Journal of Environmental Management xxx (2017) 1–10

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

# Recent advances in vapor intrusion site investigations

Thomas McHugh [a, *], Per Loll [b], Bart Eklund [c]

[a] GSI Environmental Inc., Houston, TX, United States
[b] DMR A/S, Jerslev, Denmark
[c] AECOM, Austin, TX, United States

A R T I C L E I N F O

*Article history:*
Received 18 September 2016
Received in revised form
7 January 2017
Accepted 8 February 2017
Available online xxx

*Keywords:*
Vapor intrusion
Guidance
Conceptual model
Preferential pathway
Innovative
Investigation method

A B S T R A C T

Our understanding of vapor intrusion has evolved rapidly since the discovery of the first high profile vapor intrusion sites in the late 1990s and early 2000s. Research efforts and field investigations have improved our understanding of vapor intrusion processes including the role of preferential pathways and natural barriers to vapor intrusion. This review paper addresses recent developments in the regulatory framework and conceptual model for vapor intrusion. In addition, a number of innovative investigation methods are discussed.



## 1. Introduction

Vapor intrusion is the vapor phase migration of volatile contaminants from a subsurface source into overlying buildings or other structures. Vapor intrusion has been recognized as a potential exposure pathway at contaminated sites for decades, however, before the year 2000, few regulatory guidance documents provided comprehensive recommendations for field investigation of this pathway. Following the discovery of vapor intrusion problems at a small number of sites in the late 1990s and early 2000s, this exposure pathway has received more attention in regulatory guidance and among the regulated community. As a result, our understanding of the vapor intrusion pathway has evolved rapidly since 2000.

Previously published guidance documents provide a general review of vapor intrusion and investigation methods (e.g., ITRC, 2007; USEPA, 2015a). This paper focuses on recent developments in vapor intrusion with a specific focus on recent developments to i) regulatory framework, ii) conceptual model, and iii) investigation approaches. This paper focuses on chlorinated volatile organic compounds (VOCs). There is an extensive literature related to potential vapor intrusion of petroleum hydrocarbons, methane, and radon that is largely outside the scope of this paper. Until recently, vapor intrusion for chlorinated VOCs and petroleum VOCs were addressed in a similar manner. Recently, separate guidance has been developed for petroleum VOCs (USEPA, 2015b; ITRC, 2014) because they often rapidly biodegrade in the vadose zone greatly reducing the vapor intrusion risk (McHugh et al., 2010; USEPA, 2012a).

## 2. Regulatory framework

Previous reviews of vapor intrusion guidance outside the United States found that where the vapor intrusion pathway was being addressed, the usual approach relied upon numerical modeling and risk assessment (Ferguson, 1999; Eklund, 2007). This largely continues to be the case. Field investigations to evaluate vapor intrusion are most common in only a few countries: Australia, Canada, Denmark, the United Kingdom, and the United States. As shown in Supplemental Material, Table S1, these countries have all issued guidance documents in the last decade to take into account recent developments in site characterization methods, data evaluation techniques, and site decision-making.

The United States Environmental Protection Agency (USEPA) issued a draft vapor intrusion guidance in 2002 with the intent to update and finalize the guidance within a few years. However, the

* Corresponding author. GSI Environmental Inc., 2211 Norfolk, Suite 1000, Houston, TX, United States.
*E-mail address:* temchugh@gsi-net.com (T. McHugh).

http://dx.doi.org/10.1016/j.jenvman.2017.02.015
0301-4797/

USEPA did not issue final guidance for addressing vapor intrusion at non-petroleum (USEPA, 2015a) and petroleum (USEPA, 2015b) sites until 2015. For non-petroleum sites, the USEPA guidance recommends very conservative screening criteria and intensive sampling for sites where VOC concentrations exceed these criteria. Recommended sampling includes groundwater, soil gas and indoor air with multiple rounds of sampling recommended to characterize temporal variability. The guidance recommends a multiple-lines-of evidence approach for evaluating the investigation results and sets a high bar for concluding an absence of vapor intrusion concern. Numerous state governments in the United States issued their own vapor intrusion screening levels and guidance. These guidance documents have been previously summarized (Eklund et al., 2007; Eklund et al., 2012). Compared to the USEPA guidance, the state guidance documents typically provide more detail regarding the specific procedures to be used for collection and analysis of soil gas and indoor air samples. In Canada, there is guidance at both the Federal and Provincial level. In addition to the Federal guidance listed in Table S1, there also are guidance documents for specific provinces (e.g., Alberta, Ontario, British Columbia, Atlantic provinces). In Europe (outside of the United Kingdom and Denmark), vapor intrusion is primarily addressed through modeling and risk assessment (NICOLE, 2004). In most of these countries, there is little guidance for how to proceed at sites that fail this screening and show a potentially unacceptable risk from vapor intrusion. In addition to establishing regulatory frameworks, researchers in Australia, Canada, Denmark, and the United States have been active in developing investigation methods and elucidating vapor intrusion processes.

