2005 Phase 1 site investigation conducted by Enercon (Enercon 2005). In this report, site

investigators concluded that Cho's was using good operating practices with respect to PCE use including proper maintenance of dry cleaning equipment; and proper handling and disposal of PCE. In addition no record of hazardous waste violations were found in a review of the CDPHE files. However, it was noted that mop water had historically been dumped on the pavement outside the back door. For this reason, coupled with the fact that Cho's had operated at this location for over 25 years, Enercon concluded that Cho's posed a high environmental risk to the shopping center. Soil and groundwater sampling in support of a Phase II site investigation, which was conducted in 2006 by Enviropro, confirmed that Cho's Cleaners had released PCE to soil and groundwater at the site (Enviropro 2006). An extensive audit conducted by Enviropro that same year found a number of deficiencies in handling and disposal of PCE. The audit concluded that former and current disposal practices of PCE were contributing directly to soil and groundwater contamination (Enviropro 2007). Additional sampling and remediation using In Situ Chemical Oxidation with permanganate has been conducted since the confirmation of PCE in soil and groundwater.

Environmental Data

Groundwater monitoring has been ongoing since the discovery of PCE. The contaminant plume extends approximately 300 ft. in the north-south direction and 150 ft. to the east and west (Enviropro 2007). Groundwater occurs in confined to semi-confined conditions with permeable zones of 1-5 ft. scattered throughout the site. The depth to groundwater is 5.45-9.9 ft. below ground surface (bgs.) and flows in a south-southeast direction. PCE concentrations up to 10,000 μg/L have been detected in groundwater. The groundwater data collected to date indicates that the contaminant plume is stationary and contained onsite. Residential properties in the area are connected to Arvada's municipal water supply and sewer system and the use of private groundwater wells is prohibited by city code. Therefore, ingestion of groundwater is not a pathway of concern.

Three air sampling events have also been carried out since the discovery of PCE in soil and groundwater. PCE and related VOCs have the ability to vaporize from groundwater and soil and enter the air space of overlying buildings, a process called vapor intrusion. Indoor air samples were collected from two operating businesses that are located above the groundwater plume and adjacent to the former dry cleaning facility (Ace Cash Express and Goodwill). Outdoor ambient air samples have also been collected and analyzed to establish background concentrations of site-related VOCs. Air samples were collected using 6 liter SUMMA canisters fitted with an orifice to collect samples over a sampling period of 24 hours. All air samples were sent to Ace Laboratories, Inc. in Thousand Oaks, CA for analysis of 6 target compounds by EPA Method TO-15 (PCE and daughter products). The chemical results of indoor and outdoor air samples are shown in Table 1. The air sampling locations are shown in Figure 1.

The highest concentrations of site-related VOCs in indoor air were found at Ace Cash Express, which is located directly south of the former dry cleaner and near the center of the contaminant plume. Concentrations at this location ranged from 92-300 micrograms PCE per cubic meter of air ($\mu g/m^3$). TCE was also detected at this location although at

much lower concentrations ranging from 0.1-0.55 μg/m^3. At the Goodwill, PCE concentrations in indoor air ranged from 0.62-1.0 μg/m^3 and TCE was only detected in one sample at 0.11 μg/m^3, which is just above the reporting limit of the analytical method (0.10 μg/m^3). Cis-1,2-dichloroethene, trans-1,2-dichloroethene, 1,1-dichloroethene, and vinyl chloride, which are by products of bacterial dechlorination of PCE were not detected in any sample.

The screening values used to identify contaminants of potential concern (COPCs) in indoor air are the EPA's Regional Screening Level for PCE and the ATSDR's Cancer Risk Evaluation Guide (CREG) for TCE (Table 2). Typically, PCE and TCE would be selected as COPCs only in air at Ace Cash Express. However, due to the limited amount of sampling data available, PCE and TCE were retained as COPCs at both locations.

