Health Consultation

Vapor Intrusion Assessment:

TAKU GARDENS

FORT WAINWRIGHT, ALASKA

MARCH 7, 2013

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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HEALTH CONSULTATION

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FORT WAINWRIGHT, ALASKA

Prepared By:

U.S. Department of Health and Human Services
Agency for Toxic Substances and Disease Registry (ATSDR)
Division of Community Health Investigations
Western Branch

Foreword

The Agency for Toxic Substances and Disease Registry, ATSDR, was established by Congress in 1980 under the Comprehensive Environmental Response, Compensation, and Liability Act, also known as the Superfund law. This law set up a fund to identify and clean up our country's hazardous waste sites. The U.S. Environmental Protection Agency (USEPA) and the individual states regulate the investigation and cleanup of the sites.

Since 1986, ATSDR has been required by law to conduct a public health assessment at each of the sites on the USEPA National Priorities List. The aim of these evaluations is to find out if people are being exposed to hazardous substances and, if so, whether that exposure is harmful and should be stopped or reduced. If appropriate, ATSDR also conducts public health assessments when petitioned by concerned individuals. Public health assessments are carried out by environmental and health scientists from ATSDR and from the states with which ATSDR has cooperative agreements. The public health assessment process allows ATSDR scientists and public health assessment cooperative agreement partners flexibility in document format when presenting findings about the public health impact of hazardous waste sites. The flexible format allows health assessors to convey to affected populations important public health messages in a clear and expeditious way.

Exposure: As the first step in the evaluation, ATSDR scientists review environmental data to see how much contamination is at a site, where it is, and how people might come into contact with it. Generally, ATSDR does not collect its own environmental sampling data but reviews information provided by USEPA, other government agencies, businesses, and the public. When there is not enough environmental information available, the report will indicate what further sampling data is needed.

Health Effects: If the review of the environmental data shows that people have or could come into contact with hazardous substances, ATSDR scientists evaluate whether or not these contacts may result in harmful effects. ATSDR recognizes that children, because of their play activities and their growing bodies, may be more vulnerable to these effects. As a policy, unless data are available to suggest otherwise, ATSDR considers children to be more sensitive and vulnerable to hazardous substances. Thus, the health impact to the children is considered first when evaluating the health threat to a community. The health impacts to other high-risk groups within the community (such as the elderly, chronically ill, and people engaging in high risk practices) also receive special attention during the evaluation.

ATSDR uses existing scientific information, which can include the results of medical, toxicologic and epidemiologic studies and the data collected in disease registries, to evaluate the possible health effects that may result from exposures. The science of environmental health is still developing, and sometimes scientific information on the health effects of certain substances is not available.

Community: ATSDR also needs to learn what people in the area know about the site and what concerns they may have about its impact on their health. Consequently, throughout the evaluation process, ATSDR actively gathers information and comments from the people who live or work near a site, including residents of the area, civic leaders, health professionals, and community groups. To ensure that the report responds to the community's health concerns, an early version is also distributed to the public for their comments. All the public comments related to the document are addressed in the final version of the report.

Conclusions: The report presents conclusions about the public health threat posed by a site. Ways to stop or reduce exposure will then be recommended in the public health action plan. ATSDR is primarily an advisory agency, so usually these reports identify what actions are appropriate to be undertaken by USEPA or other responsible parties. However, if there is an urgent health threat, ATSDR can issue a public health advisory warning people of the danger. ATSDR can also recommend health education or pilot studies of health effects, full-scale epidemiology studies, disease registries, surveillance studies or research on specific hazardous substances.

Comments: If, after reading this report, you have questions or comments, we encourage you to send them to us.

Letters should be addressed as follows:

Attention: Manager, ATSDR Record Center Agency for Toxic Substances and Disease Registry, 1600 Clifton Road (F-09), Atlanta, GA 30333.

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Acronyms

ADEC	Alaska Department of Environmental Conservation
ATSDR	Agency for Toxic Substances and Disease Registry
CEL	Cancer Effect Levels
CREG	Cancer Risk Evaluation Guide
DBCP	1,2-Dibromo-3-chloropropane
DHHS	Department of Health and Human Services
DPW	Department of Public Works
DRO	Diesel-Range Organic
ELCR	Excess Lifetime Cancer Risk
EMEG	Environmental Media Evaluation Guide
FCS	Former Communications Site
GRO	Gasoline-Range Organic
HVAC	Heating, Ventilation and Air Conditioning
IARC	International Agency for Research on Cancer
IC	Institutional Control
ITRC	Interstate, Technology, Regulatory Council
JATO	Jet Assisted Take Off
LOAEL	Lowest Observed Adverse Effect Level
LUC	Land Use Controls
$\mu g/m^3$	microgram per meter cubed
Max	Maximum
mg/kg	milligrams per kilogram
mg/kg/day	milligrams per kilograms per day
MRL	Minimal Risk Level
NOAEL	No Observed Adverse Effect Level
PAH	Polycyclic Aromatic Hydrocarbon
PCB	Polychlorinated Biphenyl
PCE	Tetrachloroethylene
RCRA	Resource Conservation and Recovery Act
RfC	Reference Concentration
RfD	Reference Dose

RI	Remedial Investigation
RMEG	Reference dose Media Evaluation Guide
RRO	Residual-Range Organic
RTH	Remote Test Hole
SSD	Subslab Depressurization
SVOC	Semi-Volatile Organic Compound
TCE	Trichloroethylene
USACE	United States Army Corps of Engineers
USEPA	U.S. Environmental Protection Agency
VISL	Vapor Intrusion Screening Level
VOC	Volatile Organic Compound

Summary

Introduction	The Agency for Toxic Substances and Disease Registry (ATSDR) understands that you need to find out as much information as possible about exposures to vapor intrusion in the Taku Gardens housing development. Our objective in this health consultation is to give you that information and help you protect your health.
Background	In April 2005, building began for the 54-acre Taku Gardens housing development. The houses are duplexes designed for military personnel and their families. In June 2005, when excavating the foundation for Building 52 in the compound's southwest corner, contractors noted a solvent-like odor. And during site investigations in 2005 and 2006, contractors found a "hot spot" of polychlorinated biphenyl (PCB)-contaminated soil near Building 52's footprint. In 2010, ATSDR completed a health consultation on Taku Gardens PCB contamination. The 55 Taku Gardens duplexes (110 units) sit on the Fort Wainwright Former Communications Site. When the communications site was active, Army personnel working there used solvents, heating oil, and a number of other chemicals. When the communications operation closed down, many containers in which these chemicals were originally stored remained buried on the site. In 2011, the Army asked ATSDR to look at whether those buried chemical containers could cause vapor intrusion into the Taku Gardens duplexes. And, if vapors were found, ATSDR was to decide whether such vapor exposure was a health concern for the residents. This health consultation, then, looks at possible health effects for Taku Gardens residents who might contact or might be exposed to subsurface contaminants or harmful vapors at Taku Gardens. From the clean-up efforts that have occurred thus far, we have learned a great deal about the kinds of chemicals and containers Army personnel left behind when the communications site closed down. Contractors have removed contaminated soil, scrap metal, and construction and salvage debris. But because of tight spaces between buildings and structural stability concerns, contractors couldn't get under all the duplexes to remove containers that might still be there. And some of those barrels or drums or other types of containers might hold chemicals. If any such containers with chemicals in them remain under the duplexes, vapors from those containers could enter Taku Gardens resident's indoor air. To find out as much as possible about possible contamination that could affect Taku Gardens residents' health, ATSDR reviewed all the on-hand data from such sources as the U.S. Army, the U.S. Environmental Protection Agency, and the State of Alaska. But even after its review, ATSDR can't say for sure whether any such containers remain under any of the duplexes, nor can ATSDR determine whether such containers might still hold chemicals. The instruments and technology we currently have can't get

	that information for us. ATSDR does know, however, that some volatile organic compounds (VOC), semi-volatile organic compounds (SVOC), and petroleum compounds have leached into the groundwater under the Taku Gardens site. And these compounds could be a lasting vapor source that could move up and into the Taku Gardens duplexes.
Conclusion 1	Taku Gardens residents are the group that would most likely be exposed to vapor intrusion at Taku Gardens. Containers holding chemicals might still be buried under some Taku Gardens duplexes. But ATSDR cannot say whether vapor migration into the residents' indoor air might actually occur from any such still-buried containers. ATSDR further cannot say whether such vapor migration, even if it does occur, would harm the health of Taku Gardens families.
Conclusion 1 basis	The types of buried containers removed from the site included • Drums, • Lead-acid batteries, • Paint cans, • Transformers, • Practice rockets, • Gas cylinders, • Fire extinguishers, • Oil burning furnaces (up to 30 feet long by 20 feet wide), • Hydraulic cylinders holding hydraulic oil, and • Discarded military munitions. A test dig removed drums from under a garage slab. Tight spaces between buildings limited some post-construction digging. But workers were able to find five buildings that had beneath them scrap metal, construction debris, and other junk. Another six buildings likely had material buried under them as well. Buried material left beneath buildings could include containers of volatile or semi-volatile chemicals. Yet post-construction geophysical surveys cannot extend beneath buildings. This means that these surveys cannot find out for sure whether any buried containers remain under Taku Gardens duplexes. Geophysical surveys in 2004, however, did show high magnetic signals under the ground where some duplexes have since been constructed. ATSDR weighed the possibility that subsurface containers—like drums holding volatile or semivolatile chemicals—might remain under the duplexes. If corrosion or container breakdown were to result in chemical releases from these containers, they could pose a future health risk.

	But contractors found that the vast majority of the 1058 drums excavated at the site were crushed and empty. The drums did not contain major amounts of volatile, harmful substances. Contractors found over 2,000 munitions-related items, but they were inert; some practice rockets, however, did contain propellant residue. Beneath only one building did contractors find and remove drums in excavation sidewalls. The Army estimates at less than 0.5 percent the chances of intact drums still remaining beneath any Taku Gardens duplexes. If any such containers are still there and still have liquids in them, the liquids would most likely consist of petroleum compounds with higher breakdown rates and lower toxicity than halogenated solvents. Still, the wide types of materials found at the site and ATSDR's inability to do a geophysical survey under the buildings' footprints means we're not able to rule out fully the chance that subsurface containers might still hold harmful levels of volatile chemicals. So there's still a chance that any remaining under-building containers could break down over time and release vapors into the Taku Gardens duplexes. At certain levels, these vapors could be hazardous even though no one could see or smell them. And the vapors could enter buildings at levels below odor thresholds at times when quarterly or annual sampling events might not detect them.
Next steps for conclusion 1	ATSDR supports the Proposed Post-construction Subslab Soil Gas Monitoring Program. This program will do regular subslab gas sampling and data review for 5 years, at which time a complete data check will judge the need for any further sampling. Should conditions change and soil vapors release into indoor air, a pilot subslab depressurization (SSD) study has shown that effective subslab vapor extraction systems can be put in place and can be adjusted for best results. Any buried containers could be in the same areas as other debris. So ATSDR advises that before anyone moves into buildings that have observed and likely debris under them, the Army should think about putting protective measures in place. Such measures could include installation of SSD systems before occupancy. ATSDR also supports the Alaska Department of Environmental Conservation's (ADEC) guidance suggestion. ADEC recommends collecting at least three subslab gas samples. These samples can characterize subslab gas distribution in a representative number of duplexes. ATSDR further suggests a spring sampling event. Such a sampling event would watch all units where gas levels have gone beyond screening levels (instead of just 12 select units). The sampling event could also monitor SVOCs and include monitoring after any future building renovation, construction, landscaping or earthquake. If requested, ATSDR could assist in reviewing designs for remediation and for sampling, as well as reviewing any follow-up data.

Conclusion 2	ATSDR concludes that any vapors that might enter Taku Gardens duplexes from residual soil and groundwater contamination (other than contamination from subsurface containers like drums) in all likelihood would not enter duplexes at levels that would be harmful to the health of Taku Gardens families.
Conclusion 2 basis	Researchers have carried out subslab sampling at least twice in each Taku Gardens duplex. Indoor air samples gathered from about 20% of the units—the units with the highest subslab vapor levels—didn't find that those vapor levels were harmful. Researchers have also carried out indoor air sampling together with modeling that used empirical, radon-derived attenuation factors and that measured subslab gas levels. Sampling results confirmed that vapor intrusions into Taku Gardens indoor air were not expected to occur at levels high enough to make people sick.
Next steps for conclusion 2	ATSDR supports the land use controls (LUCs) and institutional controls (ICs) as set out in the December 9, 2010 *Land Use Controls/Institutional Controls Policy Memorandum* from DPW Environmental to the Garrison Commander. The memorandum tells residents that if they smell any odors at Taku Gardens they need to notify at once the Ft Wainwright Army Garrison Directorate of Public Works (DPW) and to leave the area. The memorandum also says not to disturb Taku Gardens soil to a depth greater than 6 inches below final grade. We remind everyone that the sampling process by which we find out about contamination is uncertain. Sampling and predicting a subslab vapor intrusion pathway is likewise uncertain. The pathway might need reevaluation in the future, particularly if • The buildings are remodeled, • New construction, landscaping or earthquake occurs, • The hydrogeological setting changes, or • Toxicologic modeling shows new risks. ATSDR supports plans in the Proposed Post-construction Subslab Soil Gas Monitoring Program to continue gas level evaluation by sampling subslab gas over a minimum of the next 5 years.
For more information	If you have questions or comments, you can call ATSDR toll-free at 1-800-CDC-INFO and ask for information on the Fort Wainwright: Taku Gardens site.

Background

Taku Gardens is a housing site located between Alder and Neely roads, east of White Street and west of the Fort Wainwright Power Plant (Figure 1) (CH2MHILL.). The 54-acre site is in an area known as the Former Communication Site (FCS) within the Fort Wainwright Cantonment Area (OASIS 2007). Fort Wainwright is an active Army installation near Fairbanks, North Star Borough, Alaska.

In 2002–2003, planners selected an area known as the Former Communication Site for a military family housing development. Before construction began, the Army, the Army Corps of Engineers (USACE), and their contractors (OASIS 2007) completed an Environmental Assessment, two Geophysical Surveys, two Geotechnical Surveys, and two Chemical Surveys.

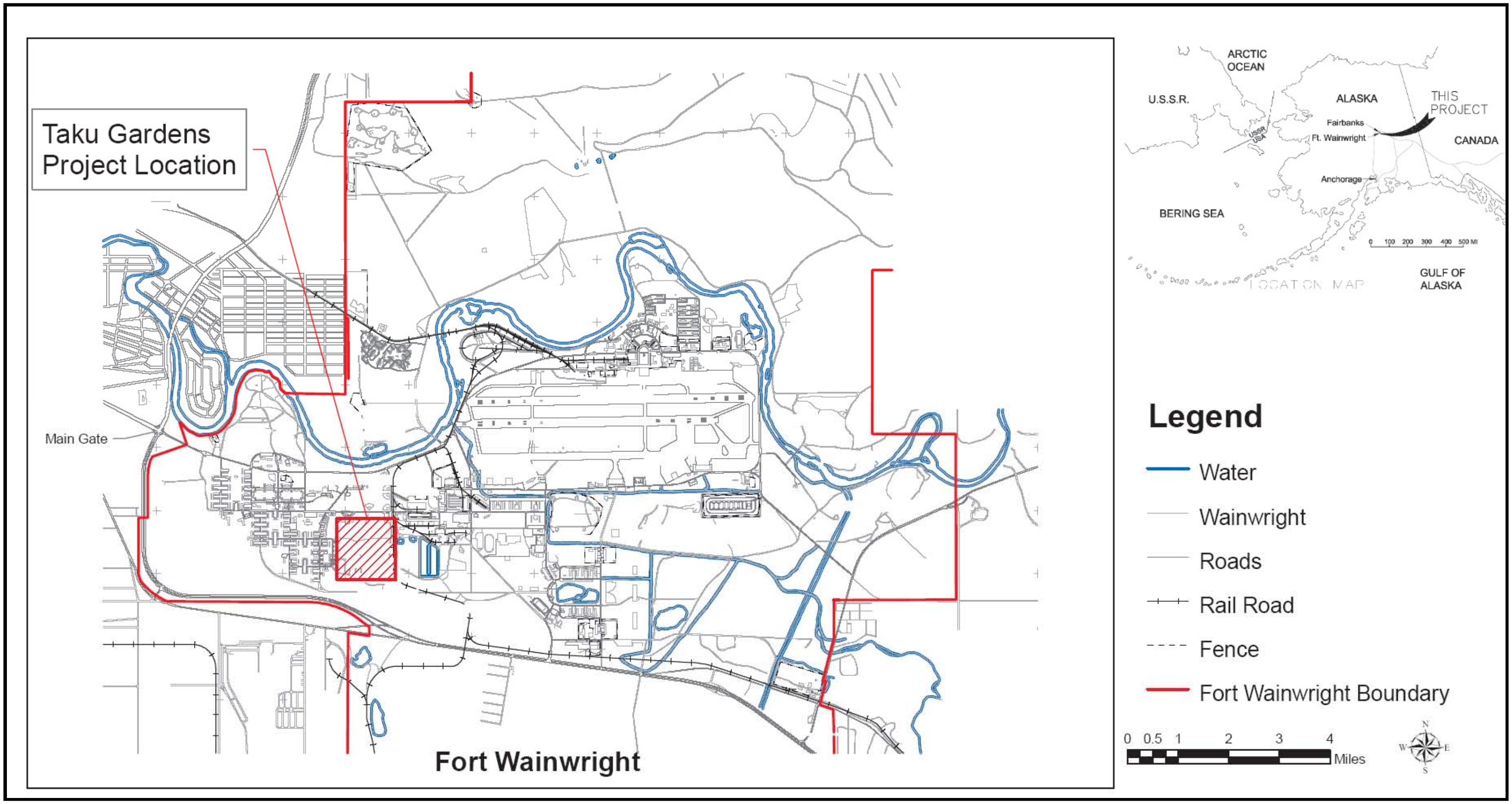
Before the April 2005 construction of the housing units, the site was in a relatively natural state (OASIS 2007). Workers cleared the northern portion and used it to store snow. A dense cover of second or third growth alder, aspen, scattered spruce, and birch covered the remainder of the site. Several trails passed through it, and local residents maintained a community garden at the site's southwest corner (USACE).

> ATSDR completed a public health assessment on Fort Wainwright in September 2003, and a public health consultation on Taku Gardens in April 2010 (see http://www.atsdr.cdc.gov/HAC/PHA/HCPHA.asp?State=AK).

In June 2005, during the excavation of the Building 52 foundation (located within Subarea E), workers noted a solvent-like odor. Ensuing investigations discovered high levels of polychlorinated biphenyls (PCBs) in the soil. This discovery halted construction activities. Environmental investigations began, followed by removal actions. Construction resumed when authorities determined that the high-level PCB contamination was localized to this specific area.

Historical information reveals that debris, drums, and heating oil tank spills affected the environment at the Taku Gardens site. After completion of housing construction, during the Remedial Investigation, contractors removed large volumes of metal debris and 1,058 drums (1,050 had no apparent residue) (RI; Appendix A). At some locations in the Taku Gardens subsurface site contractors found volatile and semi-volatile organic compounds (VOCs, SVOCs) and petroleum compounds. Under certain conditions, volatile compounds in the subsurface can migrate into indoor air. Residents might then breathe in the contaminants.

Figure 1. Location of Taku Gardens



Source: North Wind 2007

Vapor Intrusion Evaluation Process

As many studies have shown, vapor intrusion varies widely over time and area (USEPA 2008a). Because such variability is not always predictable, when assessing a vapor intrusion pathway ATSDR and other agencies use several different information sources termed “multiple lines of evidence” (ATSDR 2008; AFIOH 2008; ITRC 2007; ADEC 2009c). Current vapor sampling and modeling methodologies each have limitations that preclude any one of them from satisfactorily assessing vapor intrusion variability (USEPA 2005). ATSDR’s Vapor Intrusion Screening Checklist (Appendix B) is another tool that helps to identify lines of evidence for a completed pathway.

ATSDR’s document for Evaluating Vapor Intrusion Pathways at Hazardous Waste Sites (Appendix C) uses a 14-step approach (**Table 1**) that includes gathering information on multiple lines of evidence. The major parts of a public health evaluation are Pathway Analysis, Exposure Evaluation, Health Implications, and Conclusions and Recommendations.

