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Field data and numerical modeling: A multiple lines of evidence approach for assessing vapor intrusion exposure risks

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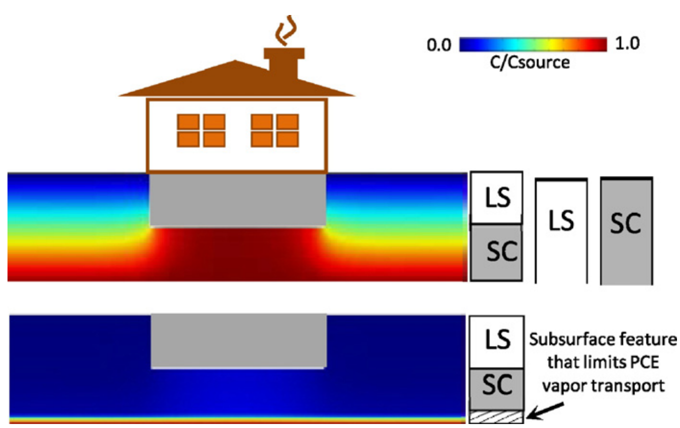
HIGHLIGHTS

- Multiple-lines-of-evidence can improve site-specific vapor intrusion risk assessments.
- Combining field data and numerical model results improves site conceptual models.
- Groundwater concentrations may not be predictive of vapor intrusion exposure risks.

GRAPHICAL ABSTRACT



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ABSTRACT

USEPA recommends a multiple lines of evidence approach to make informed decisions at vapor intrusion sites because the vapor intrusion pathway is notoriously difficult to characterize. Our study uses this approach by incorporating groundwater, soil gas, indoor air field measurements and numerical models to evaluate vapor intrusion exposure risks in a Metro-Boston neighborhood known to exhibit lower than anticipated indoor air concentrations based on groundwater concentrations. We collected and evaluated five rounds of field sampling data over the period of one year. Field data results show a steep gradient in soil gas concentrations near the groundwater surface; however as the depth decreases, soil gas concentration gradients also decrease. Together, the field data and the numerical model results suggest that a subsurface feature is limiting vapor transport into indoor air spaces at the study site and that groundwater concentrations are not appropriate indicators of vapor intrusion exposure risks in this neighborhood. This research also reveals the importance of including relevant physical models when evaluating vapor intrusion exposure risks using the multiple lines of evidence approach.

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Indoor air
Hazardous waste

Overall, the findings provide insight about how the multiple lines of evidence approach can be used to inform decisions by using field data collected using regulatory-relevant sampling techniques, and a well-established 3-D vapor intrusion model.

1. Introduction

Vapor intrusion involves indoor air contamination resulting from chemical volatilization in the subsurface beneath the building. Because of the complexities associated with characterizing the vapor intrusion pathway, the United States of Environmental Protection Agency (USEPA) recommends a "multiple lines of evidence approach" when making decisions about how to assess vapor intrusion exposure risks (USEPA, 2015a). The multiple lines of evidence approach uses field data, modeling and other pertinent site information to assess vapor intrusion exposure risks. However, approaches for integrating the various sources of data are not well established. To gain a better understanding of the implications of various approaches, the authors conducted a vapor intrusion investigation in a neighborhood with a well-characterized subsurface contamination plume and compared field data results with numerical modeling results.

USEPA issued two different documents that provide technical guidance on how to interpret and evaluate vapor intrusion data; one document is primarily related to field data, (USEPA, 2012a) and the other reports the results of a 3-D model used to evaluate various conceptual site models (USEPA, 2012b). However, the comparison of high-quality, temporally-correlated field data with model predictions remains a critical need within the vapor intrusion community (Turczynowicz and Robinson, 2007; Yao et al., 2013a).

Using a systematic comparison of the model predictions and field measurements, this paper represents one of the first attempts to report the results of a multiple lines of evidence approach using a 3-D vapor intrusion model and field data collected using regulatory-relevant sampling techniques at a real-world vapor intrusion site. The data show that in order for multiple lines of evidence to provide meaningful information about vapor intrusion exposure risks, relevant physical models must be included and evaluated.