Table 2. Selection of Contaminants of Potential Concern

Sampling Location	Maximum Detected Value of Tetrachloroethene (in μg/m^3)	EPA Regional Screening Level[1] for Tetrachloroethene (in μg/m^3)	Maximum Detected Value of Trichloroethene (in μg/m^3)	ATSDR's Comparison Value[2] for Trichloroethene (in μg/m^3)
Ace Cash Express	300	9.36	0.55	0.2
Goodwill	1.0	9.36	0.11	0.2

NOTE: μg/m^3 = microgram contaminant per cubic meter of air
[1] EPA Regional Screening Level for Residential Exposure Scenarios based on the new EPA toxicity assessment for PCE (EPA 2012). Please note the residential RSL given in the current version dated November 2011 is 0.41 in μg/m^3 based on the old PCE inhalation unit risk.
[2] ATSDR's Cancer Risk Evaluation Guide

Exposure Assessment

Individuals are currently working in the Goodwill and Ace Cash Express units. This is a complete exposure pathway for the inhalation route of exposure. To estimate the potential non-cancer and cancer health risks associated with exposure to contaminants in indoor air during work, assumptions must be made regarding the amount of time people will come into contact with the contamination. In this health consultation, the standard default exposure assumptions, established by the EPA, for industrial workers were used to estimate exposure concentrations. The major assumptions used for the industrial worker scenario are 8 hours per day, 250 days per year, over a period of 25 years. The second pathway is a potential residential scenario that will be evaluated because there is a slight chance of PCE migrating off the Lake Arbor Property and into groundwater beneath adjacent homes. However, it should be noted that all data collected to data indicates that the contaminant plume is stable and contained onsite. Furthermore, the evaluation of a potential residential scenario informs site project managers regarding future land-use restrictions in the shopping center. The major assumptions used for the potential residential scenario are exposure over 24 hours per day, 350 days per year, for a period of

30 years. This information is summarized in the conceptual site model for the site shown in Table 3.

As mentioned previously, only three indoor air samples have been collected from both the Goodwill and Ace Cash Express. Due to the limited amount of sampling data available, the maximum detected concentration of indoor air contaminants in each unit was used as the exposure point concentration for workers in those businesses. For the potential residential scenario, the maximum detected value of all indoor air contaminants was used as the exposure point concentration. This assumption was used because if the contaminant plume shifts in the future, the indoor air concentration of contaminants in homes cannot be predicted. Based on the data that is currently available, this assumption would result in the "worst-case" exposure for future potential residents.

Public Health Evaluation

The potential for non-cancer and cancer health effects is evaluated independently due to differences in the methods of health risk estimation. For example, the exposure concentration for estimating cancer risk is averaged over the lifetime of the individual whereas the exposure concentration for non-cancer health hazards is averaged over the duration of exposure. The estimated exposure concentrations for non-cancer health effects are compared to health-based guidelines developed by the ATSDR and EPA. If the estimated exposure concentration is below the health-based guidelines, adverse non-cancer health effects are not likely to occur. If the estimated exposure concentration is above the health-based guidelines, additional evaluation is warranted. To evaluate potential cancer risks, the estimated exposure concentrations for cancer are compared with the EPA acceptable cancer risk range of $1 * 10^{-6}$ to $1 * 10^{-4}$, or one excess cancer case per million exposed individuals (low-end) to 100 excess cancer cases per million exposed individuals (high-end).

Ace Cash Express Employees: As shown in Table 4, the estimated non-cancer exposure concentration of PCE exceeds the health based guideline by a factor of 2 (HQ = 1.7). The health-based guideline for PCE that was used in this evaluation is the EPA's Inhalation Reference Concentration (RfC) of 40 $\mu g/m^3$ (EPA 2012). The RfC represents the midpoint of three candidate RfCs ($56\mu g/m^3$, 56 $\mu g/m^3$, and $15\mu g/m^3$). These RfCs are based on two primary studies of occupationally exposed adult dry cleaning workers, Echeverria et al. and Cavalleri et al (EPA 2012). Echevrria et al. examined 65 dry cleaners in Detroit, Michigan using a standardized neurobehavioral test battery and found subtle changes in cognitive and visuospatial functioning amongst the workers. In this study, these neurobehavioral health effects occurred at the Lowest Observed Adverse Effect Level (LOAEL) of 56,000 $\mu g/m^3$. Cavalleri et al. examined 35 dry cleaning workers in comparison to a group of 35 controls that were matched for age, alcohol consumption, and smoking. In the PCE exposed group, workers performed worse on color vision tests than their matched controls. A LOAEL of 42,000 $\mu g/m^3$ was established in this study. The RfC was derived from these studies using a uncertainty factor of 1000.