Table 1. Approach to Evaluate the Vapor Intrusion Pathway

Part I. Pathway Analysis	
1	Are there subsurface volatile chemicals reported or suspected?
2	Are there occupied buildings within 100 feet laterally or vertically of volatile subsurface contaminants?
3	Are reported concentrations of volatile subsurface contaminants near the buildings documented to be, or plausibly above applicable screening levels?
*** If the answer to any of the 3 questions above is no, then human exposure to harmful levels of contaminants from vapor intrusion is unlikely. If the answer to all three questions is yes, continue the evaluation process with the following steps.	
4	Begin developing and improving a Conceptual Site Model.
5	Search for evidence of any urgent public health hazards.
6	Evaluate distance between contaminants and occupied buildings.
7	Evaluate environmental information, environmental concentrations of contaminants in nearby soil, groundwater, and soil gas, and potential background sources.
8	Evaluate building construction characteristics.
9	Check for any preferential pathways from contaminated soil or groundwater toward occupied buildings.
Part II. Exposure Evaluation (Dose Estimation)	
10	Are there valid indoor air measurements to use for dose calculation?
11	If there are no valid indoor air measurements, are there subslab soil gas measurements or other site specific information that can be used to estimate indoor air concentrations using reasonable but conservative attenuation factors from observations?
12	Request further site specific information and measurements if the answer to items 10 & 11 above is negative.

Part III. Public Health Implications	
13	If a valid exposure dose can be estimated from information discussed in Part II. Exposure Evaluation, proceed to evaluate the public health implications.
Part IV. Public Health Conclusions and Recommendations, and Public Health Action Plan	
14	Follow the Public Health Guidance Manual

Pathway Analysis

1. Are there subsurface volatile chemicals reported or suspected?

Yes. Since 1938, Fort Wainwright operations in the FCS area included disposal and release of construction materials, used oils, asphalt, solvents, petroleum based fuels, pesticides, PCBs, lubricants, battery fluids, painting waste, coal fly ash, batteries, and munitions debris (CH2MHILL 2010b). At the Taku Gardens site contractors found in subsurface environmental media PCBs, petroleum related chemicals, polycyclic aromatic hydrocarbons, chlorinated VOCs, SVOCs, pesticides, and herbicides. At 12 and 16 feet contractors found two subsurface soil hot spots of diesel-range organics (DRO). Soil gas analysis detected over 50 chemicals (CH2MHILL 2010b).

Figure 2. Investigation activities 2007

Contractors excavated over 7.5 acres of land down to groundwater to remove residual solvents, heating oil, PCBs, PAHs, and petroleum (**Figure2**) (CH2MHILL 2010b).

Figure 3. Geophysical survey activities

The remedial investigation used exploratory excavations based on magnetometry, historical operations, topographic features, and observations. The investigation resulted in the removal of buried debris, drums, and containers. Contractors analyzed geophysical survey measurements **(Figure 3)** above 75 mV for potential items of concern; they considered anomalies below

75 mV to represent smaller items rather than large masses of metal debris such as drums (CH2MHILL 2010b). Note that surveys like these are dependent on the size and depth of the items and on the ground surface and soil conditions (Smith 2007; Delaney 1997; Peace 1996).

Excavation yielded such items as

- Drums,
- Oil-burning furnaces (one of approximate dimensions 20 by 30 feet),
- Transformers,
- Lead-acid batteries,
- Heating oil tanks,
- Fuel lines,
- Paint cans,
- Gas cylinders,
- Fire extinguishers,
- Two practice rocket motors with propellant residue, and
- Hydraulic cylinders with hydraulic oil,
- Fuel bladders, and
- Discarded inert military munitions

Contractors found other debris in excavation sidewalls adjacent to but outside the duplex footprints. Near the duplexes, contractors also found and removed other buried materials, including construction debris, empty drums, cylinders, lead battery plates, creosote-soaked timbers, ash, and jet assisted take-off (JATO) bottles. After such extensive removals, fixed lab results confirmed that most of the floors and sidewalls of the investigated duplexes did not contain contaminants of concern that exceeded a regulatory clean-up level (CH2MHILL 2010b).

Figure 4: Crushed drum containing some tar

Figure 4 is an example of a removed drum. Of the 1,058 drums found, most were crushed and empty. Less than 0.5 percent (i.e., fewer than six drums) contained enough liquid or tar-like substance from which to collect samples for analysis (CH2MHILL 2011). Drums from which samples were taken contained

- 1,2,4-trimethylbenzene,
- 1,3,5-trimethyl-benzene,

- DRO,
- Naphthalene,
- Gasoline-range organics (GRO),
- Residual-range organics (RRO),
- Benzene,
- Cyclohexane,
- Polycyclic aromatic hydrocarbons (PAH),
- Pesticides, and
- Metals

(CH2MHILL 2010b)

Figure 5. Exposed drums under foundation during trial excavation

One duplex had drums under its foundation (**Figure 5**). Excavation removed the drums. During excavation, supports were required to stabilize the duplex's foundation.

2. Are occupied buildings within 100 feet laterally or vertically of volatile subsurface contaminants?

If the answer is no, are preferential pathways present (e.g., mining shafts, utility conduits, fractures of karst features) that could result in vapor transport over unusually long distances to occupied buildings?

Yes. In 2005, Taku Gardens construction began. The entire development comprises 110 residential units (55 duplexes). At the Taku Gardens site, surface soil, subsurface soil, soil gas, and groundwater analyses have detected site-related contaminants in close proximity to the duplexes. The heterogeneous nature of the contaminant sources and the site's complex environmental history indicate that low-level residual contamination might be present at a variety of depths within the soil column. This contamination might occur at discontinuous areas of groundwater contamination and might possibly be associated with site materials understructures. Groundwater at the site averages around 15 feet; it ranges from approximately 11 to 20 feet below ground surface (CH2MHILL 2010b). Subslab gas and indoor air samples have indicated that vapors are in direct contact with the duplexes and that vapor migration is scattered and variable (CH2MHILL 2010b).

3. Are reported concentrations of volatile subsurface contaminants near the buildings documented to be or plausibly above ATSDR screening levels or alternate screening levels, when ATSDR screening levels are not available?

Yes.

ATSDR's screening process. The first step in evaluating environmental data is typically to compare chemical concentrations to screening levels. Concentrations at or below the relevant comparison value are considered safe. Still, that doesn't mean any environmental concentration that exceeds a comparison value will produce adverse health effects. Comparison values are not thresholds for harmful health effects; rather, they're screening tools. Typically, for screening purposes researchers select the lowest available comparison value consistent with the conditions at or near a site (ATSDR 2005). In studies on experimental animals or in human epidemiologic studies, ATSDR comparison values represent contaminant concentrations many times lower than levels at which no effects have been observed.[1]

ATSDR's screening levels are called comparison values. They include the cancer risk evaluation guides (CREGs), environmental media evaluation guides (EMEGs), and reference concentrations (RfCs). CREGs are estimated contaminant concentrations that would be expected to cause no more than one excess cancer in a million (10^{-6}) for persons exposed during their lifetime (70 years). ATSDR's CREGs are calculated from USEPA's cancer slope factors for oral exposures or unit risk values for inhalation exposures. These values are based on USEPA evaluations and assumptions about hypothetical cancer risk at low levels of exposure.

EMEGs are estimated contaminant concentrations that ATSDR does not expect will result in adverse, noncarcinogenic health effects. EMEGS are based on ATSDR Minimal Risk Levels (MRLs) and on conservative assumptions about exposure, such as intake rate, exposure frequency and duration, and body weight.

An RfC is an estimate of a continuous inhalation exposure concentration to people (including sensitive subgroups) that's likely to be without risk of health effects during a lifetime. ATSDR and other government agencies developed these nonenforceable guidelines to screen and to evaluate environmental contamination further.

Groundwater Concentrations

VOCs and SVOCs in groundwater can volatilize. Through the vapor intrusion process VOCs and SVOCs in groundwater can become a soil gas source and contaminate indoor air. Thus for vapor intrusion

Comparison values are not thresholds for harmful health effects; rather, they're screening tools.

[1] No Observed Adverse Effect Levels or NOAELs. ATSDR's toxicological profiles contain the NOAEL and Lowest Observed Adverse Effect Level (LOAEL) values (see http://www.atsdr.cdc.gov/toxprofiles/index.asp).

assessments a groundwater contamination review is standard. ATSDR's process is first to screen the chemicals against comparison values and then to perform a more detailed assessment, asking whether any chemicals that exceed screening values might affect health. Groundwater screening values for vapor intrusion are based on the

- Amount of vapor that might volatilize from the surface of the water table
- Amount of attenuation that might occur as vapors migrate from the water table surface to indoor air, and
- Health-based indoor air concentrations

Researchers investigated groundwater at the Taku Gardens site beginning in 2005, following the discovery of petroleum contamination in site soils (CH2MHILL 2010b: see p. 2–12). Researchers detected petroleum hydrocarbons, chlorinated VOCs, and several other contaminants in localized groundwater areas (CH2MHILL 2010b: see p. XV). Four of the 18 chemicals of interest exceeded groundwater screening levels for vapor intrusion, as shown in Appendix D: benzene; 1,1,2,2-tetrachloroethane; trichloroethylene; and vinyl chloride. Each of these chemicals is decreasing in concentration except for vinyl chloride, a natural attenuation product of the trichloroethylene biodegradation process (JEG 2012c). Researchers localized the Taku Gardens groundwater areas of concern to six wells for benzene and two wells for the chlorinated organics. The entire Taku Gardens groundwater area comprises a network of 90 monitoring wells (JEG 2012c).

Benzene and 1,1,2,2-tetrachloroethane have decreased below the ATSDR vapor intrusion screening levels (VISL). Trichloroethylene data show that concentrations satisfy the "safe to drink" threshold (i.e., USEPA's Maximum Contaminant Levels (MCLs)) but exceed the ATSDR VISL (USEPA 2012b). Trichloroethylene's high volatility and toxicity are what results in a VISL below the MCL. Of note is that the buildings located nearest the wells that historically showed the highest trichloroethylene concentrations did not have the highest subslab gas concentrations (we discuss this further in step 11) (CH2MHill 2010b).

Vinyl chloride, a byproduct of the natural attenuation process of trichloroethylene, is increasing in groundwater in the same wells that trichloroethylene is decreasing (USEPA 2012b). The low concentrations of parent compound and the lack of vinyl chloride in subslab gas above screening levels indicate that vinyl chloride may not result in a health hazard in the future. Nevertheless, ATSDR supports continued monitoring plans to ensure that future levels don't significantly increase.

> If the answer to any of the 3 questions above is no, then human exposure to harmful levels of contaminants from vapor intrusion is unlikely. If the answer to all three questions is yes, continue the evaluation process with the following steps.

4. Begin developing and improving Conceptual Site Model (described below).

The three main components of a conceptual site model are characterization of contaminant 1) sources, 2) migration pathways, and 3) point of exposure to human receptors.

1) **Contaminant sources**

The contaminant sources at the Taku Gardens site were generated over decades of use at the Former Communications Facility (**Figure 6**). Features removed at the site include (CH2MHILL 2010b, 2011):

Communications and radar operations	- Barracks and company headquarters
Garden plot(s)	- Fire training area(s)
Equipment salvage and reclamation	- Possible ammunition storage

Debris and salvage material disposed in former Hoppe's slough (a previous loop of the Chena river), trenches and possibly other local depressions

Figure 6. Conceptual site model showing investigation activity

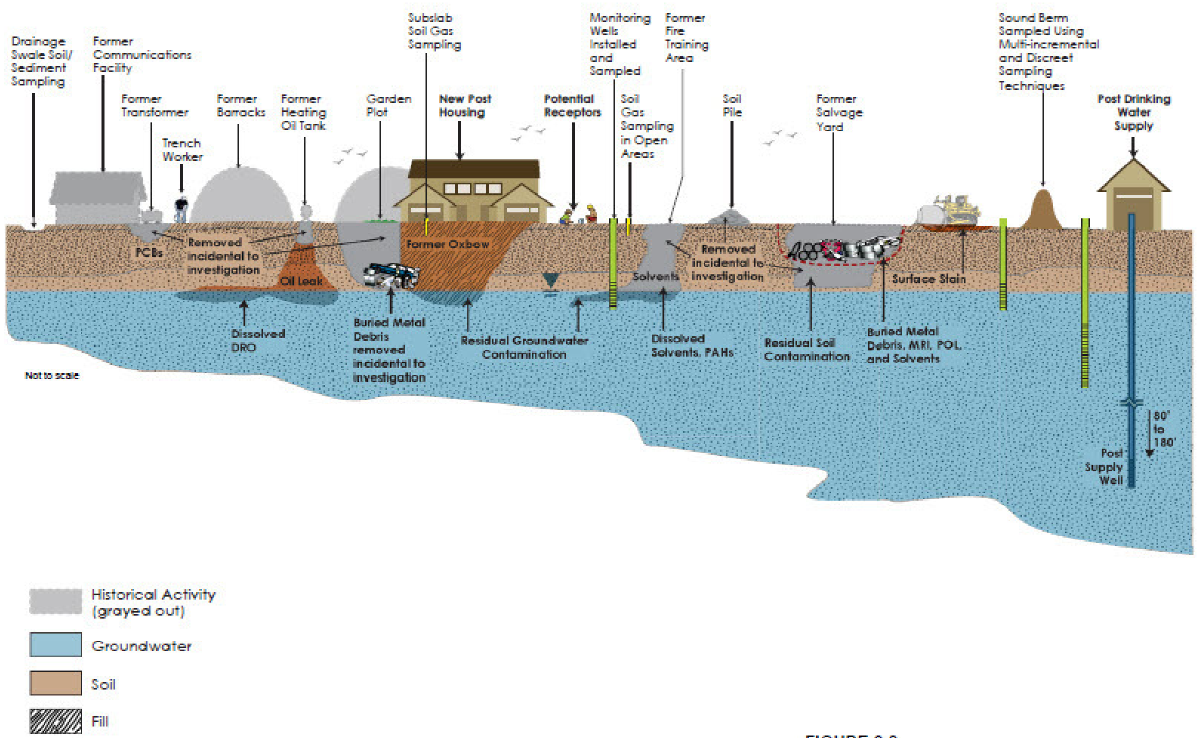


FIGURE 3-2
Preliminary Conceptual Site Model Showing Investigative Activity
Final Remedial Investigation Report
Former Communications Site, Fort Wainwright, Alaska

A variety of contaminants remain in soil, including petroleum-related hydrocarbons, polycyclic aromatic hydrocarbons, chlorinated VOCs, and SVOCs. But contractors found these contaminants in site soil only in small and isolated areas. Samples with residual soil contamination occurred primarily along excavated sidewalls; this finding indicated that while contamination sources might have been present in the past, only residual low levels remain (CH2MHILL 2011).

Figure 7. Contractors shovel petroleum, oil, and lubricant (POL) contaminated soil into a loader for transport to a soil cell.

Fuel range organics were historically present in soil hot spots and along a diesel fuel pipeline removed in 2008 (**Figure 7**; CH2MHILL 2011). Contractors remediated soil in the hot spot and pipeline areas. Residual levels of diesel range organics were found up to 15,000 mg/kg, gasoline range organics up to 630 mg/kg, and residual range organics up to 3,500 mg/kg. Still, weathering appears mostly to have eliminated the more volatile and toxic residual components—such as benzene—from the soil matrix (CH2MHILL 2011).

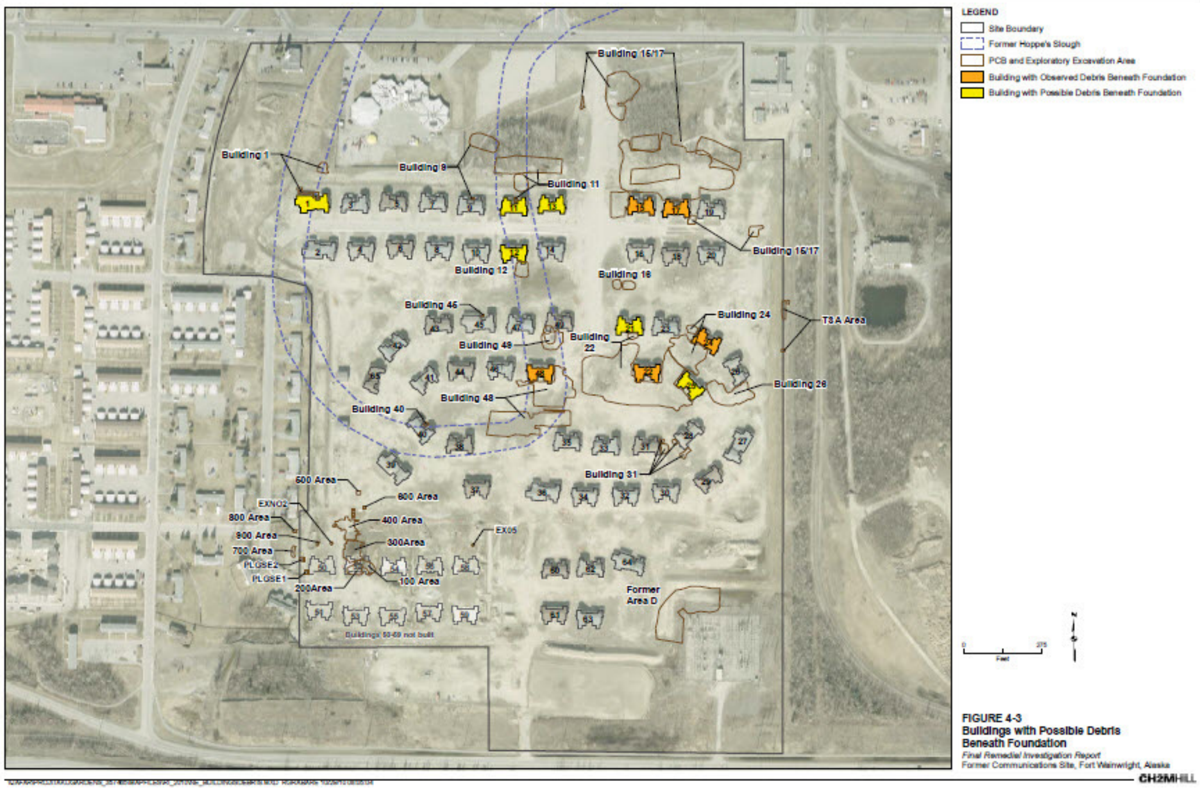
Contractors found several other residual contaminants at levels below 1 mg/kg in soil:

- 1,2-dibromo-3-chloropropane was detected in three of 216 soil samples from the 2008 excavation at levels ranging from 0.18 to 0.26 mg/kg (RI).
- 1,2,3-trichloropropane was detected in two of 624 samples at a maximum concentration of 0.5 mg/kg, but wasn't found above VISLs in any other media and will not be discussed further (CH2MHILL 2011).
- Two common SVOCs known as PAHs had maximum detected levels of 0.17 mg/kg for benzo(a)pyrene and 0.099 mg/kg for dibenz(a,h)anthracene.
- Other VOC maximum detected levels include 0.061 mg/kg for n-Nitroso-dimethylamine and 0.28 mg/kg for n-Nitrosodi-n-propylamine (CH2MHILL 2011).

Note that even if compounds aren't that volatile, if they're relatively insoluble and if water competes for the soil pore space, such compounds might be forced into a vaporous state.

Contractors found buried debris near six buildings, which indicated that debris might still be under the foundations. No drums were observed in the excavation sidewalls near these buildings, except for one building, which was remediated (to be discussed later in the document). Five other buildings remain with observed buried debris beneath their foundations. But contractors had to suspend removal due to structural stability concerns. The buried debris might or might not include chemical-containing items (**Figure 8**).

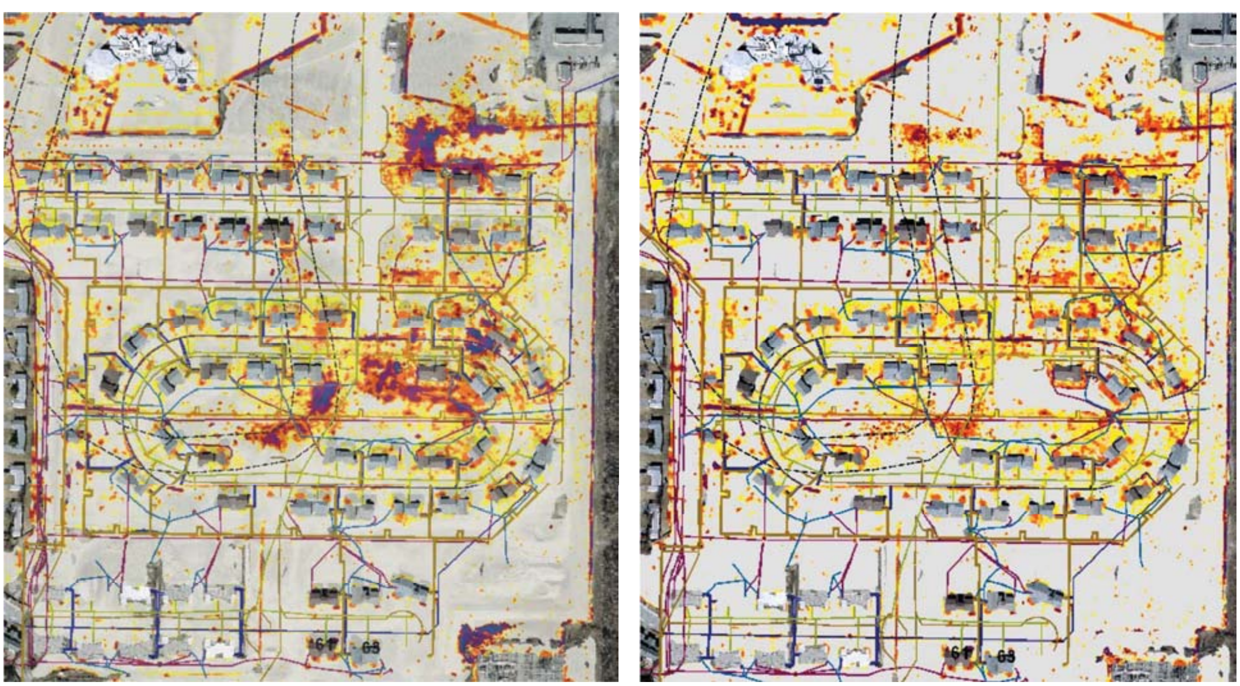
Figure 8. Buildings with possible debris beneath their foundations



By comparing the geophysical anomaly maps before and after debris excavations, we see that the most obvious signs of subsurface debris, drums, and other materials were removed (**Figure 9**).

