

PRACTICAL TIPS TO SHARE:

SOIL VAPOUR INTRUSION

Author: Dr John Andrews, EPG Ltd . on behalf of SoBRA

In June 2018, the Society of Brownfield Risk Assessment (SoBRA), The Geological Society Contaminated Land Group and RemSoc delivered a conference targeted towards early careers learning. Its aims were:

- To support technical excellence in the assessment, estimation & evaluation of risks and associated uncertainties from land affected by contaminants;
- To encourage “good practice” in the practical application of risk assessment to support decisions regarding the appropriate management of land contamination; and
- To facilitate and widen access to the dissemination of knowledge regarding land contamination risk assessment.

A commitment of this workshop has been the creation of a series of short tabular reports for each of the different discipline areas. These reports aim to

- Direct early career professionals to what is considered important;
- Provide clarity as change is often easier when we understand why we are doing it; and
- Focus on identifying small changes that are easy to deliver.

This report is neither intended to present prescriptive guidance nor be exhaustive in content. It is simply a distillation of each author’s experience, shared with the intention of directing both field staff and risk assessors in their early careers towards some good practices, and helping them to avoid common mistakes. It presents work conducted by a volunteer.

This report is made available on the understanding that neither the contributors nor the publishing organisation are engaged in providing a specific professional service. Whilst every effort has been made to ensure the accuracy and completeness of the work and this document, no warranty as to fitness for purpose is provided or implied. Neither SoBRA nor the authors of the report accept any liability whatsoever for any loss or damage arising in any way from its use or interpretation, or from reliance on any views contained herein.

Note (August 2024): This document has not been updated since publication and is considered to be largely superseded by the SoBRA guidance notes 1A Conceptual site model development for assessment of VI contaminant linkages in the UK, 1B Benefits of soil vapour sampling for assessment of VI risks, and 1C VI data collection considerations (see SoBRA, 2022).

Where analysis of soil samples will include volatile organic compounds (VOC), relevant current guidance including BS 10176:2020 (BSI, 2020) (where soil types are appropriate) should be followed, and sampling methods adopted which minimise loss of volatiles and meet data quality objectives.

SOIL VAPOUR INTRUSION

PRACTICAL TIPS	Descriptor
<p><i>Following evaluation of potential acute (short term) Vapour Intrusion (VI) risk, assess ground conditions for the presence of VOC prior to undertaking sub-floor or indoor air sampling</i></p>	<p>Except under specific conditions (e.g. complaints of odours or physiological effects by building occupants or visitors, or potentially as part of a wider VI investigation), VI assessment should follow a lines-of-evidence approach to minimise unnecessary access to properties (particularly residential).</p> <p>Due consideration should be given to potential psychological and property blight effects from undertaking direct building assessment.</p> <p>Due to the potential for background sources of many VOC within properties (e.g. smoking, paints, glues, etc) and outdoor (ambient) sources of VOC (e.g. vehicle exhaust) it is quite possible that undertaking indoor air quality evaluation alone will not provide a definitive VI assessment for ground-based VOC sources.</p>
<p><i>Do not conclude significant VI risk using only soil generic assessment criteria (GAC)</i></p>	<p>Whilst soil GAC can be calculated (e.g. CLEA) for inhalation (note: may combine dust and vapour), assessment is likely to be overly conservative for the following reasons:</p> <ol style="list-style-type: none"> 1. VOC losses during soil sampling and transport is often significant, resulting in poor representative laboratory data and under-estimation of VI potential. 2. Partitioning from the sorbed- to vapour-phase is assumed to be at equilibrium and will therefore most likely overestimate the vapour concentration in the ground (critical source along the VI pathway) and therefore VI potential. 3. Will not take full account of a VOC source in groundwater / non-aqueous phase liquid (NAPL), which may preferentially partition to the unsaturated zone soil vapour- (and pore water-) phase.

Do not conclude significant VI risk using only soil generic assessment criteria (GAC) (contd.)

4. Does not take account of potential biodegradation in the soil unsaturated zone, which can be significant for petroleum hydrocarbons, and may limit the potential for significant VI. Note: as described in Environment Agency (2009) Science Report 3Section 10.1.1, a ten-times reduction factor for soil vapour concentrations calculated from either soil or groundwater concentrations for petroleum hydrocarbons (but not chlorinated hydrocarbons) may be applied to account for partitioning and biodegradation. This is different to a sub-surface to indoor air attenuation factor calculated using the J&E model or calculated using empirical data.

Under certain circumstances (e.g. no VOC source in groundwater), however, it may be appropriate to conclude the absence of significant VI risks through comparison of soil VOC data with GAC. The potential for significant losses of VOC during sampling and transport should be considered, along with other site observations (e.g. odour, presence of NAPL or residual NAPL) and site-based VOC measurement (e.g. by photo ionisation detector (PID)).

Groundwater GAC (such as SoBRA gwvapGAC and consultant-calculated values) are a useful evaluation of the VI potential of a VOC source in groundwater as part of a multiple lines of evidence approach. However, assessment is likely to be overly conservative for the following reasons:

1. Partitioning from the dissolved- to vapour-phase is assumed to be at equilibrium and will therefore most likely overestimate the vapour concentration (critical source along the VI pathway) and therefore VI potential.
2. Groundwater GAC do not take account of biodegradation in the unsaturated zone vapour-phase, which can occur for petroleum hydrocarbons under the correct conditions (aerobic), and significantly reduce concentration (vs that predicted by partitioning) and therefore VI potential.

Do not conclude significant VI risk using only groundwater GAC

Direct assessment of unsaturated zone vapour-phase VOC conditions will measure actual concentrations rather than those conservatively predicted from soil and groundwater data.