The estimated exposure concentration for employees of Ace Cash Express is 69 $\mu g/m^3$, which is slightly higher than the health based guideline of 40 $\mu g/m^3$, but well below the exposure concentrations that were found to be associated with harmful effects in the human epidemiological studies. Therefore, the estimated non-cancer health effects from PCE exposure while working at Ace Cash Express are likely to be associated with a low increased risk of non-cancer adverse health effects. This finding, however, is associated with some uncertainty because a No Observable Adverse Effect Level (NOAEL) was not established in either study. In addition, the estimated HQs are greater than CDPHE risk management action level for non-cancer risk level (HQ = 1). For these reasons, exposure to PCE vapors while working at Ace Cash Express should be reduced. The estimated non-cancer exposure concentration for TCE is approximately 16 times lower than the health-based guideline with an estimated HQ of 0.06. Adverse health effects are not likely to occur at concentrations below the health-based guideline. Thus, exposure to TCE vapors while working at Ace Cash Express does not appear to be a concern for non-cancer adverse health effects.

The estimated theoretical cancer risks for employees of Ace Cash Express are within the EPA acceptable cancer risk range as shown in Table 5. The highest estimated lifetime excess cancer risk of $6.36 * 10^{-6}$, or 6 excess cancer cases per million exposed individuals, is a result of inhalation of PCE vapors. Exposure to TCE results in an estimated lifetime excess cancer risk that is below the acceptable cancer risk range at $1.84 * 10^{-7}$, or 0.2 excess cancer cases per million exposed individuals. Therefore, the cumulative lifetime excess cancer risk estimated for Ace employees from inhalation of PCE and TCE is $6.54 * 10^{-6}$, or 7 excess cancer cases per million exposed individuals. This level of cancer risk is associated with a low increased risk of developing cancer since the combined theoretical cancer risk is at the low-end of the acceptable cancer risk range. It should be noted, however, that the estimated theoretical cancer risk for PCE is above CDPHE's target cancer risk level of $1 * 10^{-6}$, or 1 excess cancer case per million exposed individuals. Therefore, the concentration of PCE in air at Ace Cash Express should be reduced.

Goodwill Employees: As shown in Table 4, the estimated non-cancer exposure concentrations for employees of the Goodwill are well below the health-based guidelines for PCE and TCE. In this case, the highest estimated HQ is from inhalation of TCE, which is 0.013, which means the estimated exposure concentration is approximately 77 times lower than the health-based guideline. The estimated HQ for inhalation of PCE while working at the Goodwill is 0.0057, which means the estimated exposure concentration is approximately 175 times lower than the health-based guideline for PCE. This indicates that the estimated hazards are associated with a very low increased risk of developing non-cancer adverse health effects from inhalation of PCE and TCE while working at the Goodwill.

In addition, the estimated theoretical cancer risks for employees of Goodwill is well below the EPA acceptable cancer risk range as shown in Table 5. The highest estimated lifetime excess cancer risk is from inhalation of TCE with an estimated cancer risk of $3.68 * 10^{-8}$, or 0.04 excess cancer cases per million exposed individuals. Exposure to PCE

results in an estimated lifetime excess cancer risk that is also well below the acceptable cancer risk range at $2.12 * 10^{-8}$, or 0.02 excess cancer cases per million exposed individuals. The cumulative lifetime excess cancer risk estimated for Goodwill employees from inhalation of PCE and TCE is $5.80 * 10^{-8}$, or 0.06 excess cancer cases per million exposed individuals. Therefore, exposure to PCE and TCE vapors while working at the Goodwill is associated with a very low increased risk of developing cancer. Furthermore, the estimated cumulative lifetime excess cancer risk for Goodwill employees is also well below CDPHE's target cancer risk range.