Figure 9. Comparison of 2007 and 2009 geophysical anomaly maps

(colored locations indicate subsurface detections with purple indicating the strongest signal).



As seen in **Figure 10**, however, the geophysical readings from the instrument cannot provide information from beneath the building structures.

Figure 10 Close-up of geophysical anomaly maps

(colored locations indicate subsurface detections with purple indicating the strongest signal).

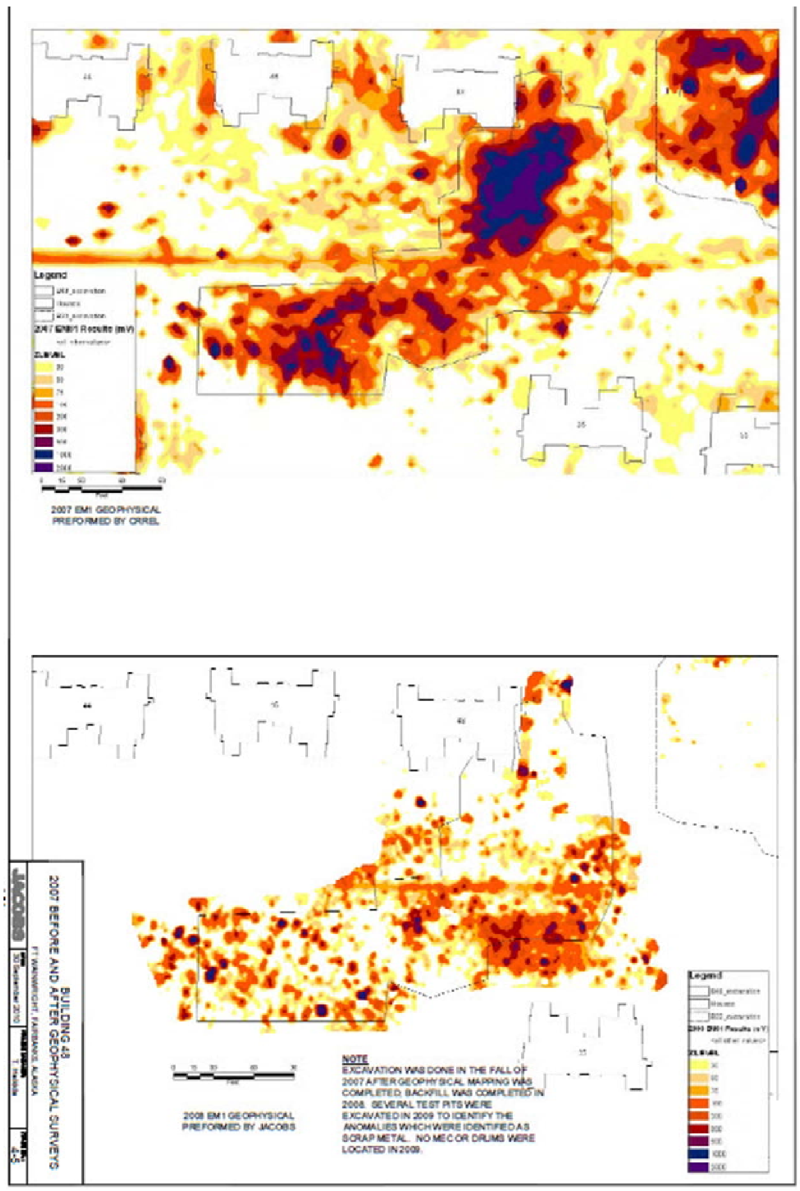
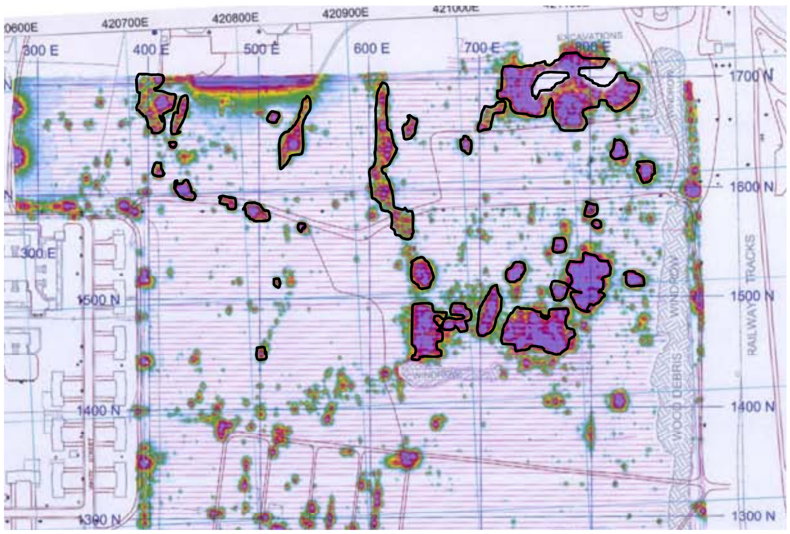


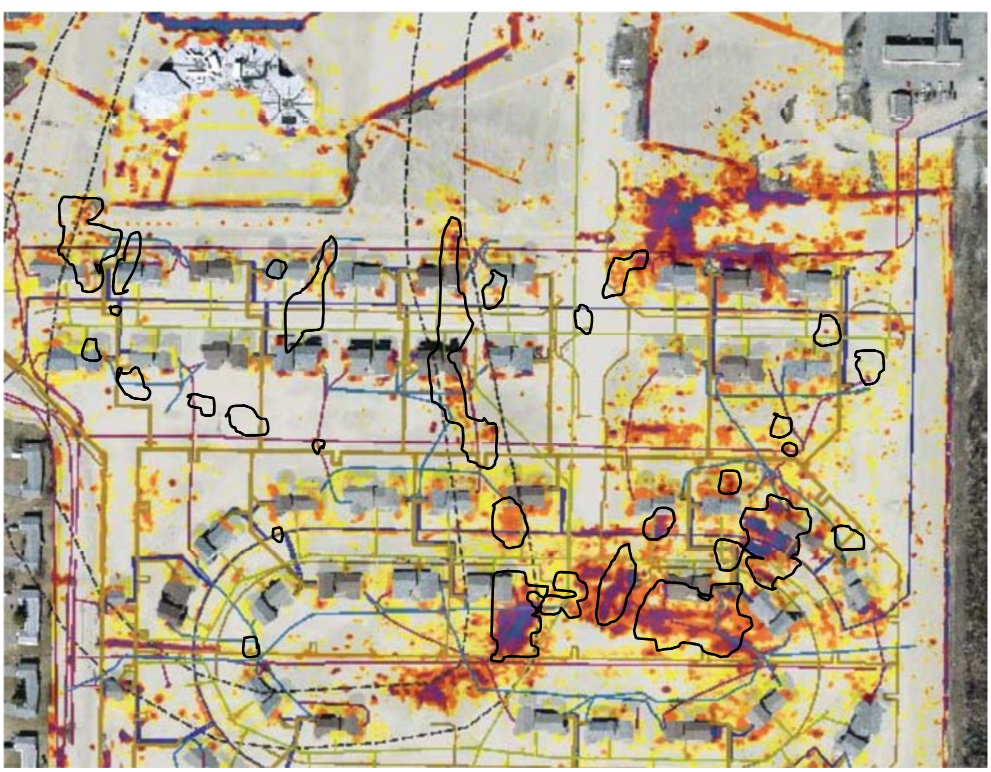
Figure 11 shows that some houses appear to have been located over areas of elevated magnetic analytic signal from the 2004 geophysical survey (CH2MHill 2010b).

Figure 11. Outline of 2004 geophysical survey map (a) and overlay onto housing map (b)
(colored locations indicate subsurface detections with purple indicating the strongest signal)

(a)



(b)



During excavations, contractors found

- Petroleum fuel and related chemicals, solvents, PAHs, and SVOCs in shallow aquifer groundwater monitoring wells and soil at the site
- That petroleum fuel (DRO and RRO) most heavily contaminated the northwestern area groundwater and soil where a previous fuel line was removed in 2008 and heating oil and tar-containing drums were remediated. Contractors also observed that lower levels of petroleum-related groundwater contaminants were scattered around the site
- Chlorinated VOCs in groundwater around the Hoppe's slough area, with highest concentrations near where drums and paint cans were excavated from beneath one of the buildings onsite. Lower concentrations of chlorinated VOCs in groundwater were scattered across the site, but did not correlate well with the low level soil detects also scattered across the site.
- Pesticides, herbicides, and SVOCs scattered at low levels across the site in subsurface soil and groundwater, but contractors found no apparent relation in contamination between soil and groundwater detections.

2) **Contaminant migration pathways**

Researchers have identified factors affecting the contaminant migration pathways from subsurface to indoor air for the Taku Gardens duplexes. Groundwater varied from about 10 to 20 feet below ground surface, with an average depth of about 15 feet (CH2MHILL 2010b). Because of the effects of changing river stages in the Tanana and the Chena Rivers, adjacent to those rivers seasonal changes in groundwater flow directions of up to 180 degrees and changes in groundwater level are not uncommon (CH2MHILL 2010b: see p. 2–3). The northern edge of the site is slightly fewer than 2,000 feet from the Chena River but over 1 mile from the Tanana River. Groundwater levels up to about 1 half-mile (2,640 feet) of the Chena River respond rapidly to changes in river stage (Glass et al. 1996). River and groundwater levels rise in spring and summer due to snow and ice melt runoff. The levels decrease in fall and winter when melting ceases and rain decreases.

VOCs and SVOCs are among the chemicals of concern at Taku Gardens. Near the water table, SVOCs can remain as vapors in equilibrium with the groundwater. If the groundwater rises or water fills the soil pore spaces rapidly, the vapors can be flushed up into buildings. Understanding the presence and distribution of chemicals in the groundwater and soil, and how those chemicals change in different conditions, will provide clues for assessing subsurface vapor migration pathways.

The native geology and soils at the site consist of soil and unconsolidated sediment, with commonly layered, varying proportions of silt, sand, and gravel (CH2MHILL 2010b). More porous sand and gravel are present about 8 to 10 feet below ground surface (CH2MHILL 2010b). Subsurface soils at the site consist of heterogeneous fill materials resulting from the extensive, construction-related landscaping, filling, excavating, and geo-engineering at Taku Gardens. Soil sections from beneath the slab reveal large cobble in some areas to fines in others. The soil heterogeneity and the groundwater contamination are consistent with the historical presence of scattered soil contamination that has leached into groundwater, then has been excavated and replaced with clean fill. Stratified and varied soil conditions in the subsurface can result in preferential routing of vapors through zones of high-porosity, low-moisture material.

3) **Point of exposure to human receptors.** Indoor air concentration is the point of exposure to human receptors. Vapors that migrate into buildings from the subsurface can become concentrated in indoor air. Factors affecting the exposure point concentration (EPC) can include heating, ventilation, and air conditioning (HVAC) system performance and exhaust systems, such as the kitchen hood and dryer exhaust vents included in the Taku Gardens housing plans (CH2MHILL 2010b). Exposures may depend on the time spent in different rooms and levels of the home. Upper floors tend to have more dilution and attenuation of vapors as they migrate farther up into the home. Preferential pathways, however, can remain that make upper floors more susceptible than lower levels (Ames 2012). Because the ground level indoor air concentrations have been low, no studies on upper levels have been performed at Taku Gardens. Considerable variability generally occurs in indoor air concentrations on an hourly, daily, and monthly basis (Hers 2001). Chronic effects depend on long-term average exposures. Background concentrations are also widely documented in generic studies and often confound vapor intrusion analyses.

The likelihood is low that any remaining containers would hold enough vaporous material and would release it in a way that could cause an urgent hazard.

5. **Search for evidence of any urgent public health hazards such as fire and explosion hazards or potential exposures to free product.**

Site overview and residual contamination. All identified hot spots and areas with accessible drums and debris have been remediated. Contractors excavated over 1000 drums (mostly crushed and empty) and over 7.5 acres of land, over half of which was excavated down to groundwater (Malen J. RPM, US Army Garrison Fort Wainwright, AK. Personal Communication Mar 19, 2012). Photoionization detector sampling guided the investigation and fixed lab samples confirmed that soil removal adequately achieved delineation during contamination removal (CH2MHILL 2010b). Measured levels of residual contamination in groundwater, soil, soil gas, and air haven't exceeded ATSDR acute comparison values for screening against immediate or short-term exposure hazards.

Potential for VOC release from subsurface containers. Though unlikely, containers of hazardous substances possibly containing free product could remain underneath some structures at the site. The remedial investigation report noted five buildings with observed buried material and six buildings with possible debris remaining beneath (CH2MHILL 2010b).

A maximum of 4 feet of engineering aggregate separates slabs and preconstruction ground conditions (JEG 2011). Debris that could not be excavated was observed in excavation side walls adjacent to but outside building footprints. Containers could have been dumped in the pits and gullies where debris had been deposited near these buildings in the past. The geophysical surveys for detecting buried material cannot extend beneath buildings to find whatever is buried under there. Examples of containers found onsite (though most were empty and inert) that could release toxic, asphyxiating, flammable or explosive vapors include drums, oil-burning furnaces, heating oil tanks, fuel lines, paint cans, gas cylinders, fire extinguishers, practice rockets, hydraulic cylinders with hydraulic oil, fuel bladders and discarded military munitions (CH2MHILL 2010b). Buried materials, including construction debris, empty drums, cylinders, lead battery plates, creosote-soaked timbers, ash, and JATO bottles were also found in the vicinity of buildings but not under buildings; they tended to be concentrated in former low-lying areas and pits that were filled and covered before the FCS was developed (CH2MHILL 2010b). The likelihood is low that remaining undetected containers still under buildings 1) hold enough vaporous material, and 2) can release that material in a way that could cause an urgent hazard. Contractors only found drums under one building, and those drums were removed. The rest of the material observed under the buildings was scrap metal, discarded equipment, and construction debris (CH2MHILL 2010b).

If containers of volatile chemicals were present beneath buildings, their integrity could become compromised by processes such as corrosion, aging, physical disturbance, freeze thaw, or seismic events. The liquid or vapor would then be released by a slow leak or rapid expulsion of the contents under pressure. The ability of vapors from a subsurface release to migrate to and accumulate in air at acutely hazardous levels would depend on factors such as soil porosity, preferential pathways, pressure differentials, and the nature of the contaminant.

Moreover, Fairbanks is in an area with considerable potential for earthquake activity (Zogorski et al. 2006). Earthquakes could rupture containers, create subsurface preferential pathways, or increase cracking in the slabs. It appears that some of the contamination remains in isolated zones at this site. And it’s possible that an earthquake could create new pathways connecting the isolated zones to indoor air spaces. If drums or containers do remain beneath other onsite buildings and do contain liquids, the liquids would most likely consist of petroleum compounds with higher degradation rates and lower toxicity than halogenated solvents.

Still, the presence of such containers beneath buildings cannot be ruled out. Installation of subslab depressurization (SSD) systems similar to commonly used radon venting systems could adequately depressurize the slab and prevent any hazard from occurring.

NOTE: Evaluation of physical hazards from explosives is beyond the scope of this health consultation. We focus here on inhalation hazards from subsurface vapors that could migrate into breathing zones. The remedial investigation report states “It is extremely unlikely that any explosive ordnance is present at the site and, furthermore, the probability of encounter by residents with any buried munitions that might be present is unlikely.”

6. Evaluate distance between contaminants and occupied buildings.

A variety of residual contaminants remain in the immediate vicinity of the Taku Gardens housing structures. Remedial actions found potentially contaminated debris near duplexes in excavation side walls where removal was terminated due to structural stability concerns. Additionally, though all identified hot spots and debris that could be remediated have been remediated, residual low-level contamination remains in soil and groundwater across the site. Groundwater is fewer than 20 feet deep. Soil gas sampling has confirmed that beneath the Taku Gardens duplexes, contaminated vapors above screening levels are migrating into subslab gas .

7. Evaluate environmental information, environmental concentrations of contaminants in nearby soil, groundwater, and soil gas, and potential background sources.

Contractors have collected over 3,500 soil samples from 77 soil borings, more than 80 groundwater monitoring wells, 87 surface soil samples, and excavation confirmation samples (CH2MHILL 2010b). Ninety groundwater wells screened in the upper part of the aquifer were sampled one to five times each. The Army continues sampling those wells in or adjacent to areas of known or potential ground water contamination (Malen J. RPM, US Army Garrison Fort Wainwright, AK. Personal Communication Mar 19, 2012). Open area vadose zone gas, subslab soil gas, indoor air and outdoor air were sampled for contaminant vapors in the Taku Gardens housing area (Table 3).

Passive soil gas sampling in fall 2006 found petroleum contamination in most areas sampled, and chlorinated VOCs near buildings (Appendix N of CH2MHILL 2010b). Soil gas sampling events took place in late summer, fall, and winter at least once per year from 2006 to 2010. Subslab gas sampling was performed under live-in conditions (thermostat set to 68^{o} F) in each of the 110 residential units in December 2008 and in one unit of each duplex in August 2009 (CH2MHILL 2010b). A single subslab gas collection point was installed beneath the garage of each unit. Subslab gas samples were collected over a 30-minute period with a representative number of samples undergoing leak-testing with helium tracer gas. Outdoor air was also sampled as a potential background source of indoor air contamination (CH2MHILL 2010b).

Table 2: Chronology of Soil Gas and Outdoor Air Sampling Events (CH2MHILL 2010b)

	Total Number of Soil Gas Samples	Outdoor Air
Fall 2006	35 passive vadose zone (8' deep, near 2 units)	0
Fall 2007	110 subslab, 49 vadose zone (5' deep, insufficient detection levels)	4
October 2008	10 subslab (HVAC off)	1
December 2008	110 subslab (68^{o}F)	6
August 2009	61 subslab (all duplexes sampled) (68^{o}F)	2
July 2010	12 subslab (68^{o}F)	10

The complex history of activities causing contamination at the Taku Gardens development, in combination with targeted excavations, has resulted in a heterogeneously contaminated site. Due to the spatial and temporal variability all but one of the units chosen for indoor air sampling in July 2010 were different from those chosen in December 2008. Discussion of the nature and extent of contamination is organized by the different types of sources below.

Chlorinated VOCs

Poor correlation occurred between chlorinated VOC concentrations in soil, groundwater, and soil gas. Additionally, the contamination was very scattered and discontinuous within each media (CH2MHILL 2010b). This spatial variability and lack of correlation between media might reflect residual contamination from sources already removed during excavations at the site, the presence of small discrete source areas, or variable vapor or source migration patterns.

Temporal variability could be explained by variation in migration patterns as conditions fluctuate. Those conditions include temperature, barometric pressure, precipitation, ground cover by snow and ice, and groundwater levels. Subslab soil gas concentrations of chlorinated VOCs were also relatively low (i.e., not greater than a few hundred µg/m^3) (USEPA 2011a). Lower soil gas contaminant levels are more prone to bias by background levels, sample collection, and lab analysis influences.