In other countries outside of North America, Europe, and Australia, there is little or no regulatory guidance on vapor intrusion. Vapor intrusion is addressed in New Zealand on a case-by-case basis, but no new guidance has been issued in the last 15 years. NICOLE Brasil, an industry-led non-governmental organization, issued vapor intrusion guidance that draws heavily upon practices used in the United States. The guide presents a conceptual model for vapor intrusion and covers investigation methods and modeling but does not recommend default screening values or attenuation factors. Malaysia has issued guidance for addressing vapor intrusion that provides screening levels for residential and industrial indoor air, guidance for soil vapor measurement, and a tiered risk assessment process. However, the guide does not recommend follow-up actions for sites where the risk assessment process indicates a potential vapor intrusion concern. In South Africa, the industry-led NICOLA group has a Working Group that is developing vapor intrusion guidance.

A number of multi-national companies have company-specific risk management policies that include evaluation of the vapor intrusion pathway even in countries without established guidance. In addition, government agencies such as the U.S. Department of Defense have evaluated vapor intrusion at some overseas installations. These parties commonly utilize vapor intrusion guidance and investigation practices from their home countries. In many of these cases, these investigations require shipment of equipment and return of samples to the United States or Europe for analysis.

## 3. Vapor intrusion conceptual model

The standard conceptual model for vapor intrusion consists of i) partitioning from groundwater or soil into soil gas, ii) diffusion through the vadose zone from the source area to the immediate vicinity of the building and iii) advection and/or diffusion through the building foundation (USEPA, 2015a, Fig. 1). Once vapors have

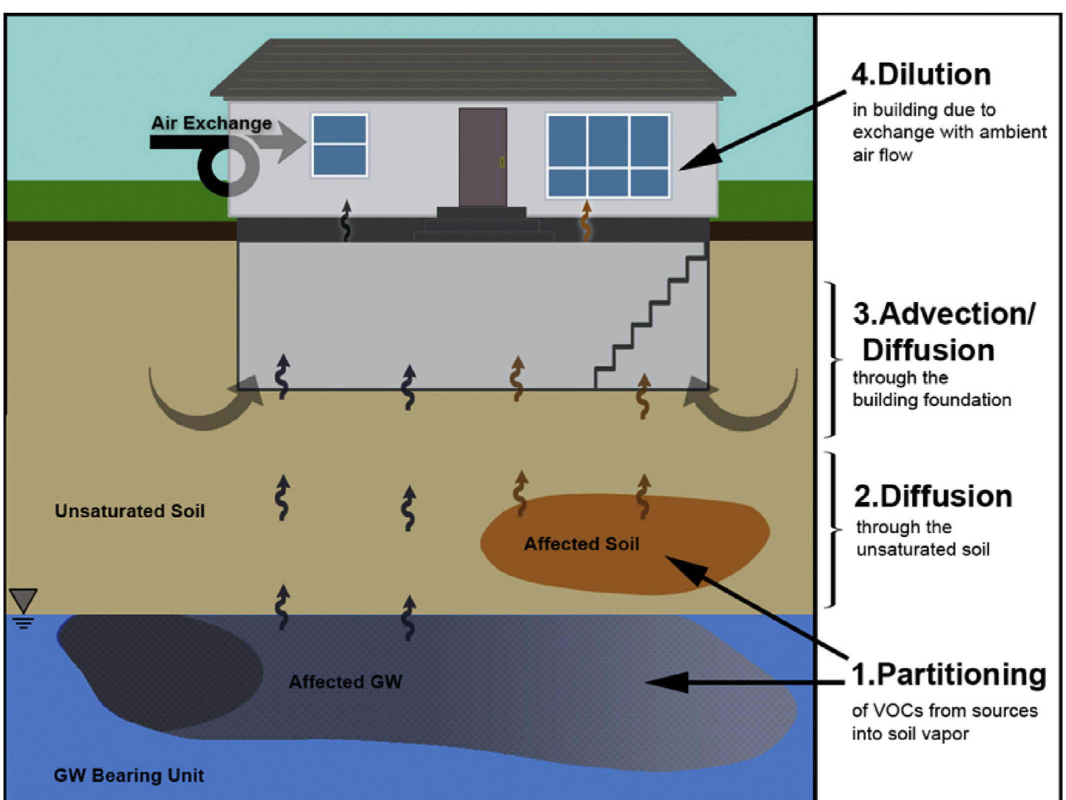


**Fig. 1.** Standard conceptual model for vapor intrusion.

Please cite this article in press as: McHugh, T., et al., Recent advances in vapor intrusion site investigations, Journal of Environmental Management (2017), http://dx.doi.org/10.1016/j.jenvman.2017.02.015