Potential Residential Scenario: The potential for non-cancer and cancer health effects was estimated for both child and adult residents. As mentioned previously, the contaminant plume is currently confined to an area within the Lake Arbor Shopping Center. Therefore, it is assumed that vapor intrusion is not occurring in homes surrounding the shopping area at this time. This scenario was evaluated as a potential exposure scenario in case the contaminant plume begins to migrate offsite in the future and, as mentioned previously, to also inform risk managers of potential health risks associated with unrestricted land-use at the site.

For non-cancer health effects, the estimated exposure concentration for adults and children is equivalent. As shown, in Table 6, the estimated exposure concentration for PCE exceeds the non-cancer health-based guideline with a HQ of 7.20 (i.e. 7 times higher than the health-based guideline for PCE). The estimated exposure concentration of TCE is lower than the non-cancer health-based guideline with a HQ of 0.26. As mentioned previously, the health-based guideline for PCE that was used in this evaluation is the EPA's Inhalation Reference Concentration of 40 $\mu g/m^3$, which is based on the midpoint of the LOAEL values of 56,000 $\mu g/m^3$ and 15,000 $\mu g/m^3$ with an uncertainty factor of 1,000. The estimated exposure concentration of PCE for potential residential exposures is 289 μg of PCE per cubic meter of air. The lowest and the highest LOAELs found in the studies used for EPA's derivation of the RfC are 52 and 184 times higher than the estimated residential exposure concentration. Therefore, residential exposure to site-related VOCs via vapor intrusion is likely to be associated with a low increased risk of developing non-cancer adverse health effects. This finding, however, is associated with some uncertainty because: (a) there is not a NOAEL value available for PCE; (b) the estimated exposures are well above the acceptable level of exposure (i.e., health based guideline); and (c) the estimated exposure concentration is well above the CDPHE risk management action level of non-cancer Hazard Quotient of 1.0.

For the cancer evaluation, the exposure concentration estimation for children and adults is not equivalent since cancer risks are averaged over a lifetime. Child exposure concentrations are based on 6 years of exposure beginning at birth. Adult exposure concentrations for cancer are estimated for exposures over 24 years (e.g., from 6 to 30 years). Estimation of a lifetime cancer risk assumes exposure from birth to the age of 30 years. As shown in Table 7, the estimated exposure concentrations of PCE and the associated carcinogenic risks for children and adults are well within the acceptable cancer risk range. The estimated cancer risk for the potential child resident from inhalation of PCE is 6 excess cancer cases per million exposed individuals ($6.41*10^{-6}$). For adult

exposure from age 6-30 years, the estimated theoretical cancer risk from PCE is 26 excess cancer cases per million ($2.56*10^{-5}$) and less than 1 excess cancer case per million individuals exposed to TCE vapors (8.9E-07).

The estimated lifetime excess cancer risk from exposure to PCE over 30 years is 32 excess cancer cases per million exposed individuals ($3.21*10^{-5}$). Inhalation of TCE vapors is a minor contributor to the estimated lifetime cumulative carcinogenic risk, which is equal to 1.27 excess cancer case per million exposed individuals ($1.27*10^{-6}$).Therefore, the cumulative lifetime excess cancer risk from exposure to PCE and TCE is 33 excess cancer cases per million exposed individuals ($3.29*10^{-5}$), which is near the midpoint of the EPA's acceptable cancer risk range. This level of cancer risk is associated with a low increased risk of developing cancer over a lifetime of exposure (0-30 years of age). However, the estimated theoretical cancer risk level is above CDPHE's target cancer risk level of $1.0 * 10^{-6}$. For this reason and due to the potential concern for non-cancer health effects based on the exceedance of the health guideline for PCE (by 7 times), remediation of the VOC groundwater plume associated with Cho's Cleaners should continue to be monitored and remediated to ensure that residential exposure does not occur in the future.