Comparison of maximum site contaminants in soil gas and outdoor air concentrations with ATSDR's comparison values for air are shown in **Table 3.** Values exceeding screening levels are highlighted. Soil gas screening levels are derived by assuming attenuation by a factor of 10 will

Table 3: Maximum Detected Soil Gas and Outdoor Air Concentrations (µg/m^3) for Chlorinated Contaminants Exceeding Screening Levels*

Chemical	Soil Gas		Outdoor Air	
	Maximum Detected Level	Screening Level	Maximum Detected Level	Comparison Values (basis) †
Carbon tetrachloride	**38**	2	**0.61**	0.2 (CREG) 100 (RfC)
Chloroform	**280**	0.4	**0.24**	0.04 (CREG) 100 (RfC)
1,2-Dibromo-3–chloropropane	**5.8**	2	**1.1**	0.2 (RfC)
1,2-Dichloroethane	**1.1**	0.4	**0.42**	0.04 (CREG) 2000 (cEMEG)
Hexachlorobutadiene	**2.3**	0.5	Not listed	0.05 (CREG)
Methylene chloride	16	20	**3.4**	2 (CREG) 600 (RfC)
1,1,2,2-Tetrachloroethane	**0.25**	0.2	Not listed	0.02 (CREG)
Tetrachloroethylene	**110**	38	1.9	3.8 (CREG) 40 (RfC)
Trichloroethylene	**110**	2.4	0.19	0.24 (CREG) 2 (cEMEG)

* Soil gas screening levels are ATSDR air comparison values, or USEPA or ADEC air screening levels in the absence of ATSDR comparison values, divided by USEPA's attenuation factor of 0.1. Chemical concentrations are from the remedial investigation and 2010 Technical Memorandum (CH2MHILL 2010a, b). Maximum soil gas and outdoor air values greater than screening levels are highlighted.

† CREG = Cancer Risk Evaluation Guide, cEMEG = chronic Environmental Media Evaluation Guide, and RfC = Reference Concentration

occur with migration into indoor air (USEPA 2012a). Of over 50 analytes and over 100 locations sampled, eight chlorinated VOCs exceeded the soil gas screening levels. As seen in **Table 3**, five of the chemicals exceeded screening levels in outdoor air, but not by more than about a factor of 10, with 1,2-dichloroethane showing the highest exceedance.

Several different types of chlorinated VOCs (and one brominated VOC) were present at the site. The chlorinated ethylenes, PCE and TCE, are commonly used solvents that degrade into dichloroethylenes and vinyl chloride. The presence of dichloroethylenes and vinyl chloride indicate that natural attenuation is occurring by microorganism reductive dechlorination. PCE was found widespread in soil gas and exceeded screening levels in groundwater, but not in soil. TCE was detected most widely across the site. TCE was found below seven units and ranged from 49 to 110 µg/m^3 in subslab gas in August 2009; but the same seven units showed much lower concentrations in July 2010 (**Table 4**).

Table 4: Subslab Gas Data Showing Temporal Variability in Late Summer (CH2MHILL 2010a,b)

Sampling Data	TCE (µg/m^3)
August 2009	Range: 49-110
July 2010	Range: nondetect-2.9

The one-time, elevated subslab gas levels could be due to less temperature suppression on the volatility of subsurface VOCs in the warmer month of August (i.e., a seasonal effect) in combination with other factors increasing susceptibility to vapor intrusion. Factors such as soil moisture, barometric pressure, and groundwater level and flow patterns can cause such variation in subsurface vapor flow. Radon attenuation factors (to be discussed in Step 11) for August 2009 were similar to March 2009 and January 2010 - evidence supporting that the effect causing elevated subslab-gas chlorinated VOCs in August 2009 was likely due to phenomenon related to the subsurface, not migration of subslab gas to indoor air.

In addition to temporal variability, spatial variability at the site has been observed in sampling results: none of the 12 duplexes with chlorinated VOC levels of concern in soil gas were adjacent to each other. The well with the historically highest TCE concentration of 14 µg/L was near the center of the site. Levels appear to be slowly decreasing at this well (CH2MHILL 2011). The closest building to the well did not exhibit high subslab soil gas TCE levels, but the next building over (to the west) had the highest subslab gas TCE level measured. Whether the TCE in groundwater is the source of the TCE in subslab gas is unknown.

The volatile chemical 1,2-dibromo-3-chloropropane, a nematocide fumigant banned in 1977, was detected in three soil samples and two subslab gas samples, but not in groundwater. Concern over laboratory practices has suggested that the presence of 1,2-dibromo-3-chloropropane in laboratory analysis could be an artifact. Previous use of the FCS area for garden plots, however, (CH2MHILL 2010b) and the documented presence of parasitic plant nematodes in the region (Bernard 1986) indicate that previous use of fumigants could possibly have occurred at the site. That said, ATSDR cannot verify whether the fumigant was used at the site at any time in the past.

Other chlorinated VOCs used as solvents exceeded screening levels in the soil gas. Chloroform, carbon tetrachloride, and methylene chloride were relatively elevated in scattered samples of soil gas, but not detected above screening levels in soil or groundwater.

Petroleum and Petroleum-related Compounds

Sampling and analysis found fuel-grade hydrocarbons and some of its individual components including benzene and PAHs above groundwater and soil gas screening levels across the site. The highest concentrations were for fuel-grade hydrocarbons in groundwater and soil within the Hoppe's slough area. Fuel-grade hydrocarbons are a mixture of gasoline, diesel, or other fuel range hydrocarbons of which benzene is often considered the most toxic. Though fuel grade hydrocarbons were over 100 times screening levels, benzene was less than ten times screening levels in soil and groundwater (CH2MHILL 2010b), with the highest levels occurring in earlier sampling events. Soil gas detections were widespread and levels appeared to be decreasing over time. Hydrocarbons are typically less persistent in the environment than are chlorinated volatile organics, because hydrocarbons often undergo natural attenuation processes (Tri-Services 2008). The maximum detected level of benzene in outdoor air was higher than that in soil gas (**Table 5**). Benzene and 1,2,4-trimethylbenzene soil gas exceeded screening levels by slightly more than a factor of ten, with the remaining contaminants below ten times screening levels in soil gas (**Table 5**).

Table 5: Maximum Soil Gas and Outdoor Air Concentrations (µg/m^3) for Petroleum Related Contaminants Exceeding Screening Levels*

Chemical	Soil Gas		Outdoor Air	
	Maximum Detected Level	Screening Level	Maximum Detected Level	Comparison Value (basis)
Benzene	1.1	1	3.6	0.1 (CREG)
1,2,4-trimethylbenzene	160	73	1.7	7.3 (ADEC)

* Soil gas screening levels are ATSDR air comparison values, or USEPA or ADEC air screening levels in the absence of ATSDR comparison values, divided by USEPA's attenuation factor of 0.1. Chemical concentrations are from the remedial investigation and 2010 Technical Memo (CH2MHILL 2010a,b). Levels higher than air screening values are highlighted.

Background

In addition to evaluating historical contamination sources at the site, background sources of indoor air contamination should also be considered. **Table 6** shows indoor air background levels that are based on 15 indoor air studies conducted between 1990 and 2005 in North American residences (USEPA 2011a). Levels detected in indoor air at Taku Gardens are below these background levels for benzene, carbon tetrachloride, and chloroform, and slightly higher for 1,2-dichloroethane. Indoor air background sources in the Taku Gardens duplexes are expected to be limited in comparison with typical household residences, because the units have not been occupied and the usual household products have not been brought into the homes. Therefore, possible background sources in the Taku Gardens residences are building materials, carpets, adhesives, concrete sealers, cabinet finishes, maintenance supplies, and chemicals associated with utilities. Also, VOCs possibly associated with the workers' presence in the units, such as vehicles in the garage, personal care products, or cigarette smoke. The Army also considered offgassing from carpets, adhesives, concrete sealers, and cabinet finishes as potential sources (Malen J. RPM, US Army Garrison Fort Wainwright, AK. Personal Communication Mar 19, 2012).

Table 6. Select Data from *Background Indoor Air Concentrations of Volatile Organic Compounds in North American Residences (1990-2005): A Compilation of Statistics for Assessing Vapor Intrusion* (USEPA 2011a) (µg/m³)

Chemical	N*	RL Range*	Range of 50th%*	Range of 95th%*	% Detects
1,2-dichloroethane	1,432	0.08-2.0	<RL	<RL-0.2	13.8
Benzene	2,615	0.05-1.6	<RL-4.7	9.9-29	91.1
Carbon tetrachloride	1,248	0.15-1.3	<RL-0.68	<RL-1.1	53.5
Chloroform	2,278	0.02-2.4	<RL-2.4	4.1-7.5	68.5

* N = number of samples, RL = laboratory reporting limit

A study of homes in Fairbanks, AK (ABSN 2002) found benzene levels were highest in homes with attached garages and no centralized ventilation system. Higher benzene levels were found when older vehicles were stored in garages. Homes with tuck-under garages, such as several of the Taku Garden configurations, showed higher indoor benzene levels than those with one-wall-attached garages. Fifty-five percent of the homes in the Fairbanks study were projected to exceed 11 µg/m³, with a maximum detected level of 140 µg/m³. Levels detected in the Taku Gardens indoor air study were below typical background levels in Fairbanks (CH2MHill 2010a, b; ABSN 2002). The Taku Gardens homes are supplied with steam/glycol hydronic heating systems, which eliminates a common source of indoor air VOC contamination in cold-climate homes (i.e., furnaces).

8. Evaluate building construction characteristics, such as basements, sumps, drainage, ventilation systems, relative elevation, and other critical features.

The following building-specific factors at Taku Gardens could affect the duplexes' susceptibility to vapor intrusion:

- Slab: the test duplex slabs showed extensive cracking (JEG 2011). The garage slab in each duplex unit was poured separately from the slab under the main living space (JEG 2011). In the absence of one, monolithic slab, vapors can migrate through the expansion joint between slabs (USEPA 2008b).
- Exhaust systems: operation of kitchen fume hoods or dryers vented to the outside can transiently create lower indoor pressure, such as seen in the housing plans for the duplexes (Appendix S of CH2MHILL 2010b).
- Subslab heterogeneity:
  - Subslab aggregate tended to be more compact under the garage storage rooms than the middle of the duplexes (JEG 2011). This indicates that in the area beneath the living space, gas flow might be less restricted.
  - During testing, subsurface support beams impeded subslab vapor connectivity between the depressurization point and locations where pressure differential was

measured, (i.e., depressurization was minimal when footings interceded between the venting well and the port where pressure differential was measured). The support beams provide support for the 2nd floor duplexes and consist of thickened slab up to 10 inches with placement varying among floor plans (JEG 2011). In the absence of a depressurization system these beams/barriers might cause some areas to have higher concentrations than others.

- While support beams decreased vapor connectivity, subslab pipe chases and porous materials surrounding internal footings increased the radius of influence of the SSD system by dissipation (JEG 2011). SSD systems are similar to commonly used radon venting systems, but to prevent vapor intrusion the systems need to draw vapors effectively from beneath the entire slab.

- Garage space may be closed off from the ventilated indoor air section of the house. This would likely result in different pressure influence on the subsurface than under the ventilated portion of the homes. Subsurface wall footings between the garage and living space could also result in the subslab gas samples under the garage not finding any soil gas under the main living area of the buildings.

Construction Features

Architectural documents for the Taku Gardens site show a variety of different floor plans (A through F) with options for enlarged kitchens and laundry rooms (CH2MHILL 2010b). Plans for other structures at the site include warming huts/picnic pavilions and mechanical and communication buildings, though people probably would not spend much time in these ancillary buildings. Foundation slabs at the site are approximately 4" thick with up to 4' of engineering aggregate beneath. Slabs of at least 3 ½" are recommended (USEPA 2008b). Similar construction methods will likely result in less variability in vapor migration from subslab to indoor air from duplex-to-duplex (for a given floor plan) than between duplex units built with different construction methods.

Information from Subslab Depressurization Pilot Testing

From January to March 2011, contractors carried out the *Former Communications Site Active Subslab Depressurization Pilot Test*. Test results revealed a significant amount of information regarding fate and transport of soil gases beneath duplexes. The tests were to assess the installation and performance of active SSD systems at four "worst-case" duplexes (JEG 2010). The worst-case duplexes were chosen based on observations of subsurface metal debris beneath and near the buildings.

According to the Remedial Investigation (CH2MHILL 2010b), five buildings had residual debris observed beneath the foundation and six buildings might have had debris beneath. Observed debris consisted of scrap metal, equipment, and construction debris (Malen J. RPM, US Army Garrison Fort Wainwright, AK. Personal Communication Mar 19, 2012). If subsurface remains contained hazardous volatile material and became compromised, vapors could be emitted that could enter overlying buildings. NOTE: Only one building had observed intact containers of volatile chemicals. The subslab containers were removed in a separate pilot study (Malen J. RPM, US Army Garrison Fort Wainwright, AK. Personal Communication Mar 19, 2012).

The Subslab Depressurization System Pilot Study evaluated the difference between baseline subsurface vapor migration patterns and patterns with active subslab depressurization systems. Researchers assessed the spatial variability of subslab gases and the rate at which subslab gases dissipated. The pressure differences between subslab and indoor air were also measured. For the SSD performance testing:

- A tracer (sulfur hexafluoride) was introduced into the subsurface
- Migration and dissipation was then monitored in remote test holes with and without the SSD system activated
- Pressure field extension tests were performed

Among three different floor plans evaluated in the SSD pilot study, similarities in pressure communication trends were seen with similar placement of six remote test holes (RTHs). Foundation footings appeared to slow subslab gas flow but resulted in more preferential pathways. RTHs 20–35 feet from the suction point had essentially no pressure differential from subslab to indoor air. Sulfur hexafluoride, however, was still removed within 2 hours during active testing, which is 2–20 times faster than in baseline studies.

ITRC generally recommends a pressure differential of 4 Pascal for SSD systems to protect against subslab gas infiltration to indoor air (ITRC 2007). The SSD pilot report recommended double suction point subslab depressurization systems in duplexes with potential subslab debris—ATSDR agrees with this approach (JEG 2011). The performance of the systems should be evaluated and adjusted as necessary to achieve 4 Pascals of depressurization across the slab to prevent subslab vapors from intruding into living spaces.

9. Check for any preferential transport pathways from contaminated soil or groundwater toward occupied buildings (i.e., buried utility lines, known shallow fracture flow zones, or solution channels).

The following features could possibly increase the preferential gas flow through the subsurface and are discussed below:

- Utility lines and corridors
- Surface cover adjacent to buildings by snow and ice
- Heterogeneous subsurface
- Permafrost

Utility Lines

Premanufactured, direct-bury utility lines were placed in compacted bedding sand and backfilled with unclassified spoil material from the compound. The lines come to the mechanical rooms on one side of a duplex (Malen J. RPM, US Army Garrison Fort Wainwright, AK. Personal Communication Mar 19, 2012). The porosity of the utility line bedding is uncertain. If these channels are more porous than the native soils, they could serve as a preferential pathway external to the building. In the Taku Gardens SSD pilot study, pressure differential patterns indicated that subslab utility line corridors served as preferential pathways. Evaluating the potential for preferential pathways is an important aspect of characterizing the fate and transport of vapors at sites where subslab gas levels exceed screening levels.

In addition to the typical plumbing, communication, cable TV, and electric utilities, a system of glycol heating lines run from onsite mechanical buildings to duplexes and within the subslab aggregate. Entry holes with insulated covers allow access to isolation valves for maintenance. During the SSD pilot study, glycol lines warmed the subslab space (JEG 2011), which could result in a mini-stack-effect, (i.e., the tendency for heated air in the subslab to rise into the building).

As Henry's law shows, volatility is dependent on temperature. Thus heated conduits that traverse the site and connect directly to buildings provide enhanced pathways for vapors to migrate across the site and into duplexes. For example, the building closest to the highest TCE groundwater well did not exhibit elevated subslab gas, but the adjacent duplex had the highest subslab gas level. Soil gas data have shown multiple instances where subslab gas was elevated in one unit of a duplex, but subslab gas beneath the adjacent unit was low (CH2MHILL 2010b). No soil gas samples from the utility corridors were available for review.

Surface Cover

During SSD testing, depressurization failed in a location where snow melt exposed the external French drain adjacent to the building. French drains can vent subslab gas to the outdoor air. Pennell (2009) modeled such behavior where subsurface permeability and the presence or absence of impervious surface cover surrounding a building affected atmospheric dilution below the slab. Subsurface venting to the outside can decrease subslab gas concentrations by dilution. But subsurface venting can also prevent adequate depressurization of the slab. Venting can short-circuit the subslab depressurization system's radius of influence to outdoor air and can decrease the depressurization level below the 4 Pa deemed effective for preventing entry into indoor air (ITRC).

Subsurface Heterogeneity

The heterogeneous nature of the onsite contamination and hydrogeology indicate the potential for significant variability in preferential pathways for vapor intrusion across the site. During digging of the SSD pilot test suction pits, contractors found heterogeneous subsurface materials to vary from large rounded stone with little to no fines to sections with mostly fines and few stones (JEG 2011). The presence of such zones with higher and lower permeability can result in irregular vapor flow patterns. Soil borings and test pits found "moist" soil near the groundwater table in some places and up to the surface in other places (CH2MHILL 2010b). Moisture within various soil layers can substantially limit vapor transport.

Permafrost

The Taku Gardens duplexes were generally constructed on porous (gravel/sand) foundations to help prevent frost/heave from occurring underneath the structures, which helps protect slab integrity. Excavations in 2011 to effect utility repairs did not reveal any signs of settlement (Malen J. RPM, US Army Garrison Fort Wainwright, AK. Personal Communication Mar 19, 2012). If present, permafrost might complicate subsurface vapor flow (ITRC 2007). Permafrost in the Fairbanks region varies between 0.5 and 50 meters (ATSDR 2003). Developed land tends to be less susceptible to permafrost than undeveloped land and can result in thaw-bulb regions that could become an areal pathway for vapor flow. Soil borings onsite have only detected permafrost in the SE area (CH2MHILL 2010b), so the effect of permafrost on subsurface vapor migration in the vicinity of the Taku Gardens housing duplexes is expected to be minimal.

Exposure Evaluation (Dose Estimation)

10. Are there valid indoor air measurements to use for dose calculation?

Yes. The health assessment process focuses on indoor air levels as the point of future duplex occupant exposures to contaminants. The most direct approach to evaluating exposure is to measure indoor air directly. Valid indoor measurements are available for a select number of units at Taku Gardens.

Selection of Units for Indoor Air Testing

In attempts to identify directly indoor air problems, contractors chose for indoor air sampling structures with the highest subslab gas levels. Two rounds of indoor air sampling were performed under live-in conditions. Ten of the 110 units were chosen in December 2008 and twelve units were chosen in July 2010. Concurrent 24-hour indoor and outdoor air samples were collected in summa canisters; subslab vapor samples were collected over 30 minutes.

Indoor Air Results and Discussion

The results of the indoor air testing are shown in **Table 7**. Samples likely showed vapor intrusion if those samples had contaminant concentrations above outdoor and background levels and below subslab gas levels. 1,2-dibromo-3-chloropropane (DBCP) was the only chemical that met these criteria and was above the lowest comparison value. Only one unit found DBCP in indoor air. Resampling of this unit in March 2009 and sample analysis by two separate labs found no DBCP. Another DBCP detection occurred in subslab gas at a different unit in July 2010, but indoor contaminant levels were below outdoor levels.

Four of the chemicals were more concentrated in indoor air than in subslab gas. This could be from indoor (background) sources or from subslab samples not representing the subslab source adequately. The location of the subslab sampling, as well as the nature of the foundation, could play a role in sample concentration. Still, the isolated and sporadic nature of low-level 1,2-dibromo-3-chloropropane detections in indoor air and the relatively low levels of all other indoor air constituents indicate that vapor intrusion is not expected to be a health concern at Taku Gardens. To reduce uncertainty regarding this contaminant, the limited dataset and evidence of spatial and temporal variability in vapor migration at the site indicate that continued sampling should include 1,2-dibromo-3-chloropropane.

Table 7. Maximum Indoor Air and Corresponding Soil Gas Concentrations for Contaminants Exceeding Screening Levels in μg/m^3*

Chemical	December 2008		July 2010		Max Outdoor Air/Background¥	Indoor Air (basis)/Subslab Gas Comparison Values
	Max Indoor Air	Max Subslab Gas‡	Max Indoor Air	Max Subslab Gas‡		
Benzene	3.3	0.13U	0.5	0.007 U	3.6 / 29	0.1 (CREG) / 1
Carbon tetrachloride	0.55	0.17 J	0.54	0.32	0.61 / 1.1	0.2 (CREG) / 2
Chloroform	0.63	1.2	0.072 J	3.8	0.24 / 7.5	0.04 (CREG) / 0.4
1,2-Dibromo-3-chloropropane	Not listed	Not listed	1.4 UJ	1.6 UJ	1.1	0.2 (RfC) / 2
1,2-Dichloroethane	0.96	0.013 U	0.37 U	0.035 U	0.42 / 0.2	0.04 (CREG) /e0.4
TCE	0.64	0.015 U	0.014 U	0.007 U	0.19 / 3.3	0.24 (CREG) / 2.4

* Chemical concentrations are from the remedial investigation and 2010 Technical Memo (CH2MHILL 2010a,b). The highest value for each chemical is highlighted.