Results discussed herein provide scientific insight about the multiple lines of evidence approach, and also are grounded in the realistic constraints that a "living" site poses. This study intentionally does not investigate new or emerging characterization techniques; rather its main purpose is to provide novel insights about comparisons between data collected using common field sampling techniques and results of a well-established vapor intrusion numerical models. Accordingly, the findings summarized herein are timely and relevant to the broad vapor intrusion community including researchers, practitioners and regulatory agency staff.

2. Methods and materials

2.1. Site description

The field study site is the neighborhood adjacent to a former chemical handling facility where bulk tetrachloroethylene (PCE) (and other chlorinated solvents) was transported for off-site use. Over the period of time that the site operated (1955–2002), the soil and groundwater became contaminated. Groundwater contamination (chlorinated VOCs, predominantly PCE with little to no evidence of degradation) migrated northeast (GEI, GEI Consultants, 2009). The neighborhood consists of residential and commercial properties, as well as an elementary school. The site had been involved in regulatory action for several years, dating back to the mid-2000s. As part of the ongoing regulatory activities mandated by the Massachusetts Department of Environmental Protection (MassDEP), the vapor intrusion pathway was evaluated. A number of vapor intrusion mitigation systems had been installed at buildings throughout the neighborhood, including the school, and many residences. In accordance with MassDEP regulation, ongoing monitoring was conducted to evaluate other buildings that might require mitigation and whether current mitigation systems are performing adequately (GEI, GEI Consultants, 2009). This study was conducted to gain additional insight about the vapor intrusion pathway at the site and to investigate the use of a 3-D vapor intrusion model to inform and interpret vapor intrusion data sets.

The field study site is schematically shown on Fig. 1. The study included three properties A, B and C. The selection of properties was made based on proximity to the source of contamination and the property owners' (and property tenants') willingness to participate in the study. Each property owner allowed research personnel access to his or her outdoor and indoor premises on a repeated basis from 2010 through 2012. Throughout the field study, members of the research team discussed results and the associated vapor intrusions risks with the property owners, and MassDEP.

Property A includes a three story multi-family home (basement depth approximately 5.5 ft bgs) with a paved patio (approximately 32 ft by 23 ft) and a grassy area (42 ft by 29 ft) northwest of the home. Property B includes an open space grassy field (approximately 50 ft by 50 ft) with a three-story multifamily home located in the southwest corner. Property C is a slab-on-grade building that was used for commercial purposes. The entire surface area for Property C was asphalt paved (maximum dimensions were approximately 58 ft by 93 ft). The contaminant source was located to the west of these properties.

All three of these properties were inhabited and in use throughout the study. Accordingly, like most vapor intrusion sites across the country, each property had certain limitations that could not be overcome. For instance, Property B had an active vapor intrusion mitigation system and the basement floor and walls had been sealed prior to this research. Therefore, we did not specifically evaluate indoor air concentrations from this property; however vapor intrusion exposure risks were evaluated by using soil gas and groundwater data, along with 3D modeling. Other specific circumstances are noted in Table 1.

2.2. Multiple lines of evidence approach

As a first step in the multiple lines of evidence approach, USEPA recommends to review site historical data and develop a site conceptual model. Then, risk-based site screening using empirically derived attenuation factors (α) is often performed (USEPA, 2015a).

$$\alpha_i = \frac{C_{\text{indoor air}}}{C_{\text{location,i}}} \tag{1}$$

$C_{\text{indoor air}}$ is indoor air concentration and $C_{\text{location, i}}$ is the gas-phase concentration at a given ("i") location. USEPA (2015a) recommends "screening" attenuation factors based on the location "i". For instance, if the denominator is the chemical concentration in groundwater, then the term $\alpha_{\text{groundwater}}$ is used. If the denominator is the chemical concentration in the subslab, then the term α_{subslub} is used.

Where:

$$\alpha_{\text{groundwater}} = \frac{C_{\text{indoor air}}}{C_{\text{gas-phase groundwater}}} = \frac{C_{\text{indoor air}}}{C_{\text{groundwater}} \times H}. \tag{2}$$