Uncertainty/Limitations

In general, any risk evaluation is likely to over- or underestimate environmental exposures and the associated health risks because of the uncertainty associated with various exposure assumptions and toxicity values. 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.

- Limited indoor air data is available. This limitation is overcome by using the maximum detected value for health risk estimation which could over- or under-estimate risk.
- Indoor air contaminant values are likely to fluctuate over time depending on weather and other variables.
- The cancer and non-cancer risks for a future potential residential scenario are estimated using the current maximum detected air concentration, which may under- or over-estimate future potential risks.

Conclusions

Based on a review of the available indoor air data and the potential public health implications of inhalation exposures, CCPEHA has reached the following conclusions:

Exposure to PCE and TCE in indoor air is not likely to harm the health of Ace Cash Express and Goodwill employees. This conclusion was reached because the estimated non-cancer and theoretical cancer risks are associated with a low increased risk of

developing cancer and non-cancer health effects. Specifically, the estimated non-cancer hazards from inhalation of PCE are just above the acceptable level of 1 for employees of Ace Cash Express. In addition, the estimated lifetime excess cancer risks are within the acceptable cancer risk range for employees of Ace Cash Express., Overall, the estimated exposures are above CDPHE's risk management action level of non-cancer hazard quotient of 1.0 and long term cancer risk goal of 1 excess cancer case per million exposed individuals (1E-06).

Currently there is no residential exposure to PCE in indoor air (i.e. not a complete pathway at this time). However, if the contaminant plume moves offsite and beneath the homes of surrounding residents in the future, it is not expected to harm people's health; however, this conclusion is associated with some uncertainty because the estimated exposures are above acceptable levels and enter a range of potential concern. It should be noted that residential exposure is a potential exposure pathway that is not currently expected to occur. However, if this pathway occurs in the future, the estimated non-cancer hazards from PCE exposure are 7 times above the acceptable level (i.e., health-based guideline), but are well below levels known to be associated with harmful health effects. In addition, the estimated theoretical cancer risks are well within EPA's acceptable cancer risk range. However, the estimates of future potential exposures are well above CDPHE's risk management action level of non-cancer hazard quotient of 1.0 and long term cancer risk goal of 1 excess cancer case per million exposed individuals (1E-06).

Recommendations

Based upon a thorough review of the current indoor air data and the associated public health implications of inhalation of Volatile Organic Compounds (VOCs) at the Cho's Cleaners site, the following recommendations were made to be preserve public health:

- In order to achieve CDPHE's non cancer risk management action level and long term cancer risk goal of one in a million (1E-06), the indoor air concentration of VOCs at Ace Cash Express should be reduced. This is particularly true for the indoor air concentration of PCE.

- If mitigation systems are installed to reduce indoor air contaminant levels, additional indoor air sampling should be conducted to verify the effectiveness of the system.

- Continue to monitor the groundwater contaminant plume to ensure that the contamination does not spread to neighboring residential properties.

- Continue to remediate the groundwater contamination associated with Cho's Cleaners.

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:

- As necessary, CCPEHA will review any additional data collected from the Cho's Cleaner site.

- Upon request, CCPEHA will provide assistance to State and Local environmental officials on sampling plans and analysis.

- Upon request, CCPEHA will provide the appropriate level of health education on the findings of this health consultation to stakeholders and the community.