‡ The "J" qualifier in the table indicates that there is uncertainty in the value due to analytical limitations. The "U" qualifier in the table indicates that this value is below the analytical detection limit.

¥ *Background Indoor Air Concentrations of Volatile Organic Compounds in North American Residences (1990-2005)*

Maximum outdoor air concentrations and reference background levels were greater than indoor concentrations of benzene, carbon tetrachloride, 1,2-dichloroethane, and tetrachloroethylene. This could indicate that indoor levels might be influenced by outdoor air, by reference background, or by both, and that subslab gas may not be the dominant source of indoor air contamination.

11. **If there are no valid indoor air measurements, are there subslab soil gas measurements and other site specific information that can be used to estimate indoor air concentrations using reasonable but conservative attenuation factors from observations (Dawson, Hers, & Truesdale, 2007) or from appropriate models, such as the Johnson and Ettinger model? (http://www.epa.gov/oswer/riskassessment/ainnodellpdfl2004_0222_3phase_user s~de.pdf).**

Indoor air measurements are available for a select number of homes. Attenuation factor studies have also been performed to support the indoor air measurements and to model vapor intrusion at Taku Gardens. These additional lines of evidence appear in Appendix E.

12. **Request further site-specific information and measurements if the answer to the items 10 & 11 above is negative.**

Though items 10 and 11 are not negative, ATSDR has additional concerns that collection of supplementary evidence lines could address. Appendix F includes further discussion of these concerns as the basis for this report's recommendations.

Public Health Implications

13. **If a valid exposure dose can be estimated from information discussed in Part II, proceed to evaluate the public health implications as described in the Public Health Assessment Guidance Manual**

Comparison of air levels with health based criteria

Table 8 contains the estimated indoor air concentrations for duplexes at Taku Gardens as well as ATSDR's comparison values and the actual levels at which adverse health effects have been observed in scientific studies: Lowest Observed Adverse Effect Levels (LOAELs). LOAELs are the lowest tested dose of a substance reported to cause harmful (adverse) health effects in people or animals. Outdoor air contaminant levels measured at the Taku Gardens complex and their corresponding odor thresholds are also provided for comparison.

Table 8 shows that the indoor air levels of the VOCs are far below LOAELs, the levels actually shown to cause noncancer and cancer health effects in scientific studies. Although five of the chemicals' indoor air values exceeded ATSDR's Cancer Risk Evaluation Guide,[2] those values were within USEPA's risk management range of cancer risk (ELCR = 1 in 10,000 to ELCR = 1 in 1,000,000).

1,2-dibromo-3-chloropropane exceeded a noncancer screening value, but appeared to be particularly isolated and sporadic in the sampling events. And it was only detected on two occasions. Additionally, 1,2-dibromo-3-chloropropane was well below its LOAEL and, if infrequently breathed at the levels detected, not likely to result in noticeable health effects.

Benzene, carbon tetrachloride and PCE were detected at higher concentrations in outdoor air at Taku Gardens than the highest estimated indoor air levels. These outdoor air levels, however, were well below LOAELs. Some chemical groups might change over time due to natural or accelerated biodegradation processes, such as vinyl chloride creation from chlorinated solvents. That said, vinyl chloride has yet to be detected in Taku Gardens air above health-based screening levels.

[2] CREGs are the same as USEPA's lowest threshold for acceptable Excess Lifetime Cancer Risk (ELCR).

Table 8. Maximum Air Exposure Point Concentrations, Health Based Levels, and Odor Thresholds (all values in µg/m^3)*

Chemical	Maximum Detected Indoor Air‡	Maximum Detected Outdoor Air‡	Comparison Values (type)	LOAEL (type & subject of study)¥	Odor Threshold¥
Benzene	3.3	3.6	0.1 (CREG)	974 (chronic, human)	200,000
Carbon tetrachloride	0.55	0.61	0.2 (CREG)	63,950 (acute, rodents)	10,000
Chloroform	0.95	0.24	0.04 (CREG)	9,930 (chronic, human)	422,000
1,2-dibromo-3-chloropropane	1.4	1.1	0.2 (RfC)	5,802 (chronic, rodent)	96,500
1,2-dichloroethane	0.96	0.42	0.04 (CREG)	411,390 (acute, rabbit & guinea pig)	49,400
Trichloroethylene	0.64	0.19	0.24 (CREG)	21 (intermediate & chronic, rodent)	537,000

* The higher of indoor and outdoor air highlighted

‡ Maximum detected values from 22 indoor air samples and ambient air samples (CH2MHILL 2010a,b) .

¥ LOAELs and odor thresholds were obtained from ATSDR's toxicological profiles (http://www.atsdr.cdc.gov/toxprofiles/index.asp). LOAELs are actual effect levels that are presented for educational purposes. LOAELs do no incorporate safety factors and are not intended to be used for screening purposes. The type and subject of study refer to the duration of exposure and the recipient of the toxin in the study that showed the LOAEL; (i.e., the values have not been adjusted to always reflect the chronic, human case).

Healthy approach to reducing exposures to VOCs in air

Though Taku Gardens air-contaminant estimates are below levels expected to cause observable health effects, a slightly increased estimated cancer risk remains. USEPA advises that people should be aware of their indoor and outdoor air exposures to VOCs and reduce exposures when practical. VOC levels in homes can accumulate to levels 2 to 5 times higher than levels in outdoor air (USEPA 2011b). The main indoor VOC sources are

- Environmental tobacco smoke (secondhand smoke),
- Stored fuels,
- Paint supplies,
- Household cleaning and maintenance products,

- Commercial air fresheners,
- Building materials, and
- Carpet, furniture, and automobile emissions in attached garages

Actions that can reduce VOC exposure include eliminating smoking within the home, providing for maximum ventilation while using VOC-containing household products (NLM 2010), and safely discarding VOC-containing household products that will not be used immediately (USEPA 2011b).

Odors can be an indicator that air contaminants might be at levels that can affect health. In some cases, odor thresholds are greater than chronic LOAELs; people shouldn't rely on them to determine health hazards. Still, odors have identified contamination source areas at Taku Gardens in the past. People should report immediately any noticeable chemical odors in indoor or outdoor air to the Ft Wainwright Army Garrison Directorate of Public Works (DPW).

Indoor air vapors' spatial and temporal variability compound the already inherent uncertainties in sampling contaminant levels and in estimating human exposures. Human-to-human differences in susceptibility to chemicals and uncertainties in estimating toxicological effect levels from controlled or epidemiological studies also contribute to an overall uncertainty in health effects estimations. Such variability and uncertainty in environmental exposure evaluation makes all the more important a comprehensive approach to reducing health-threatening exposures.

Conclusions

1) ATSDR concludes that breathing airborne contaminant vapors that migrate into housing from residual soil and groundwater contamination (excluding contamination from subsurface containers like drums) is not expected to harm the health of families residing at the Taku Gardens complex.

2) Subslab sampling has been performed at least twice in each duplex. Indoor air samples gathered from approximately 20% of the units (i.e., the units with the highest subslab gas levels) didn't find hazardous contaminant levels. Indoor air sampling in combination with modeling using empirical, radon-derived attenuation factors and measured subslab gas levels indicated that indoor air levels high enough to harm people's health from vapor intrusion are not expected to occur.

3) Future monitoring should ensure that rising vinyl chloride levels in groundwater and SVOCs in soil gas do not become a concern.

4) ATSDR cannot conclude whether vapor migration from subsurface containers such as drums to indoor air might occur and cause harm to the health of families residing at the Taku Gardens complex. ATSDR considered the possibility that subsurface containers such as drums containing volatile or semi-volatile chemicals might remain beneath the buildings. Excavations revealed five buildings with observed scrap metal, construction debris, and junk beneath. Another six buildings have material possibly buried beneath. In the past, containers could have been dumped in pits and gullies where debris had already been deposited. The post-construction geophysical surveys for detecting buried material cannot extend beneath buildings to identify directly what lies beneath. Geophysical surveys in 2004 showed areas with elevated magnetic analytical signals that appeared to correlate with locations where some buildings were constructed.

5) Release of hazardous vapors from subsurface containers into Taku Gardens indoor air could occur if four conditions are met:
   a. Containers are located close to buildings,
   b. Containers hold significant amounts of volatile and hazardous materials,
   c. Containers corrode or become compromised, and
   d. Containers release vapors of sufficient quantity and at sufficient rates to become hazardous.

Recommendations

After reviewing the Taku Gardens data, ATSDR recommends the following for protection of future residents' health:

Site characterization

1) ATSDR supports the Proposed Post-construction Subslab Soil Gas Monitoring Program. DoD or DoD contractors or both will reevaluate monitoring and conceptual site model information after each monitoring event and at the end of an initial 5-year period. The reevaluation will determine whether continued monitoring or actions are necessary to protect the health of families or other Taku Gardens complex occupants. Reevaluations should consider the possibility that subsurface containers remain intact for many decades before degradation. ATSDR is available to review future monitoring data upon request.
2) ATSDR recommends sampling of subslab gas in at least three locations at a representative number of residences to characterize the spatial variability of contaminant vapors in the subslab space. ADEC guidance advises this sampling protocol. It is especially important given that no further indoor air sampling is planned.
3) ATSDR recommends performing at least one of the comprehensive subslab soil gas sampling events after construction is complete. Sampling should be conducted during spring for all residences to capture conditions during the spring thaw and during snowmelt.
4) ATSDR recommends continued subslab gas and indoor air monitoring of units where screening levels were exceeded (i.e., a clean round of sampling shouldn't be used to eliminate any building from future study). NOTE: This would result in sampling more units than the 12 houses selected for monitoring in the Proposed Post-construction Subslab Soil Gas Monitoring Program.
5) ATSDR recommends including SVOCs and 1,2-dibromo-3-chloropropane in all monitoring plans.
6) ATSDR recommends that the Army consider protective and precautionary measures such as installing SSD systems in the buildings identified as having observed and possible debris beneath. The Army should install these SSD systems before occupancy. NOTE: The Proposed Post-construction Subslab Soil Gas Monitoring Program only considers installation of the system *after* quarterly or annual monitoring has detected vapor intrusion.

7) ATSDR recommends monitoring at appropriate intervals following any changes to the site that might affect vapor flow, such as earthquake, building renovation, new construction, or landscaping. This applies to future changes as long as contamination remains onsite above screening or background levels.
8) ATSDR recommends soil gas sampling collocated within a representative number of utility lines and recommends sampling within utility line access ports (entry holes). Such sampling will provide evidence for or against utility line spaces as active vapor migration pathways.

Information for future residents

ATSDR supports LUCs and ICs as specified in the December 9, 2010 *Land Use Controls/Institutional Controls Policy Memorandum* from DPW Environmental to the Garrison Commander (CH2MHill 2010b). The memorandum directs residents to should immediately report odors or visible contamination to the Directorate of Public Works or emergency responders and to leave the area. The memorandum also restricts digging in and near the Taku Gardens site. Soil disturbing activities in excess of 6 inches below grade require coordination with the DPW environmental office, the USEPA and the ADEC before commencement of any work.

People should be made aware of past operations in the Taku Gardens area and informed about the LUCs and ICs and the operation and maintenance of subslab depressurization systems, if installed. ATSDR supports efforts of health education regarding:

- The nature of contamination at Taku Gardens
- The nature and location of subslab depressurization systems or other remedial and exposure mitigation measures, if put in place
- What to do if odors or visible contamination are noted
- Monitoring procedures, schedules, and what to expect during and following monitoring events

Public Health Action Plan

The public health action plan for the site contains a description of actions ATSDR has taken and will take. This plan identifies public health hazards found in the public health consultation and provides action items designed to mitigate and to prevent harmful human health effects resulting from breathing hazardous substances in the environment.

Completed public health actions:

ATSDR reviewed

- Available historical information on FCS activities and waste disposal practices and information from environmental investigations including
  - Field screening, soil excavations, and debris removal during housing construction activities and the remedial investigation,
  - Air, soil, soil gas, and groundwater sampling,

  - Proposed LUCs, ICs, and future monitoring plans, and
  - Results and analysis of subslab depressurization system pilot testing.

Scheduled public health actions:

- Completion of the ATSDR health consultation
- ATSDR is available for technical assistance upon request to review
  - Work plans for future site characterization, remediation, and mitigation and to make recommendations to protect public health,
  - Sampling data from follow-up environmental investigations and make recommendations to protect public health,
  - Design and performance information for subslab depressurization systems, if installed.

ATSDR is available to assist in addressing health concerns upon request by

- Providing fact sheets on
  - The potential for toxicological effects from chemicals of concern,
  - Indoor air quality and ways to minimize indoor air contaminant levels,
  - Protocols to follow should persons encounter suspicious materials or odors,
- Holding public availability sessions to discuss individual concerns or site-related issues,
- Collaborating with local physicians and medical facilities to help medical professionals interpret the potential for health effects from exposure to site-related contaminants exposures, should any such exposures occur.

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Appendix A. ATSDR Glossary of Environmental Health Terms

The Agency for Toxic Substances and Disease Registry (ATSDR) is a federal public health agency with headquarters in Atlanta, Georgia, and 10 regional offices in the United States. ATSDR's mission is to serve the public by using the best science, taking responsive public health actions, and providing trusted health information to prevent harmful exposures and diseases related to toxic substances. ATSDR is not a regulatory agency, unlike the U.S. Environmental Protection Agency (EPA), which is the federal agency that develops and enforces environmental laws to protect the environment and human health. This glossary defines words used by ATSDR in communications with the public. It is not a complete dictionary of environmental health terms. If you have questions or comments, call the agency's toll-free number, 1-800-CDC-INFO (1-800-232-4636).

Absorption
The process of taking in. For a person or an animal, absorption is the process of a substance getting into the body through the eyes, skin, stomach, intestines, or lungs.

Acute
Occurring over a short time [compare with chronic].

Acute exposure
Contact with a substance that occurs once or for only a short time (up to 14 days) [compare with intermediate duration exposure and chronic exposure].

Adverse health effect
A change in body function or cell structure that might lead to disease or health problems

Ambient
Surrounding (for example, ambient air).

Attenuation
The decrease in concentration that typically occurs by dispersion, dilution, and other factors as vapors move from the subsurface into indoor air.

Background level
An average or expected amount of a substance or radioactive material in a specific environment, or typical amounts of substances that occur naturally in an environment.

Biologic uptake
The transfer of substances from the environment to plants, animals, and humans.

Biota
Plants and animals in an environment. Some of these plants and animals might be sources of food, clothing, or medicines for people.

Body burden
The total amount of a substance in the body. Some substances build up in the body because they are stored in fat or bone or because they leave the body very slowly.

Cancer
Any one of a group of diseases that occur when cells in the body become abnormal and grow or multiply out of control.

Cancer risk
A theoretical risk for getting cancer if exposed to a substance every day for 70 years (a lifetime exposure). The true risk might be lower.

Carcinogen
A substance that causes cancer.

Chronic
Occurring over a long time [compare with acute].

Chronic exposure
Contact with a substance that occurs over a long time (more than 1 year) [compare with acute exposure and intermediate duration exposure]

Comparison value (CV)
Calculated concentration of a substance in air, water, food, or soil that is unlikely to cause harmful (adverse) health effects in exposed people. The CV is used as a screening level during the public health assessment process. Substances found in amounts greater than their CVs might be selected for further evaluation in the public health assessment process.

Completed exposure pathway [see exposure pathway].

Concentration
The amount of a substance present in a certain amount of soil, water, air, food, blood, hair, urine, breath, or any other media.

Contaminant
A substance that is either present in an environment where it does not belong or is present at levels that might cause harmful (adverse) health effects.

Dermal
Referring to the skin. For example, dermal absorption means passing through the skin.

Dermal contact
Contact with (touching) the skin [see route of exposure].

Detection limit
The lowest concentration of a chemical that can reliably be distinguished from a zero concentration.

Dose
The amount of a substance to which a person is exposed over some time period. Dose is a measurement of exposure. Dose is often expressed as milligram (amount) per kilogram (a measure of body weight) per day (a measure of time) when people eat or drink contaminated water, food, or soil. In general, the greater the dose, the greater the likelihood of an effect. An "exposure dose" is how much of a substance is encountered in the environment. An "absorbed dose" is the amount of a substance that actually got into the body through the eyes, skin, stomach, intestines, or lungs.

Dose-response relationship
The relationship between the amount of exposure [dose] to a substance and the resulting changes in body function or health (response).

Environmental media
Soil, water, air, biota (plants and animals), or any other parts of the environment that can contain contaminants.

Environmental media and transport mechanism
Environmental media include water, air, soil, and biota (plants and animals). Transport mechanisms move contaminants from the source to points where human exposure can occur. The environmental media and transport mechanism is the second part of an exposure pathway.

EPA
United States Environmental Protection Agency.

Epidemiology
The study of the distribution and determinants of disease or health status in a population; the study of the occurrence and causes of health effects in humans.

Exposure
Contact with a substance by swallowing, breathing, or touching the skin or eyes. Exposure may be short-term [acute exposure], of intermediate duration, or long-term [chronic exposure].

Exposure assessment
The process of finding out how people come into contact with a hazardous substance, how often and for how long they are in contact with the substance, and how much of the substance they are in contact with.

Exposure pathway
The route a substance takes from its source (where it began) to its end point (where it ends), and how people can come into contact with (or get exposed to) it. An exposure pathway has five parts: a source of contamination (such as an abandoned business); an environmental media and transport mechanism (such as movement through groundwater); a point of exposure (such as a private well); a route of exposure (eating, drinking, breathing, or touching), and a receptor population (people potentially or actually exposed). When all five parts are present, the exposure pathway is termed a completed exposure pathway.

Geographic information system (GIS)
A mapping system that uses computers to collect, store, manipulate, analyze, and display data. For example, GIS can show the concentration of a contaminant within a community in relation to points of reference such as streets and homes.

Groundwater
Water beneath the earth's surface in the spaces between soil particles and between rock surfaces [compare with surface water].

Harm
Physical or mental damage.

Hazard
A source of potential harm from past, current, or future exposures.

Hazardous waste
Potentially harmful substances that have been released or discarded into the environment.

Health consultation
A review of available information or collection of new data to respond to a specific health question or request for information about a potential environmental hazard. Health consultations are focused on a specific exposure issue. Health consultations are therefore more limited than a public health assessment, which reviews the exposure potential of each pathway and chemical [compare with public health assessment].

Indeterminate public health hazard
The category used in ATSDR's public health assessment documents when a professional judgment about the level of health hazard cannot be made because information critical to such a decision is lacking.

Incidence
The number of new cases of disease in a defined population over a specific time period [contrast with prevalence].

Ingestion
The act of swallowing something through eating, drinking, or mouthing objects. A hazardous substance can enter the body this way [see route of exposure].

Inhalation
The act of breathing. A hazardous substance can enter the body this way [see route of exposure].

Intermediate duration exposure
Contact with a substance that occurs for more than 14 days and less than a year [compare with acute exposure and chronic exposure].

In vitro
In an artificial environment outside a living organism or body. For example, some toxicity testing is done on cell cultures or slices of tissue grown in the laboratory, rather than on a living animal [compare with in vivo].

In vivo
Within a living organism or body. For example, some toxicity testing is done on whole animals, such as rats or mice [compare with in vitro].

Lowest-observed-adverse-effect level (LOAEL)
The lowest tested dose of a substance that has been reported to cause harmful (adverse) health effects in people or animals.

Metabolism
The conversion or breakdown of a substance from one form to another by a living organism.

Metabolite
Any product of metabolism.

mg/kg
Milligram per kilogram.

Migration
Moving from one location to another.

Minimal risk level (MRL)
An ATSDR estimate of daily human exposure to a hazardous substance at or below which that substance is unlikely to pose a measurable risk of harmful (adverse), noncancerous effects. MRLs are calculated for a route of exposure (inhalation or oral) over a specified time period (acute, intermediate, or chronic). MRLs should not be used as predictors of harmful (adverse) health effects [see reference dose].

No apparent public health hazard
A category used in ATSDR's public health assessments for sites where human exposure to contaminated media might be occurring, might have occurred in the past, or might occur in the future, but where the exposure is not expected to cause any harmful health effects.

No-observed-adverse-effect level (NOAEL)
The highest tested dose of a substance that has been reported to have no harmful (adverse) health effects on people or animals.

No public health hazard
A category used in ATSDR's public health assessment documents for sites where people have never and will never come into contact with harmful amounts of site-related substances.

Pica
A craving to eat nonfood items, such as dirt, paint chips, and clay. Some children exhibit pica-related behavior.

Point of exposure
The place where someone can come into contact with a substance present in the environment [see exposure pathway].

Population
A group or number of people living within a specified area or sharing similar characteristics (such as occupation or age).