References

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Report Preparation

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ATTACHMENT 1: Additional Tables and Figures

Table 1. Indoor Air Quality Data

Sampling Location	Sampling Date	Tetrachloroethene (in μg/m^3)	Trichloroethene (in μg/m^3)	cis-1,2-DCE (in μg/m^3)	trans-1,2 DCE (in μg/m^3)	1,1 DCE (in μg/m^3)	Vinyl Chloride (in μg/m^3)
Ace Cash Express	9/8/2010	92	0.21	<37 (ND)	<62 (ND)	<5.0 (ND)	<0.072 (ND)
Ace Cash Express	11/5/2010	300	0.55	<37 (ND)	<62 (ND)	<5.0 (ND)	<0.072 (ND)
Ace Cash Express	1/13/2011	200	0.10	<37 (ND)	<62 (ND)	<5.0 (ND)	<0.072 (ND)
Goodwill	9/8/2010	1.0	<0.10 (ND)	<37 (ND)	<62 (ND)	<5.0 (ND)	<0.072 (ND)
Goodwill	11/5/2010	0.94	0.11	<37 (ND)	<62 (ND)	<5.0 (ND)	<0.072 (ND)
Goodwill	1/13/2011	0.62	<0.10 (ND)	<37 (ND)	<62 (ND)	<5.0 (ND)	<0.072 (ND)
Ambient[1]	9/8/2010	25	0.46	<37 (ND)	<62 (ND)	<5.0 (ND)	<0.072 (ND)
Ambient[2]	11/5/2010	0.65	0.19	<37 (ND)	<62 (ND)	<5.0 (ND)	<0.072 (ND)
Ambient[3]	11/5/2010	0.45	<0.10 (ND)	<37 (ND)	<62 (ND)	<5.0 (ND)	<0.072 (ND)
Ambient[4]	1/13/2011	<0.31	<0.10 (ND)	<37 (ND)	<62 (ND)	<5.0 (ND)	<0.072 (ND)

NOTE: μg/m^3 = microgram contaminant per cubic meter of air, cis-1,2-DCE = cis-1,2-dichloroethene, trans-1,2-DCE = trans-1,2-dichloroethene, 1,1 DCE = 1,1-dichloroethene, ND = Not Detected

[1] Outdoor ambient air at the Fire station across the street from the Lake Arbor Shopping Center

[2] Outdoor ambient air on the roof of the Safeway grocery store

[3] Outdoor ambient air on the roof of unit #7523 in the Lake Arbor Shopping Center

[4] Outdoor ambient air at the Lake Arbor Recreation Area

Table 3. Conceptual Site Model

Source	Point of Exposure	Affected Environmental Medium	Timeframe of Exposure	Potentially Exposed Population	Route of Exposure	Pathway Designation
Cho's Cleaners	Businesses Lake Arbor Shopping Center that overlay the plume	Groundwater, Indoor Air	Past, current, and future[1]	Industrial Workers	Inhalation of VOCs in Indoor Air	Complete
					Ingestion of contaminated groundwater	Incomplete[2]
	Residential Properties adjacent to the Lake Arbor Shopping Center	Groundwater, Indoor Air	Future[3]	Residents	Inhalation of VOCs in Indoor Air	Potential[3]
					Ingestion of contaminated groundwater	Incomplete[4]

NOTE:
[1] The groundwater contaminant plume was discovered during a Phase II subsurface investigation conducted in 2006. It is not known how long the contamination has been present in soil and groundwater.
[2] Businesses in the Lake Arbor Shopping Center are connected to the municipal water supply.
[3] This is considered a potential exposure pathway because the groundwater plume is contained onsite in the area directly south-southeast of the former location of Cho's Cleaners. Furthermore, the evaluation of a potential residential scenario informs site project managers regarding future land-use restrictions in the shopping center.
[4] The City of Arvada prohibits domestic groundwater use and all residents are connected to the municipal water supply.