Prevalence
The number of existing disease cases in a defined population during a specific time period [contrast with incidence].

Prevention
Actions that reduce exposure or other risks, keep people from getting sick, or keep disease from getting worse.

Public health hazard
A category used in ATSDR's public health assessments for sites that pose a public health hazard because of long-term exposures (greater than 1 year) to sufficiently high levels of hazardous substances or radionuclides that could result in harmful health effects.

Public health hazard categories
Public health hazard categories are statements about whether people could be harmed by conditions present at the site in the past, present, or future. One or more hazard categories might be appropriate for each site. The five public health hazard categories are no public health hazard, no apparent public health hazard, indeterminate public health hazard, public health hazard, and urgent public health hazard.

Public health statement
The first chapter of an ATSDR toxicological profile. The public health statement is a summary written in words that are easy to understand. The public health statement explains how people might be exposed to a specific substance and describes the known health effects of that substance.

Public meeting
A public forum with community members for communication about a site.

Receptor population
People who could come into contact with hazardous substances [see exposure pathway].

Reference dose (RfD)
An EPA estimate, with uncertainty or safety factors built in, of the daily lifetime dose of a substance that is unlikely to cause harm in humans.

Remedial investigation
The CERCLA process of determining the type and extent of hazardous material contamination at a site.

Risk
The probability that something will cause injury or harm.

Risk reduction
Actions that can decrease the likelihood that individuals, groups, or communities will experience disease or other health conditions.

Risk communication
The exchange of information to increase understanding of health risks.

Route of exposure
The way people come into contact with a hazardous substance. Three routes of exposure are breathing [inhalation], eating or drinking [ingestion], or contact with the skin [dermal contact].

Safety factor [see uncertainty factor]

Sample
A portion or piece of a whole. A selected subset of a population or subset of whatever is being studied. For example, in a study of people the sample is a number of people chosen from a larger population [see population]. An environmental sample (for example, a small amount of soil or water) might be collected to measure contamination in the environment at a specific location.

Sample size
The number of units chosen from a population or an environment.

Source of contamination
The place where a hazardous substance comes from, such as a landfill, waste pond, incinerator, storage tank, or drum. A source of contamination is the first part of an exposure pathway.

Special populations
People who might be more sensitive or susceptible to exposure to hazardous substances because of factors such as age, occupation, sex, or behaviors (for example, cigarette smoking). Children, pregnant women, and older people are often considered special populations.

Statistics
A branch of mathematics that deals with collecting, reviewing, summarizing, and interpreting data or information. Statistics are used to determine whether differences between study groups are meaningful.

Substance
A chemical.

Surface water
Water on the surface of the earth, such as in lakes, rivers, streams, ponds, and springs [compare with groundwater].

Toxic agent
Chemical or physical (for example, radiation, heat, cold, microwaves) agents that, under certain circumstances of exposure, can cause harmful effects to living organisms.

Toxicological profile
An ATSDR document that examines, summarizes, and interprets information about a hazardous substance to determine harmful levels of exposure and associated health effects. A toxicological profile also identifies significant gaps in knowledge on the substance and describes areas where further research is needed.

Toxicology
The study of the harmful effects of substances on humans or animals.

Uncertainty factor
Mathematical adjustments for reasons of safety when knowledge is incomplete. For example, factors used in the calculation of doses that are not harmful (adverse) to people. These factors are applied to the lowest-observed-adverse-effect-level (LOAEL) or the no-observed-adverse-effect-level (NOAEL) to derive a minimal risk level (MRL). Uncertainty factors are used to account for variations in people's sensitivity, for differences between animals and humans, and for differences between a LOAEL and a NOAEL. Scientists use uncertainty factors when they have some, but not all, the information from animal or human studies to decide whether an exposure will cause harm to people [also sometimes called a safety factor].

Urgent public health hazard
A category used in ATSDR's public health assessments for sites where short-term exposures (less than 1 year) to hazardous substances or conditions could result in harmful health effects that require rapid intervention.

Other glossaries and dictionaries:
Environmental Protection Agency (http://www.epa.gov/OCEPAterms/)
National Library of Medicine (NIH) (http://www.nlm.nih.gov/medlineplus/mplusdictionary.html)

Appendix B. Vapor Intrusion Screening Checklist

This is a list of several factors that identify the potential for vapor intrusion. This checklist is not an exhaustive list of all the factors that suggest vapor intrusion, but includes the most common factors identified within ATSDR's work as of 2/11/2011. This checklist identifies the potential for the pathway, not the magnitude or the risk. Check a box if the factor exists or use: No, NA (Not Applicable), and UK (unknown).

1) Sources on the property or nearby
   - X Contaminated groundwater (measurement if available) see CH2MHILL 2010b
   - X Contaminated soil (soil vapors detected, measurement) see CH2MHILL 2010b
   - ❑ USTs on or near property –(circle one) with without product
   - X Indoor air vapors detected
2) Pervious foundation
   - ❑ No foundation
   - ❑ Post and beam construction
   - ❑ Cracks in foundation
   - ❑ Basement
   - ❑ No moisture barrier
3) Conveyance to/into building
   - ❑ Unsealed electrical conduits
   - ❑ Unsealed plumbing
   - ❑ Lack of water trap
   - X Pressure gradient flow is enhanced (decomposing material, landfill, etc) extremely cold and icy climate
   - ❑ Fractured bedrock
   - X Heterogeneous fill (note kind if available) frost/heave, possible ice shelves, localized source & debris excavation followed by fill that may differ from native subsurface
   - ❑ Tree roots into building
   - X Other preferential pathways observed ice cap in the surrounding area with possible neighborhood-wide permafrost melt bulb created under buildings
4) Stack effect
   - X Heated building (2-story)
   - ❑ HVAC influence (positive pressure, fresh air supply, intake/exhaust location, etc)
   - ❑ Tall building
   - ❑ Adjacent buildings are not as warm in winter
5) Sub-surface influence (hydrologic pumping)
   - ❑ Intense drought followed by high rain events (wet dog effect)
   - X Tidally-influenced groundwater – rapid river rise due to snow melt may translate to rapid rise in groundwater
   - ❑ Shallow groundwater (less than 15 ft) below lowest level – depth to groundwater averages about 15 ft; potable wells are screened at 60-80'
   - X Property adjacent to building is impervious (circle: ice, concrete, pavement, or other building) – seasonal solid ice/snow
   - X Soil Type – gravel, sand, permafrost in region, but ruled out under housing

6) Conditions during inspection or during sampling - not reported
- ❑ Weather conditions (rainy/clear/recently rained)_____________________
- ❑ Soil moisture ___________________________
- ❑ Soil Grain Observation ___________________

Notes: Place any sampling data or additional information here that helps to validate or refute the pathway. For example: common chemicals in subsurface and indoor air.

1) - Sources on the property or nearby – leakage from heating oil tanks, operational solvent releases, soil excavations were performed (where PCBs were detected and for subsurface debris detected by magnetometry around housing), soil gas not correlated with groundwater contamination
2) Pervious foundation
3) Conveyance to/into building - possible utility conduit migration
4) Stack effect
5) Sub-surface influence (hydrologic pumping) snow melt into adjacent river may cause rapid groundwater rise, buried debris known or suspected beneath bldg 15, 17, 22, 24, 48, 49
6) Conditions during inspection or during sampling
   - Sampling events in December and August span seasonal extremes.
   - Conditions 68 degrees indoors, except the Oct 2008 sampling event.
   - See CH2MHILL 2010b for many more details

Appendix C. Evaluating Vapor Intrusion Pathways at Hazardous Waste Sites

Agency for Toxic Substances and Disease Registry (ATSDR), 2008. *Evaluating Vapor Intrusion Pathways at Hazardous Waste Sites*, Atlanta: US Department of Health and Human Services, Feb 6, 2008.
Available online at: http://www.atsdr.cdc.gov/document/evaluating_vapor_intrusion.pdf

Introduction

Volatile organic chemicals (VOCs), such as solvents, are among the most common contaminants released into the environment from hazardous waste sites. In addition to contaminating groundwater and soils, these chemicals may off-gas from soils and groundwater and seep into the air of homes and commercial buildings. Asphyxiating and flammable gases can also behave similarly to VOCs, in addition to some non-organic volatiles, such as mercury, radon, carbon dioxide, hydrogen sulfide and sulfur dioxide. This movement of volatile chemicals and gases from soil and groundwater into indoor air is known as the vapor intrusion pathway.

Designed for environmental health professionals, this document focuses on how to evaluate the public health implications of vapor intrusion. This document is being issued as a technical supplement to the January 2005 Public Health Assessment Guidance Manual (PHAGM) prepared by the Agency for Toxic Substances and Disease Registry (ATSDR). As a supplement, the discussion will not repeat the basic concepts and processes of the public health assessments found in the PHAGM (http://www.atsdr.cdc.gov/HAC/PHAManual/index.html) (1).

Although sometimes associated with VOC contaminated groundwater, landfill gas will not specifically be addressed in this document. For a discussion of landfill gas, readers should review the ATSDR Landfill Gas Primer at http://www.atsdr.cdc.gov/HAC/landfill/htm/intro.html (2).

Since the 1980s, vapor intrusion has been the subject of increasing research and scientific discussion. However, the research and discussion did not yield a national consensus on methods of evaluation until 2002. Problems in consistent characterization of vapor intrusion at hazardous waste sites led the U.S. Environmental Protection Agency (EPA) to issue draft guidelines in 2002 (http://www.e.pa.gov/epaoswer/hazwaste/ca/eis/vapor.htm) (3). Many state health and environmental agencies have also issued their own guidelines for evaluating vapor intrusion. The majority of the state guidelines appear to follow the approach proposed by EPA with the addition of state-specific screening levels for contaminants. Many states are developing vapor intrusion guidance, and a frequently updated list of state guidance documents is available at http://www.envirogroup.com/links.php (4). Recently, a comprehensive guidance document on vapor intrusion was prepared by scientists and engineers from 19 state and four federal agencies and members of the regulated community and released by the Interstate Technology and Regulatory Council (ITRC; http://www.itrcweb.org) (5).

This document does not attempt to duplicate the in-depth information provided by EPA, state agencies, or the ITRC. Instead, the guidance documents prepared by other agencies are used as references and springboards for discussion of public health practices when evaluating vapor intrusion. In particular, the ITRC document, *Vapor Intrusion: A Practical Guideline* (http://www.itrcweb.org/Documents/VI-l.pdf) (5) is recommended for use by health assessors as a reference for vapor intrusion issues. The ITRC vapor intrusion guidance is intended to aid regulatory agencies in their investigation and remediation of vapor intrusion problems. The ITRC guidance also includes a discussion (Appendix H) of how screening levels are created and used by state agencies.

As a document intended for internet publication, links to appropriate references and source documents, such as the ITRC guidance noted above, will be provided throughout this document. Readers are forewarned that these links may not be updated. If a link fails, readers are encouraged to use appropriate search programs to find the updated web address, assuming the document is still available on the internet.

ATSDR recognizes that many environmental and health organizations have developed excellent resources to evaluate vapor intrusion fate and transport. ATSDR uses the information gained from vapor intrusion fate and transport analyses to determine if exposure to a contaminant poses a health hazard. This evaluation requires a tool that provides dependable information for making health conclusions. ATSDR finds that some guidances serve ATSDR's mission better for some site-specific criteria. Therefore, this document was developed to assist health assessors with choosing from the many available policies for their site-specific needs.

What are the health risks from the vapor intrusion pathway?

As discussed in the Wisconsin Department of Health guidance on chemical vapor intrusion and residential air (http://dhfs.wisconsin.gov/eh/Air/pdf/VI guide.pdf) (6), vapor intrusion into indoor air can be of public health concern because volatile organic compounds (VOCs) in air are readily absorbed by the lungs. If groundwater is contaminated with VOCs, inhalation of VOCs from groundwater may pose a greater hazard than drinking the water. Intrusion of contaminated soil gases into indoor air may lead to the following health and safety issues: fire, explosion and acute, intermediate and chronic health effects. Asphyxiation is a possible but less likely problem.

Fire and explosion

Vapors from leaking buried fuel tanks and fuel pipelines may enter nearby occupied buildings; creating the potential for fire and explosion if they accumulate to sufficient concentration in a confined space such as a basement room or a utility room. If carried by shallow groundwater, the fuels tend to stay at the top of the saturated zone in relatively high concentrations and thereby increase the potential for entry into any building basement or a buried utility system (i.e. storm sewers) that might intercept a high water table.

Acute health effects

Acute (short term) health effects from VOCs include headaches, nausea, eye and respiratory irritation. Such health effects are sometimes associated with petroleum-based air contaminants, such as diesel fuel and heating oils. Benzene is a chemical associated with fuel vapors that may be acutely irritating at low levels (http://www.epa.gov/ttn/atw/hlthef/benzene.html) (7). People with pre-existing respiratory problems (such as asthma and chronic obstructive pulmonary disease) and children may be affected more than healthy adults.

Intermediate health effects

Health effects from intermediate duration exposures (14 days to 364 days) to VOCs can include liver, neurological and reproductive effects. Few studies involving human exposures have been performed for intermediate duration exposures. However, effect levels observed in animal studies are modified by safety factors to give conservative values for screening. If these screening values are exceeded, ATSDR's Toxicological Profiles (http://www.atsdr.cdc.gov/toxpro2.html) (8) and current toxicological literature should be consulted to evaluate potential health effects. Chapter 8 of ATSDR's PHAGM provides guidance on the in-depth analysis of health effects.

Chronic health effects

Health effects associated with long-term inhalation of air contaminants include both cancer and non-cancer health effects. The non-cancer health effects most frequently associated with inhalation of relatively high levels of chlorinated VOCs are damage to the liver, kidneys, and nervous system.

Cancer health effects

Many VOCs are classified as known human carcinogens or reasonably anticipated to be a human carcinogen. For many carcinogenic chemicals, there is no clear threshold below which there is no increased risk of cancer. Therefore, even though most indoor air concentrations of chemicals from vapor intrusion are not likely to result in observable increases in cancer rates for exposed populations, prudent public health practice is to minimize exposures to cancer causing chemicals.

Asphyxiation

Infiltrating vapors, particularly heavier than air gases such as carbon dioxide, can displace and reduce the oxygen in occupied spaces to below life sustaining levels. Though low indoor air oxygen levels have resulted from infiltration of landfill and petroleum derived gases, the asphyxiation hazard has not been associated with infiltration of chlorinated VOCs.

When should a vapor intrusion pathway be evaluated?

There are two basic criteria for determining if it is necessary to evaluate vapor intrusion at a hazardous waste site. First, volatile contaminants must be present in the subsurface, and second, buildings must be laterally and vertically close enough to the subsurface contaminants for concentrations above health concern levels to reach indoor breathing zones. The 2005 California Department of Toxic Substances Control guidance at http://www.dtsc.ca.gov/loader.cfm?url=/commonspot/security/getfile.cfm&pageid=11492. (9)

discusses these criteria in more detail. Future use of contaminated areas should also be considered.

Why is it so difficult to assess the public health hazard posed by the vapor intrusion pathway?

Vapor intrusion is a complex problem with multiple variables (factors) and often too few measurements. Determining the environmental health hazards from air contaminants in homes and commercial buildings is often difficult because of the dynamic nature of the media and the need to assess the entire period of time people are inhaling the contaminants.

The concentrations of contaminants entering the indoor air from subsurface are dependent upon site and building specific factors such as building construction, number and spacing of cracks and holes in foundation, and the impact of the heating and air conditioning system on increasing or decreasing flow from the subsurface. Soil type and moisture between the building and source area, time of year, and tidal effects also affect vapor migration to indoor air.

Health assessors are seldom provided with adequate information to discriminate the contribution of vapor intrusion contaminants from other sources of indoor air contamination. Common sources of indoor air contaminants include household products, stored fuels, furniture, flooring products, dry cleaned clothing, and outdoor air contaminants. In addition, indoor air is a dynamic media with frequent changes in air flow and air composition. Concentrations of air contaminants may change significantly over the course of a single day as a result of air exchange with outside air or the introduction of a temporary source of contaminants, such as furniture polish or paint.

What is the best approach for a public health evaluation of the vapor intrusion pathway?

Many experienced investigators, including those who produced the ITRC guidance, believe that a multiple lines of evidence approach provides the best means of evaluating the vapor intrusion pathway. Such an approach is used in the public evaluation steps described in the following section.

Public Health Evaluation

The EPA and ITRC guidance documents and most of the state guidance documents establish a multiple lines of evidence approach to evaluating vapor intrusion. For example, the ITRC guidance has a 13 step approach that includes gathering information on multiple lines of evidence such as subsurface samples, preferential pathways, geology, soils, and building conditions. This document recommends a very similar approach with several steps that parallel the ITRC guidance. The major parts of a public health evaluation are Pathway Analysis, Exposure Evaluation, Health Implications, and Conclusions and Recommendations.

Outline of Evaluation Process (detailed explanation of evaluation steps starting with Step 4 follows outline)

I. Pathway Analysis

1) Are there subsurface volatile chemicals reported or suspected?

2) Are there occupied buildings within 100 feet laterally or vertically of volatile subsurface contaminants? If the answer is no, are preferential pathways (such as mining shafts, utility conduits, fractures or karst features) present that may result in transport over unusually long distances to occupied buildings?

3) Are reported concentrations of volatile subsurface contaminants near the buildings documented to be, or plausibly above applicable screening levels? Appendix H of the ITRC guide discusses the development and application of screening levels.

If the answer to any of the 3 questions above is no, then human exposure to harmful levels of contaminants from vapor intrusion is unlikely. If the answer to all three questions is yes, continue the evaluation process with the following steps.

1) Begin developing and improving Conceptual Site Model (described below).

2) Search for evidence of any urgent public health hazards such as fire and explosion hazards or potential exposures to free product.

3) Evaluate distance between contaminants and occupied buildings.

4) Evaluate environmental information, environmental concentrations of contaminants in nearby soil, groundwater, and soil gas, and potential background sources.

5) Evaluate building construction characteristics, such as basements, sumps, drainage, ventilation systems, relative elevation, and other critical features.

6) Check for any preferential transport pathways from contaminated soil or groundwater toward occupied buildings (i.e. buried utility lines, known shallow fracture flow zones, or solution channels).

II. Exposure Evaluation (Dose Estimation)

1) Are there valid indoor air measurements to use for dose calculation?

2) If there there are no valid indoor air measurements, are there subslab soil gas measurements and other site specific information that can be used to estimate indoor air concentrations using reasonable but conservative attenuation factors from observations (Dawson, Hers, & Truesdale, 2007) (17) or from appropriate models, such as the Johnson and Ettinger model (http://www.epa.gov/oswer/riskassessment/ainnodellpdfl2004_0222_3phase_user s~de.pdf) (18)?

3) Request further site specific information and measurements if the answer to the items 10 & 11 above is negative.

III. Public Health Implications

1) If a valid exposure dose can be estimated from information discussed in Part II, proceed to evaluate the public health implications as described in the Public Health Assessment Guidance Manual.

IV. Public Health Conclusions and Recommendations, and Public Health Action Plan

1) Follow the Public Health Assessment Guidance Manual

Detailed Explanation of Evaluation Steps-starting with Step 4.

Step 4) Conceptual Site Model:

Develop and improve a conceptual model of the site and the pathway as you gather, review, and evaluate site specific information. Depending on the need for detailed analyses and reporting, the conceptual site model (CSM) may only be a mental visualization or may be a written or graphic description of the site and the vapor intrusion pathway.

As discussed in the New Jersey Department of Environmental Protection Vapor Intrusion Guidance (http://www.nj.gov/dep/srp/guidance/vaporintrusion/) (10), the basic components of a CSM are: known or suspected contaminant sources, contaminant migration pathways, potential human receptors, and the exposure routes by which these receptors may come in contact with contaminants on a site specific basis.

Sometimes the source of the VOCs reported in private and monitoring groundwater wells is not known or multiple sources are suspected rather than a single source. Even without a specific source, a CSM can still be constructed that provides a visualization of contaminant movement from groundwater toward indoor air.

Spatial information, both vertical and horizontal, such as maps, aerial photography, borehole logs, and regional or local stratigraphy, is very useful for formulating a CSM. For sites involving several buildings spread over more than a city block area geographic information systems (GIS) provide extremely useful analytical and visualization tools for CSMs and pathway analyses.

In developing the CSM, pay particular attention to the lateral and vertical distances between sample locations of contaminants and the locations of occupied buildings and subsurface work areas (i.e. buried utilities with man-hole access). For example, determine the lateral and vertical distance from a monitoring well with reported concentrations of a VOC and the basement of a nearby residence. For additional information on CSM, health assessors are referred to section 2.1 (page 12) of the ITRC guidance titled Developing a Conceptual Site Model.

Step 5) Evaluate Presence of Urgent Public Health Hazards:

When reviewing information on the site, first check for any urgent public health hazards such as fire, explosion, oxygen depletion or the presence of free product. For example, ATSDR found flammable levels of methane and Threshold Limit Value (TLV) levels of hydrogen sulfide while investigating indoor air impacted by groundwater at Cady Road, Ohio (http://www.atsdr.cdc.gov/NEWS/cadyroad pr 082902.html) (11). If residents or building occupants report unexplainable (no known indoor sources such as fuel tanks or leaking fuel lines), persistent and pervasive fuel odor within the home or building, local fire officials should be contacted to check for possible flammable or explosive conditions. Also local fire officials should be contacted to check oxygen levels in homes or buildings if occupants voice combined complaints about headaches or dizziness and problems such as pilot lights going out. Seeping carbon dioxide or other gases might be replacing the oxygen in the same portion of the building. The National Institute for Occupational Safety and Health (NIOSH) Pocket Guide to Chemical Hazards lists safety hazards associated with specific chemicals from exposures in an occupational setting (http://www.cdc.gov/niosh/npg/)(12).This topic is also discussed in section 2.3 (page 15) of the ITRC guidance titled Step 1: Does the Site Represent an Acute Exposure Concern?

Step 6) Evaluate Subsurface Environment:

Evaluate the distance between subsurface sources of VOCs (e.g., contaminated groundwater and soil gas) and occupied buildings. According to EPA and state guidance documents, buildings 100 feet beyond the edge of groundwater or soil-gas with concentrations of contaminants above applicable screening levels are less likely to be affected by harmful levels of contaminated gases entering by vapor intrusion than buildings within 100 feet of screening levels. A vertical distance of 100 feet between bottom floor of a building and the top of a contaminated groundwater zone is also often considered an adequate buffer. Both distances assume no preferential pathways are present and other factors such as fluctuations in groundwater levels are minimal. For further discussion of distance between source and buildings, health assessors should review section 2.6 (page 16) of the ITRC guidance titled Step 4: Are Buildings Located in Close Proximity to Volatile Chemicals in Soil, Soil Gas, or Groundwater?

Step 7) Evaluate Environmental Information:

Evaluate the reported contaminant concentrations in groundwater, soil gas and indoor air and the sample locations. As with all environmental health issues (see PHAGM), evaluate the applicability of the sampling and analytical methodology before using the reported results for further public health evaluation. Review Chapter 2 (Investigation of the Soil Vapor Intrusion Pathway) and Chapter 3 (Data Evaluation and Recommendations for Action) from the New York State Department of Health guidance document for more detailed information (http://www.health.state.ny.us/nysdoh/gas/svi guidance/docs/svi main.pdf) (13).

Please note that the presence of indoor air contaminants does not always indicate a completed pathway from the subsurface to indoor air. Always evaluate the presence and concentrations of indoor air contaminants in relation to all sources of contaminants, including the range of background concentrations found in surveys of indoor air contaminants. The New York State Department of Health guidance provides several tables of background concentrations for indoor air contaminants in Appendix C.

Evaluating the applicability of background data to individual sites is recommended on a site-by-site basis. If background sources are present, the EPA Introduction to Indoor Air Quality website (http://www.epa.gov/iaq/ia-intro.htmJ)(15) can be consulted for general information about indoor air pollutants and improving indoor air quality. Data evaluation and background

concentrations are discussed in Section 2.4 (page 15) and Section 3.5.4 (page 28) of the ITRC guidance. The Minnesota Department of Health also provides a useful guidance entitled Indoor Air Sampling at VOC Contaminated Sites: Introduction, Methods, and Interpretation of Results at the following website:
http://www.health.state.mn.us/divs/eh/hazardous/topics/iasampling0l06.pdf(14).

Step 8) Evaluate Building Construction:

Evaluate building construction characteristics, such as foundation type (e.g., basement, slab, crawl-space), foundation condition (e.g., cracks or other openings in basement floors and walls; blocked crawlspace vents), sumps, ventilation systems, drainage, relative elevation, and other critical features. Some construction (post and beam) is largely variable with respect to retarding vapor intrusion. Tightly sealed buildings commonly found in cold climates are more prone to vapor intrusion than houses with vented crawl spaces found in warmer regions. For more information see the building features discussion on page 2 of the Wisconsin Department of Health guidance at the following website: http://www.dhfs,wisconsin.gov/eh/Air/pdf/VI guide.pdf. Also, the ITRC guidance contains (Appendix G) the building checklist developed by the New York Department of Health.

Step 9) Preferential Pathways:

Check for any preferential transport pathways from contaminated soil or groundwater toward occupied buildings. Drains, trenches, and buried utility corridors (such as tunnels and pipelines) can act as conduits for gas movement The natural geology often provides underground pathways, such as fractured rock, porous soil and buried stream channels, where the gas can migrate. Fluctuations in groundwater levels from flooding or tidal influence may hydraulically flush soil gases to the surface. During the winter time, frozen soils may impede VOCs from escaping from open ground surfaces, thereby increasing the migration of VOCs through unfrozen soil under buildings.

Step 10) Are there valid indoor air measurements to use for dose calculation?

Health Assessors should review the indoor air sampling plan and QA/QC plan to determine if the analytical results are adequate for making public health decisions. The sampling plans can be compared with the recommendations for indoor air sampling in the New York State Health Department guidance for indoor air (http://www.health.state.ny.us./nysdoh/indoor/docs/guidance.pdf) and the New York State Health Department guidance for vapor intrusion (http://www.health.state.ny.us/enviromnental/investigations/soil gas/svi guidance/docs/svi main.pdf). As noted in the NYSDOH guidance, the health assessor should check the analytical methods used to determine validity and compatibility with EPA analytical methods.

As a reminder, the indoor air samples cannot distinguish whether the source is from vapor intrusion, ambient air, or transient sources such as commercially dry cleaned clothing stored in a closet. Therefore the indoor air results should be compared with ambient air samples and soil gas samples (particularly subslab soil gas samples) taken at the same location and time to evaluate the potential for these media to be the source of indoor air contamination. If possible, information should include more than a single point in time sampling. Low confidence is generally attributed to decisions based on one sampling event, unless there is clear evidence that this will result in a health protective decision. Outdoor air monitoring that reflects seasonal variations for the site should provide a better basis for an exposure estimate. The California guidance recommends at least a late summer/early fall sample in addition to a late winter/early spring sample. Page D-22 of the ITRC guide also discusses indoor air sample locations and frequency.

Step 11) What if no valid indoor air measurements are available?

If no valid indoor air measurements are available, determine if there is sufficient site specific information (such as subslab soil gas samples, or crawlspace air samples) to estimate indoor air measurements. When using results from subslab gas samples, crawlspace air samples, or groundwater samples, reasonable but conservative attenuation factors should be used in estimating indoor air concentrations. The ITRC guidance document provides more information on using subslab gas samples on pages 24 and 39 and more information on attenuation factors on pages H-2, B-3, H-9 and H-10. A recent compilation by EPA of measured attenuation factors from groundwater and subslab to indoor air reported a 95th percentile attenuation factor of about 0.02 for subslab vapor to indoor air (Dawson, Hers, & Truesdale 2007) (17). This database is expected to become publicly available in the near future for review of the information by all interested parties.

When no subslab gas, soil gas or crawlspace air measurements are available, an environmental transport model, such as the Johnson and Ettinger vapor intrusion model, can be used with conservative assumptions to estimate indoor air concentrations of VOCs moving from groundwater through the soil column and into an occupied building. However, even the best model can lead to erroneous estimates if input parameters do not correctly characterize site specific conditions, such as depth to groundwater, soil type, soil moisture, and structure characteristics; as well as building features such as sump pumps, earthen floors, fieldstone walls, crawlspaces, etc. Please review the ATSDR Division of Health Assessment and Consultation (DHAC) guidance on use of fate and transport models at http:/intranet.cdc.gov/nceh-atsdr/dhac/hac modeling.pdf. Also carefully review the guidance provided by USEPA (http://www.epagov/athens/publications/reports/Weaver600R05106ReviewRecentResearch.pdf) before using any model to estimate indoor air concentrations.

Cases where groundwater monitoring results were below detection limits have been found to exhibit elevated soil gas contaminant levels. Consequently, groundwater results alone may not accurately predict susceptibility of buildings to the vapor intrusion pathway. Field verification sampling is strongly encouraged to confirm model results, particularly when the model suggests the site poses no risk.

Also consider whether collecting additional environmental measurements might be a better use of resources instead of modeling if too many site specific parameters, such as soil moisture and soil type, are unknown or if there is too much variability across the site for other parameters, such as building construction. Supplemental measurements might also be wise if previous sampling was performed after recent precipitation or unusual meteorological events (ITRC guidance, D-27 and D-28).

Before using a model or requesting additional environmental measures, check requirements of state specific guidance for vapor intrusion. Some state guidelines require additional investigation if groundwater and/or soil gas measurements exceed published screening values.

Step 12) Request further site specific information and measurements if there are no indoor air data and sufficient information is not available to estimate indoor air concentrations based on observed attenuation factors or modeling.

When requesting additional information, consider both the quantity and quality of environmental measurements needed to estimate an exposure dose. If multiple occupied buildings may be impacted, how many and which buildings should be sampled? Consider the cost and intrusiveness of both subslab sampling and indoor air sampling. For additional information on alternatives for additional environmental measurements, health assessors should review Chapter 3 of the ITRC vapor intrusion guidance.

Step 13) If a valid exposure dose can be estimated from information discussed in Part II, proceed to evaluate the public health implications as described in the Public Health Assessment Guidance Manual.

Step 14) Follow the PHAGM to provide the appropriate Public Health Conclusions, Recommendations, and Public Health Action Plan.

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[ATSDR 2008] Appendix A.

Lessons learned from health assessments of Ohio vapor intrusion sites

From Robert Frey, Ph.D., Ohio Department of Health

~ Current vapor intrusion models have limited utility with regard to predicting impacts of vapor intrusion on residential and commercial structures

~ Vapor intrusion sites have to be investigated and evaluated on a site specific basis -Ohio sites have indicated numerous exceptions to some of the generalities that have been made to date with regard to the vapor intrusion pathway

~ These evaluations are only as good as the data collected to support these investigations -more accurate diagnoses come when you have all of the data groundwater, deep soil gas, subslab soil gas, and indoor air -not just one or two pieces of the puzzle

~ Soil gas levels are often an order of magnitude or more higher than groundwater concentrations (ex. Springfield Street site: maximum PCE in groundwater =257 ppb versus PCE in soil gas at 7,700 ppb/v; Behr-Dayton site: maximum TCE in groundwater = 16,000 ppb versus TCE in soil gas at 160,000 ppb/v)

~ Residences with crawl spaces and dirt floors may actually have lower levels of vapor-phase VOCS indoors than homes with concrete basements (homes with crawl spaces are often vented to the outside and typically are less "energy efficient" than homes with finished basements)

~ Important to establish a public health team (including the local health department) to support the Environmental Protection Agency’s enforcement activities and establish good contacts and communications with the impacted communities to better facilitate the investigations and corrective actions that might be taken

[ATSDR 2008] Appendix B.

Background VOC Studies References Provided by Henry Nehls-Lowe Bureau of Environmental & Occupational Health Division of Public Health Wisconsin Department of Health & Family Services

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Appendix D. Groundwater Vapor Intrusion Screening

The ATSDR screening levels shown in Table D-1 are based on the conservative assumption that chemicals would vaporize from the surface of the groundwater table and undergo a 1000-fold attenuation during migration to indoor air (EPA 2012a). NOTE: The screening levels in Table D-1 are not predictive of actual hazardous conditions for the site, i.e. they are only presented for screening purposes. Some chemicals (such as trichloroethylene and benzene) with high volatility and toxicity actually have VISLs lower than EPA's drinking water criteria (MCLs) and ATSDR's drinking water screening levels (Table D-1). The one chemical that remains above the MCL (1,2,3-trichloropropane) is not very volatile and is screened out as a vapor intrusion concern.

Table D-1. Groundwater Vapor Intrusion Screening Level (VISL) Derivation

Contaminant		Air Comparison Value ($\mu g/m^3$)	Comparison Value Source	Henry's Law Constant (unitless)	ATSDR Groundwater VISL (µg/L)*	Drinking Water Screening Level (µg/L) and Source †
Petroleum Hydrocarbons	Benzene	0.1	CREG	0.227	0.441	0.6 CREG
Chlorinated VOCs	1,1,2,2-Tetrachloroethane	0.02	CREG	0.015	1.333	0.2 CREG
	Trichloroethylene	0.24	CREG	0.403	0.596	5 MCL
	Vinyl chloride	0.1	CREG	1.14	0.088	0.02 CREG

* The ATSDR vapor intrusion groundwater screening level was calculated as follows:

†CREG = cancer risk evaluation guide, MCL = EPA's maximum contaminant level, VOC = volatile organic chemical

Cgw-sl = Cair-sl / (H * α_{gw} * UCF) where

- Cgw-sl = ATSDR Groundwater VISL (µg/L)
- Cair-sl = ATSDR's lowest air comparison value ($\mu g/m^3$)
- H = Henry's law constant (unitless)
- α_{gw} = EPA's attenuation factor recommended for screening groundwater = 0.001
- UCF = unit conversion factor = 1000 L / 1 m^3

The maximum detected groundwater levels for VOCs and SVOCs above ATSDR's screening levels for vapor intrusion are shown in **Table D-2**. Trichloroethylene monitoring through 2011 showed that, while levels are below the MCL, levels are still higher than ATSDR's VISL **(Figure D-1).** However, the current trend indicates that levels are expected to decrease below the VISL within the next several years, and hazardous indoor air levels have not been detected. This is supported by site-specific studies discussed in step 11 that indicate there is likely more attenuation at this site than assumed with EPA's default attenuation factors. The increasing concentrations of vinyl chloride **(Figure D-2)** will continue to be monitored in groundwater and soil gas according to the *Proposed Post-construction Subslab Soil Gas Monitoring Program.*

Table D-2. Maximum (Max) Groundwater Concentrations for Contaminants Exceeding Screening Levels*

Contaminant		Groundwater Concentration (µg/L)			
		Historical Max	2010[‡] Max	2011[¥] Max	VISL (µg/L)
Petroleum Hydrocarbons	Benzene	2.6	0.06	0.05	0.44
Chlorinated VOCs	1,1,2,2-Tetrachloroethane	9.8	3.4	0.71	1.3
	Trichloroethylene	14	7.6	3.7	0.60
	Vinyl chloride	0.84	0.34	1.0	0.088

* Screening levels are groundwater levels in equilibrium with ATSDR's air comparison values assuming a thousand fold attenuation. Highlighted values are greater than the VISL. Chemical concentrations are from CH2MHILL 2010b.

[‡] JEG 2012a

[¥] JEG 2012b

Figure D-1. TCE Plume Over Time (JEG 2012c)

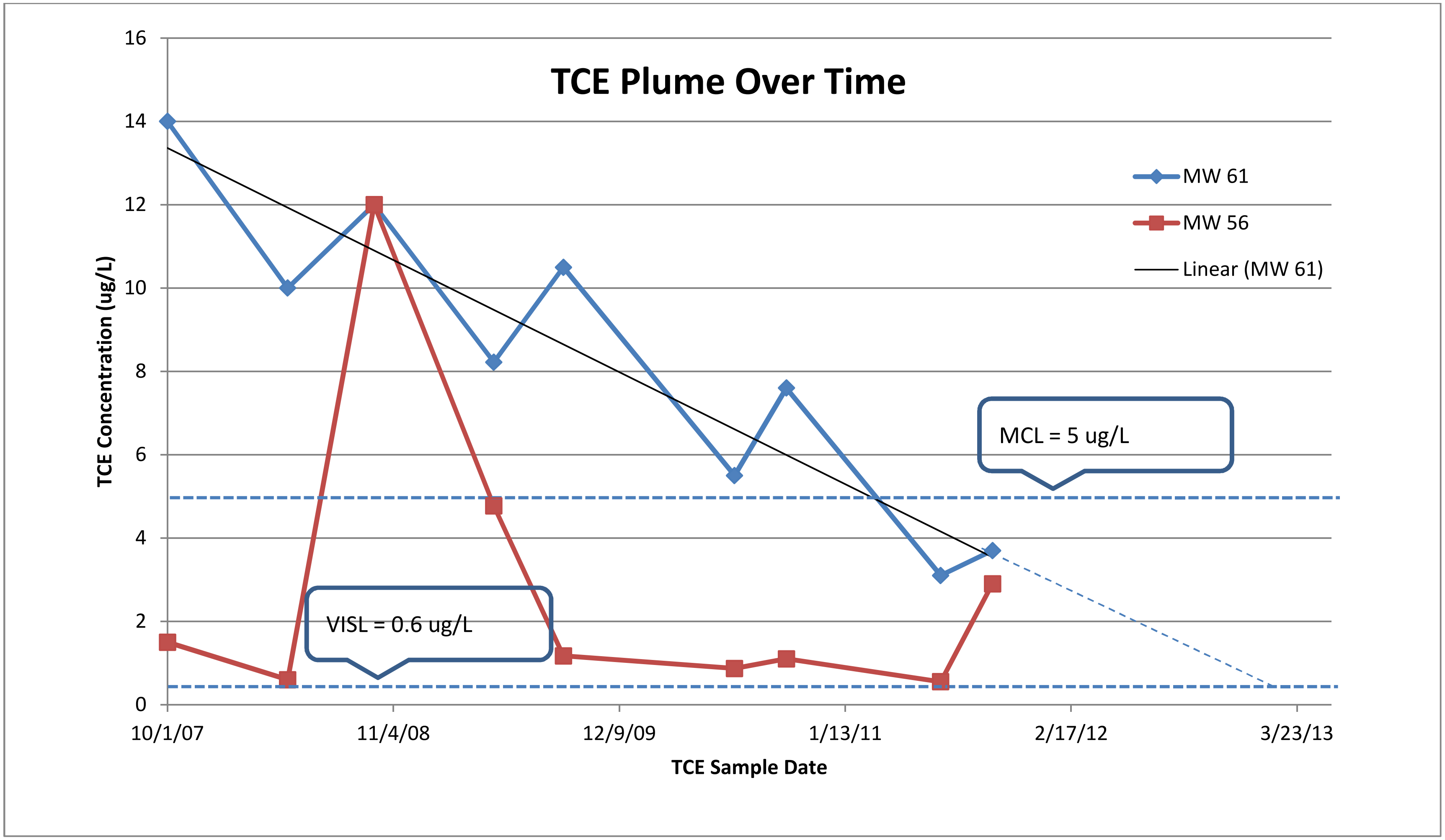
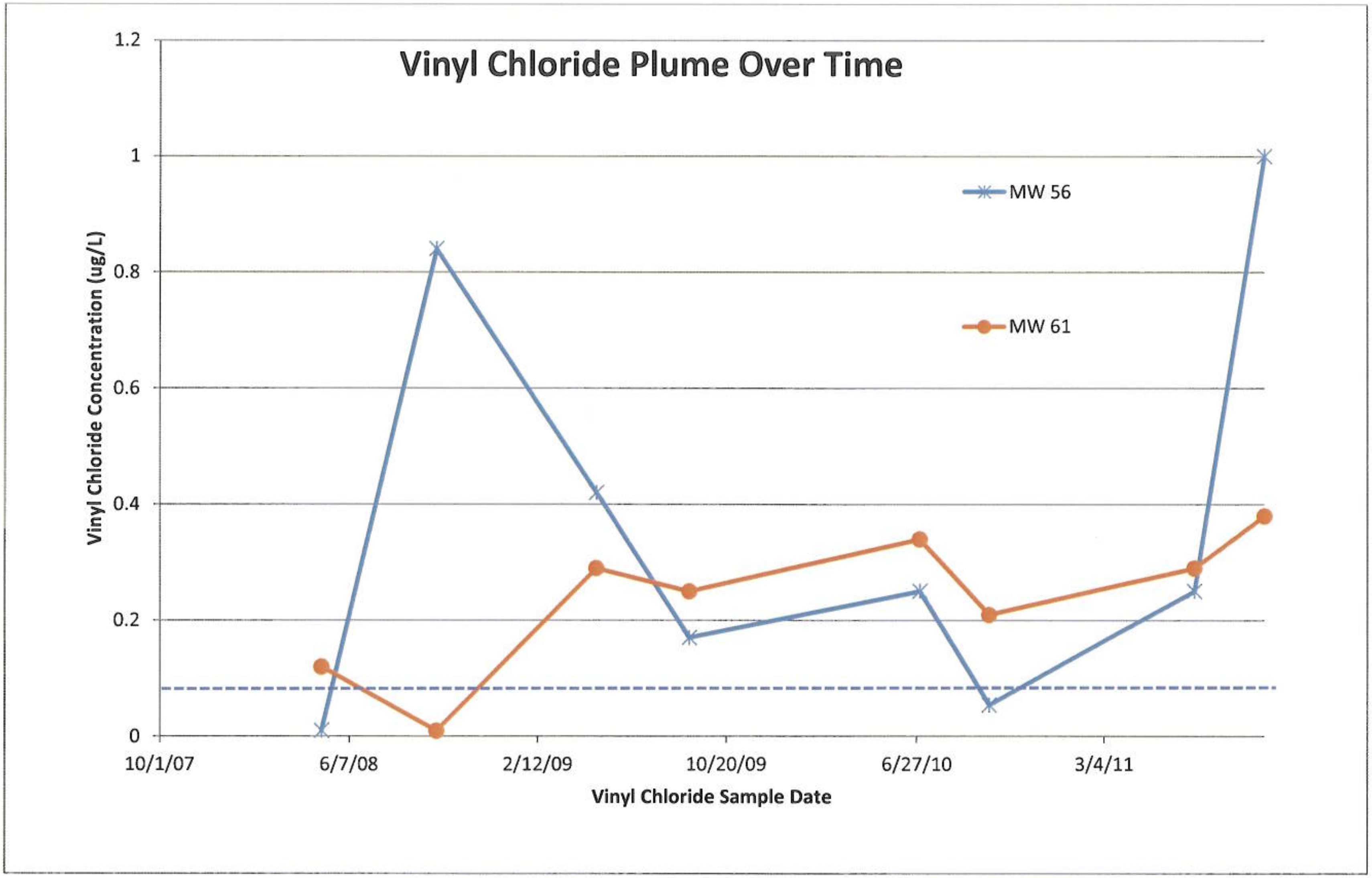


Figure D-2. Vinyl Chloride Plume Over Time (JEG 2012c)



Appendix E. Attenuation Factor Analysis and Modeling

The following datasets were gathered to estimate attenuation factors and characterize subslab gas and indoor air at the site:

- VOC samples: Paired subslab gas, indoor and outdoor air in select residences
- Radon samples: Paired subslab gas, indoor and outdoor air in select residences
- Comprehensive subslab gas sampling for VOCs at duplexes

Subslab VOCs were sampled for each duplex, sometimes for each unit, for application of site specific attenuation factors to model indoor air levels. Subslab gas may be less variable than indoor air levels and less susceptible to background effects, thus making it an indicator of the potential for indoor air problems. Paired measurements of subslab and indoor air VOCs did not provide sufficient information to estimate site-specific attenuation factors. The site-specific attenuation factors determined by radon measurements were used to provide estimates of indoor air for all units based on subslab gas data.