Table 4. Non-cancer Exposure Concentration Results and Hazard Quotients for Industrial Workers

Location of Industrial Worker	Industrial Worker Estimated Non-Cancer Exposure Concentration of PCE (in μg/m^3)	Industrial Worker Estimated Non-Cancer Exposure Concentration of TCE (in μg/m^3)
Ace Cash Express	6.85E+01	1.26E-01
Goodwill	2.28E-01	2.51E-02
Location of Industrial Worker	**Industrial Worker Estimated Non-Cancer Hazard Quotient from PCE Exposure**	**Industrial Worker Estimated Non-Cancer Hazard Quotient from TCE Exposure**
Ace Cash Express	**1.71E+00**	6.28E-02
Goodwill	5.71E-03	1.26E-02

NOTE: μg/m^3 = microgram contaminant per cubic meter of air, values highlighted in red exceed the health-based guideline

Table 5. Cancer Exposure Concentration Results and Theoretical Cancer Risk Estimates for Industrial Workers

Location of Industrial Worker	Industrial Worker Estimated Cancer Exposure Concentration of PCE (in μg/m^3)	Industrial Worker Estimated Cancer Exposure Concentration of TCE (in μg/m^3)
Ace Cash Express	2.45E+01	4.48E-02
Goodwill	8.15E-02	8.97E-03
Location of Industrial Worker	**Industrial Worker Estimated Theoretical Cancer Risk from PCE Exposure**	**Industrial Worker Estimated Theoretical Cancer Risk from TCE Exposure**
Ace Cash Express	6.36E-06	1.84E-07
Goodwill	2.12E-08	3.68E-08

Table 6. Non-cancer Exposure Concentration Results and Hazard Quotients for Potential Residents

Receptor	Residential Estimated Non-Cancer Exposure Concentration of PCE (in μg/m^3)	Residential Estimated Non-Cancer Exposure Concentration of TCE (in μg/m^3)
Potential Resident[*]	2.89E+02	5.29E-01
Receptor	**Residential Estimated Non-Cancer Hazard Quotient from PCE Exposure**	**Residential Estimated Non-Cancer Hazard Quotient from TCE Exposure**
Potential Resident[*]	7.20E+00	2.64E-01

NOTE: μg/m^3 = microgram contaminant per cubic meter of air, values highlighted in red exceed the health-based guideline
[*]As per EPA RAGS F, the calculations for Child and Adult residents are equivalent

Table 7. Theoretical Cancer Risk Estimates for Potential Residents

Potential Resident	Residential Estimated Theoretical Cancer Risk from PCE Exposure	Residential Estimated Theoretical Cancer Risk from TCE Exposure
Child(0-6 years)	6.41E-06	3.80E-07
Adult (6-30 years)	2.56E-05	8.92E-07
Lifetime (Adult+child 0-30 years)	3.21E-05	1.27E-06

NOTE: Cancer risk for TCE was estimated using the mutagenic mode for kidney cancer for children and non mutagenic mode for non Hodgkin Lymphoma (NHL) and liver cancer.

Table 8. Toxicity values and Comparison Screening Values

Contaminant of Potential Concern	Screening Value for Resident Air Exposures (in $\mu g/m^3$)	Non-Cancer Health Based Guideline (in $\mu g/m^3$)	Inhalation Unit Risk (in $\mu g/m^3)^{-1}$
PCE	0.41[a]	0.04[c]	2.6E-07[e]
TCE	0.2[b]	2[d]	4.10E-06[f]

NOTE: $\mu g/m^3$ = microgram contaminant per cubic meter of air

[a] EPA Regional Screening Values (last update 11/2011)

[b] ATSDR Cancer Risk Evaluation Guide Comparison Value (12/2011)