VOCs Most of the VOCs detected in indoor air were not present at levels significantly over outdoor air or typical background levels. During indoor and subslab air sampling, two of the ten samples yielded chemical concentrations sufficient to calculate attenuation factors: indoor/subslab = 0.12J[3]/190 µg/L = 0.00063 for chloroform, and indoor/subslab = 0.58/110 µg/L = 0.0053 for tetrachloroethylene. Smaller attenuation factors correspond to more attenuation of vapors from subslab to indoor air; conversely larger attenuation factors assume less dilution or attenuation of vapors migrating indoors from the subslab. EPA's study of 12 sites with chlorinated VOCs found a median attenuation factor of 0.003 (EPA 2012c). So the Taku Gardens site VOCs show more attenuation than the median found in EPA's study. The two attenuation factors calculated from VOCs are not sufficient to assess the spatial and temporal variability in attenuation for all 110 units. Therefore radon sampling was used as a surrogate.

Radon. Radon gas sampling has been shown to be an effective method of evaluating the attenuation of subslab gases upon migration into indoor air (ITRC 2007). Radon was present at reliably measurable levels in the Taku Gardens duplexes. Samples were collected in March and August 2009 and in January and July 2010 to evaluate indoor air attenuation factors for representative buildings (CH2MHILL 2010b). The sampling targeted units with the highest chlorinated VOC concentrations in soil gas and evaluated each style of floor plan. The initial samples tested five units. The January 2010 radon sampling event expanded to 19 units representing about ~18% of the units (CH2MHILL 2010b). A summary of the results is shown in **Table E-1** below.

[3] J = lab qualifier indicating an estimated value)

Table E-1: Radon subslab gas attenuation factors*

	Range
March 2009 (5 Taku units)	0.0008 - 0.0016
August 2009 (5 Taku units)	0.0006 - 0.0024
January 2010 (19 Taku units)	0.0006 - 0.0034
July 2010 (12 Taku units)	0.000003 - 0.0011
EPA Attenuation Factor Study†	0.000025-0.94

* Table N-5 of Appendix N in the Remedial Investigation document showed data for all 19 units in Jan 2010 (CH2MHILL 2010a, b)
† (EPA 2012c)

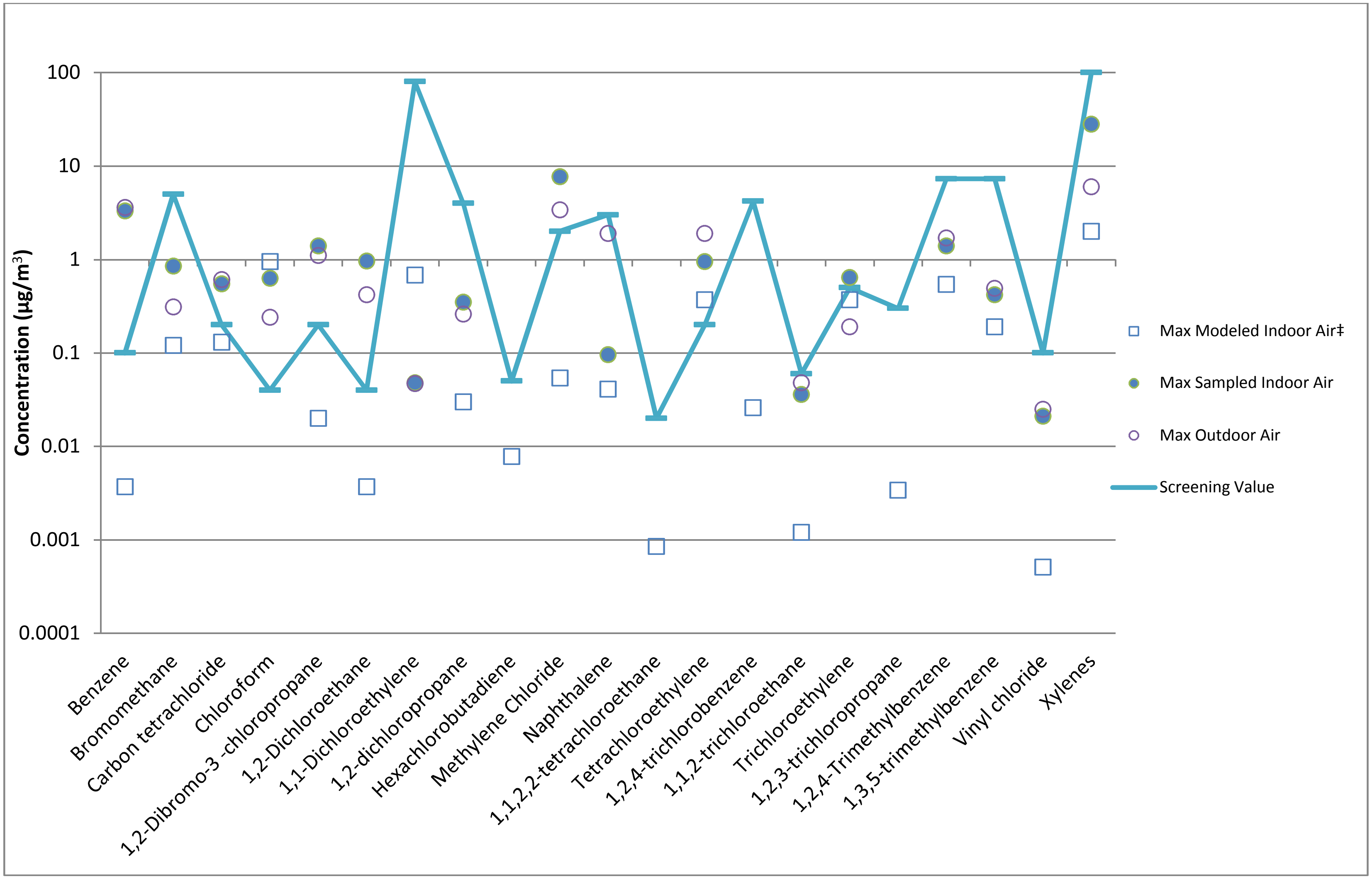
Temporal analysis by radon sampling showed consistent subslab attenuation factors between March 2009, August 2009, and January 2010, with values spanning less than 6 fold difference. This narrow range is likely due to the similarity of housing construction and weather conditions at the site from house to house. The subslab gas attenuation factors measured in the July 2010 radon sampling event have a similar upper bound to the other sampling events but have a much smaller lower bound. It is likely that the first three sampling events represent typical conditions and the low attenuation factors in the July 2010 sampling event occurred because of an anomaly, because the lowest value was 10 fold lower than EPA's lowest measured attenuation factor in all studies (EPA 2012c). EPA's study showed a median (50^{th} percentile) of 0.003, which is close to the upper values seen in the Taku Garden studies.

Comprehensive Analysis Maximum detected contaminant concentrations in subslab gas and an attenuation factor of 0.0034 were used to model maximum expected indoor air values. **Table E-2** shows the maximum modeled values side-by-side with the maximum measured indoor and outdoor air contaminant values and the screening values. The modeled indoor air values were less than the detected indoor air values for all chemicals except chloroform and 1,1-dichloroethylene, which slightly exceeded the modeled values (**Figure E-1**). This comparison shows that the modeled values are not reflective of measured indoor air levels in most cases. Actual indoor air levels are the result of the combined influence of all indoor, outdoor and subslab sources, as well as variability inherent in the sampling and analysis process. Johnson and Ettinger modeling was not attempted, because it is not likely to be a good indicator of vapor intrusion that results from non-uniformly distributed sources.

When measured indoor air contamination is present above levels predicted by the model, the following situations may be occurring:

1) Higher indoor air levels may be caused by background contributions.
2) The model is under-predicting the extent of vapor intrusion. The preferential pathways in the subslab space could result in subsurface migration from localized sources of VOCs that behave differently from the dispersed radon emissions measured.
3) Indoor air was sampled for site related contaminants and radon attenuation factors in about 20% of the units. Differences between units could contribute to the lack of agreement between modeled and measured indoor air.

Figure E-1. Comparison of Air Values for Chemicals Exceeding Screening Levels



Indoor air contaminant concentrations, regardless of their source, are the most important factor in assessing potential health effects at sites. Estimating indoor air contaminant levels at vapor intrusion sites is challenging due to their fluctuating levels and the variability of vapor entry by the vapor intrusion pathway. Additionally, low level indoor air contamination measurement is particularly susceptible to background interference and uncertainties introduced during sample collection and lab analysis. The most prudent approach to evaluating health effects is to choose a representative indoor air concentration and evaluate whether or not that value poses a health concern. The choice of representative indoor air contaminant concentration at Taku Gardens depends on conclusions from multiple lines of evidence that include measured indoor air concentrations; indoor air concentrations extrapolated from subsurface media and background; and information about the influence that variability and uncertainty may have on the adequacy of the chosen indoor air concentration. Actual measured indoor air levels of VOCs are considered more reliable than modeled values and will be evaluated in relation to health-based values in Step 13. The lower modeled values increase confidence that higher levels from vapor intrusion are not expected to occur.

Table E-2: Comparison of Modeled and Sampled Indoor Air and Outdoor Air for Chemicals Exceeding Screening Levels in Subslab Gas (µg/m^3)*

Chemical	Maximum Modeled Indoor Air‡	Maximum Measured Indoor Air¥	Maximum Outdoor Air¥	Indoor Air Comparison Values
Benzene	0.0037	3.3	3.6	0.1 CREG
Bromomethane	0.12	0.85	0.31	5 RfC
Carbon tetrachloride	0.13	0.55	0.61	0.2 CREG
Chloroform	0.95	0.63	0.24	0.04 CREG
1,2-dibromo-3-chloropropane	0.020	1.4 UJ	1.1	0.2 RfC
1,2-dichloroethane	0.0037	0.96	0.42	0.04 CREG
1,1-dichloroethylene	0.68	0.048 U	0.047	80 iEMEG
1,2-dichloropropane	0.030	0.35 U	0.26	4 RfC
Hexachlorobutadiene	0.0078	N/A	N/A	0.05 CREG
Naphthalene	0.041	0.096 U	1.9	3 RfC
1,1,2,2-tetrachloroethane	0.00085	N/A	N/A	0.02 CREG
Tetrachloroethylene	0.37	0.95	1.9	3.8 CREG
1,2,4-trichlorobenzene	0.026	N/A	N/A	4.2 ADEC
Trichloroethylene	0.37	0.64	0.19	0.24 CREG
1,2,4-trimethylbenzene	0.54	1.4	1.7	7.3 ADEC
1,3,5-trimethylbenzene	0.19	0.42 J	0.49	7.3 ADEC
Vinyl chloride	0.00051	0.021 U	0.025	0.1 CREG
Xylenes	2.0	28.1	6.0	100 RfC

* The maximum of the three indoor air predictors (maximum modeled indoor air, maximum sampled indoor air and maximum outdoor air) are highlighted, and screening values are highlighted when exceeded by any of the three indoor air predictors. The "J" qualifier in the table indicates that there is uncertainty in the value due to analytical limitations. The "U" qualifier in the table indicates that this value is below the analytical detection limit.

‡ Modeled from maximum subslab gas data and a radon based attenuation factor of 0.0034.

¥ N/A = not included in analysis. Data source: CH2MHILL 2010a,b

Appendix F. Discussion of Multiple Lines of Evidence

Subslab Depressurization Systems The current plan is for the subslab depressurization system pilot study equipment to be removed in its entirety and the slab penetrations filled with concrete and sealed. The floor coverings will then be replaced to match existing materials (Malen J. RPM, US Army Garrison Fort Wainwright, AK. Personal Communication Mar 19, 2012). ATSDR supports the conclusion from the SSD pilot study that a dual suction point setup is an appropriate starting point in system design should SSD systems be used in the future. For a subslab depressurization system to be effective against migration of subslab contamination into indoor air, a 4 Pascal pressure differential between the subslab space and corresponding indoor air is suggested in the ITRC Vapor Intrusion Pathway document (ITRC 2007). Performance measured by tracer and pressure field extension testing has been shown effective for evaluating subslab gas removal and pressure differential in Taku Gardens duplexes. Testing performed under conditions that may impart different internal pressures, i.e. seasonal HVAC influence and during operation of exhaust systems, such as a kitchen hood or dryer, would provide more confidence that consistent performance occurs during occupancy. Periodic indoor air radon measurements over the initial 5-year evaluation period is a practical method to verify long-term operation of the system. If SSD systems are used on-site, appropriate operation and maintenance protocols, such as periodic performance testing and inspection of SSD equipment, should be implemented for the duration of the equipment's use (EPA 2008b).

Monitoring Program Design The Ft Wainwright Army Garrison Directorate of Public Works (DPW) Proposed Post-construction Subslab Soil Gas Monitoring Program includes a schedule for periodic data review and monitoring of VOCs in subslab gas. Monitoring is planned to occur in select locations over the next 5 years, with discontinuation after 5 years contingent on stable sampling results that indicate no health hazard from subslab vapor. Quarterly subslab sampling and data review is proposed for the first 2 years in 12 select residences, with all 110 units being sampled and reviewed at the beginning and end of the first 2-year period. For the next 3 years annual sampling and data review is proposed for the 12 select residences each February.

- **Reevaluate Pathway Following Earthquake Events or Site Changes** Fairbanks is located in an area with considerable potential for earthquake activity (Wesson et al. 2007), which could rupture containers, create subsurface preferential pathways, or increase cracking in the slabs. It appears that some of the contamination exists in isolated zones at this site. However, it is possible that an earthquake could create new pathways connecting the isolated zones to indoor air spaces. Adding a follow-up sampling event in the case of earthquake to the monitoring plan (during or after the 5-year monitoring plan) is recommended. Additionally, site changes, such as building renovation, construction, or landscaping, should also be followed up with vapor intrusion evaluation.
- **Monitoring Program Analyte List** The proposed five year samples will be analyzed for VOCs. Analysis for SVOCs is recommended to detect naphthalene, which has been detected at one of the locations, and Aroclor 1232, which has variable volatility and sometimes occurs in hydraulic fluids (ATSDR 2000). Continued inclusion of 1,2-dibromo-3-chloropropane (CH2MHILL 2010b) in air sampling analysis could provide further insight into the sporadic occurrence of this chemical in soil, soil gas, and indoor air at the site.
- **Selection of Units for Monitoring from 3 to 5 Years** During the previous focused indoor air sampling events, 10 of the 110 units were selected for sampling in December

2008 based on subslab gas VOC levels. In July 2010, 12 units were selected based on the August 2009 comprehensive subslab gas sampling. However, only one of the units found to have the highest exceedances from the December 2008 event was reselected in July 2010. ATSDR supports continued evaluation of units that have exceeded screening levels at any given point in time, in case meteorological or other conditions that caused the exceedance may regularly occur. A clean round of sampling shouldn't be used to eliminate the building from future study (Hers 2001). Paired indoor air and subslab gas sampling is standard procedure for vapor intrusion assessments and should be performed during the monitoring.

- **Satisfy ADEC Subslab Sampling Guidance Protocol** The Alaska Department of Environmental Conservation (ADEC) draft vapor intrusion guidance indicates that at least three subslab locations should be sampled per building (ADEC 2009c). EPA (2012) indicates that internal building partitions, HVAC layout, utility conduits, and preferential pathways should be considered in determining the placement of subslab samples. The garage slabs were poured separately from slabs under the living space. Additional subslab sampling points in a representative number of residences could provide information on spatial variability under slabs, including whether differences occur beneath the slabs of the garage (where all subslab gas samples are being collected) and the living space. Understanding this relationship is useful because future monitoring plans include no indoor air samples, i.e. they will consist entirely of subslab gas samples taken from garages. If vapors collect under the living space slab but do not translate to the garage subslab space (e.g., subsurface footings separate the two areas) vapor intrusion may occur without detection. If it can be demonstrated that vapors translate freely between the garage and living space subslab areas, this will increase the confidence in the garage subslab sampling monitoring data being applicable to indoor air. Existing ports from the SSD system pilot study could be used for this evaluation during the routine periodic sampling events for a representative number of residences to improve knowledge about the spatial variability of vapors in the subslab space.
- **Capture Spring Conditions** Spring season sampling could reveal groundwater and soil gas changes due to snow melt. Drainage swales on the west direct heavy spring runoff and summer storm-water to the north (CH2MHILL 2010b). The drainage swale hydraulic connectivity and infiltration rates on the site are unknown, but such factors could influence soil gas patterns. The Chena River lies 1,500 feet (0.28 miles) north of the Taku Gardens housing area (CH2MHILL 2010b). A USGS study has found that water levels in wells within about half a mile of the Chena river changed rapidly to changes in river stage (USGS 1996).
- **Evaluate Vapors within Utility Conduits** Soil gas samples collocated within subsurface utility lines and within manholes could reveal vapor flow pathways and how contamination is being transported, such as along the heating line conduits that traverse the site.
- **Comprehensive Monitoring After Construction is Complete** Comprehensive subslab soil gas and indoor air sampling after construction is complete would provide information on the long-term site conditions that may not be reflected before or during construction.

Site Future Use Considerations The December 9, 2010 *Land Use Controls/Institutional Controls Policy Memorandum* from DPW Environmental to the Garrison Commander (CH2MHill 2010b) provides specific guidance and general recommendations which call for the reduction in potential for health hazards from environmental contaminant exposure at the Taku Gardens complex (CH2MHILL 2011). If potentially hazardous material or debris is discovered, the base LUC and IC control policy directs that all activity in the area should cease, individuals should move away and the DPW or emergency responders should be contacted (CH2MHILL 2011). Future construction shall consider the potential for vapor intrusion of hazardous materials into indoor air and incorporate facility designs to protect health (CH2MHILL 2011). Alternatives for addressing contamination should consider the potential to affect vapor intrusion at the Taku Gardens complex. Particularly, attenuation by natural or in situ chemical oxidation may lead to the presence of toxic degradation products from chlorinated VOCs, such as vinyl chloride. The objective of the Proposed Post-construction Subslab Soil Gas Monitoring Program is to monitor the progress of attenuation to ensure that any shifting of the suite of chemicals present do not endanger health from individual or combined chemical effects. The migration patterns of contaminants resulting from temporal and spatial variability should be taken into consideration in designing and evaluating remedial alternatives.