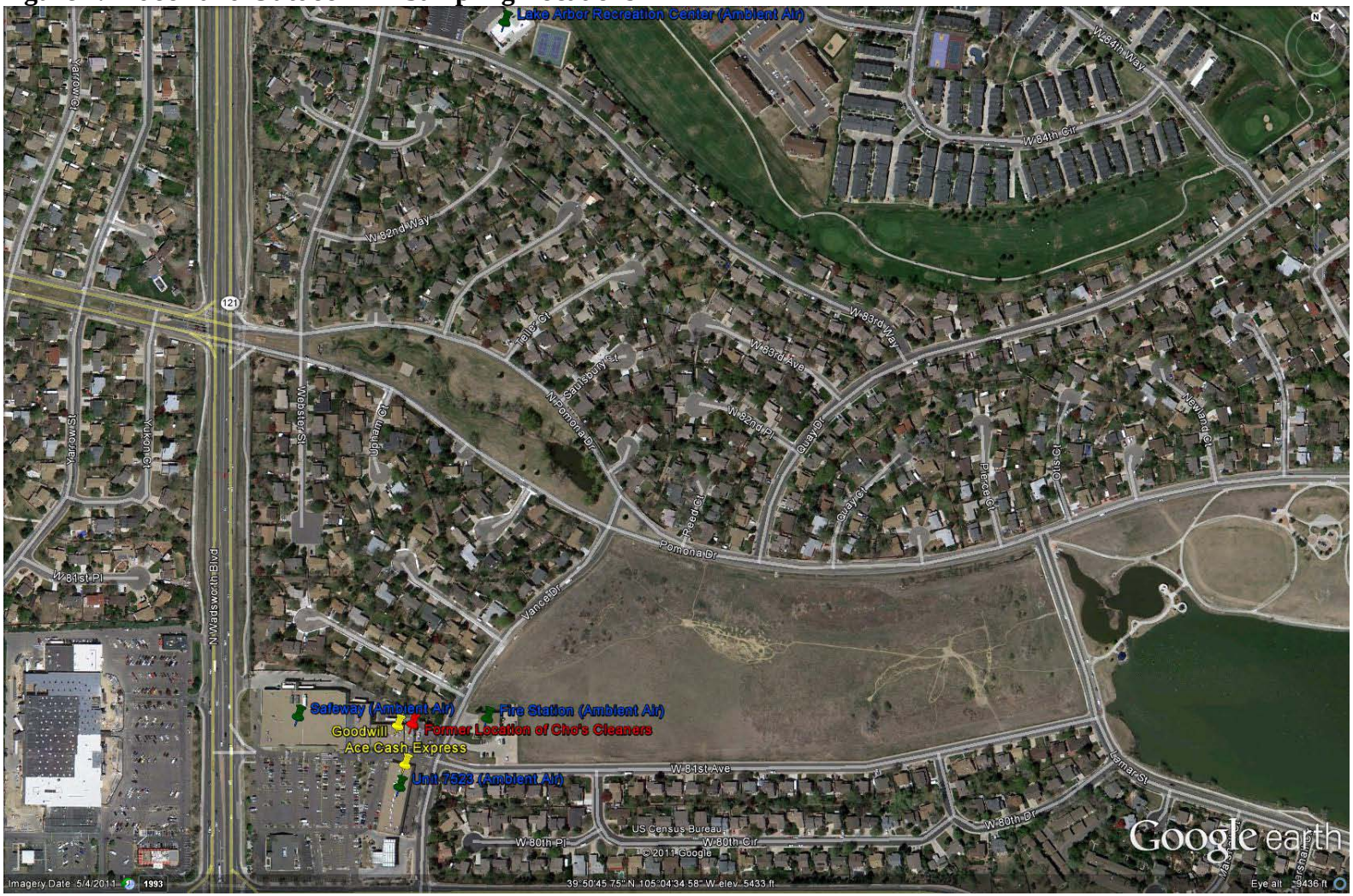
[c] ATSDR Chronic Inhalation Minimal Risk Level (last update 12/2010)

[d] EPA Inhalation Reference Concentration (EPA Integrated Risk Information System)

[e] EPA Inhalation Unit Risk (EPA 2012)

[f] EPA Integrated Risk Information System. Please note that residential cancer risks for children were estimated using IUR of 1E-06 $(\mu g/m^3)^{-1}$ for the kidney cancer and 3.1E-06 $(\mu g/m^3)^{-1}$ for the NHL and liver cancer.

Figure 1. Indoor and Outdoor Air Sampling Locations



SOURCE: Google Earth

KEY: Yellow = Indoor air sampling locations, Blue = Outdoor ambient air sampling locations, Red = Former location of Cho's Cleaners