Where there is the potential for significant VI (based on soil and / or groundwater assessment), undertake direct evaluation of the critical soil vapour-phase source through sampling from dedicated unsaturated zone boreholes

Soil vapour VOC concentrations can be directly compared with vapour-phase GAC, produced for various end-use scenarios, such as consultant-calculated values.

Do not short-cut the investigation by assessing soil vapour conditions in the absence of soil and groundwater (if present) data. VOC present in all media should be assessed in order to develop a robust VI conceptual site model (CSM).

<p><i>Soil-vapour VOC cannot migrate to give a higher concentration than at the source</i></p>	<p>A basic principle of vapour migration is that VOCs migrate down either a concentration gradient (diffusion) or a pressure gradient (advection), which can therefore result in an increase in concentration (where there was none or less previously), but cannot result in a higher concentration than at the source.</p>
<p><i>Understand your data quality objectives and required analytical detection limits.</i></p>	<p>Inhalation health criteria values (acceptable indoor VOC concentrations) may be two to three orders of magnitude lower than GAC for soil vapour. Analytical detection limits must be low enough for direct comparison with quality criteria, however the required detection limits for indoor air samples are far lower than for soil vapour samples.</p>
<p><i>Do not assume that a VOC concentration measured at depth (in soil vapour or groundwater) is necessarily representative of more shallow conditions, i.e. further along the critical VOC migration pathway</i></p>	<p>VOC concentrations in both groundwater and unsaturated zone vapour-phase often exhibit significant concentration profiles with depth, which may cause either under- or over-estimation of VI potential.</p> <p>In groundwater, concentration profiles are typically caused by the presence of light non-aqueous phase liquids (LNAPL) or dense non-aqueous phase liquids (DNAPL) combined with low VOC diffusion rates, low vertical hydraulic gradients or rainwater infiltration (dilution of VOC in shallow groundwater).</p> <p>In the soil vapour-phase, concentration profiles are typically caused by biodegradation (petroleum hydrocarbons) and diffusion rates (i.e. differential diffusion rates in different soil types or soils with varying soil moisture content).</p> <p>A groundwater sample taken at depth below LNAPL (or residual NAPL) may therefore under-estimate the critical concentration where VOC partition from the groundwater surface to the soil vapour-phase. VI potential may be under-estimated in this instance.</p> <p>Conversely, a deep groundwater sample collected in the zone of DNAPL (chlorinated or non-chlorinated compounds) may therefore over-estimate the critical concentration where VOC partition from the groundwater surface to the soil vapour-phase. VI potential may be over-estimated.</p>

<p><i>Do not assume that a VOC concentration measured at depth (in soil vapour or groundwater) is necessarily representative of more shallow conditions, i.e. further along the critical VOC migration pathway (contd.)</i></p>	<p>Significant soil-vapour VOC concentration profiles may exist in the soil unsaturated zone due to biodegradation (particularly petroleum hydrocarbons), with concentrations typically reducing with less depth from the ground surface as conditions change from anaerobic to aerobic.</p> <p>Such effects may be observed within the top few metres of the soil profile due to the ingress of atmospheric oxygen into shallow soils and may be affected by soil type and moisture content (air permeability), source strength (oxygen depletion), soil contamination and organic matter content (oxygen depletion). Note that anaerobic conditions can exist in shallow soils where there is a significant source (e.g. NAPL) and biodegradation is limited by the rate of oxygen migration into the area (e.g. in clay-rich soil or in areas beneath hard-standing or large buildings) compared with the rate at which oxygen is consumed.</p> <p>Borehole response zones and sampling methods should therefore be carefully considered, along with the benefits of undertaking multiple-depth sampling to assess concentration profiles.</p> <p>Measuring soil vapour-phase VOC concentration profiles is typically required to prove that concentration reduction through biodegradation in more shallow soils is occurring. Soil microcosm tests can also be undertaken to indicate the presence and abundance of suitable bacteria.</p>
<p><i>Treat the VI potential for chlorinated compounds and petroleum hydrocarbons separately</i></p>	<p>The VI potential of petroleum hydrocarbons may be significantly reduced or mitigated by biodegradation in the soil unsaturated zone vapour-phase under appropriate site conditions. This is not typically the case with chlorinated compounds, which do not biodegrade appreciably in aerobic (shallow) environments.</p> <p>The risk profiles of chlorinated compounds and petroleum hydrocarbons differ markedly (migration potential and toxicity), with the former typically posing higher VI risks.</p>
<p><i>Measure oxygen concentrations whilst undertaking soil-vapour sampling</i></p>	<p>Measurement of oxygen (together with methane and carbon dioxide) will provide an indication of the degree of aerobic condition and therefore biodegradation potential (for petroleum hydrocarbons) in shallow soils.</p> <p>Oxygen concentration profiles should be measured where investigation of VOC concentration profiles (in soil vapour or groundwater) are undertaken.</p>

VI from petroleum hydrocarbons is often overestimated and may be mitigated by suitable lateral or vertical separation distances between source and receptor

Due to the typically rapid biodegradation of petroleum hydrocarbons in the soil vapour-phase, practitioners in the US (Lahvis et al., 2013) have developed so-called lateral and vertical exclusion distances for petroleum hydrocarbon leaks from small underground fuel storage sites (e.g. retail fuel stations), beyond which the potential for significant VI is low. Such distances / scenarios can be used as an initial screening approach, to minimise the unnecessary investigation of low-risk sites.

Assess the presence of NAPL and residual-NAPL

NAPL will present the strongest VOC sources for VI, particularly where it occurs in the unsaturated zone or at the groundwater interface (where it may have a high lateral migration potential).

Residual-NAPL may be present within the groundwater capillary zone (e.g. through groundwater/LNAPL depth fluctuation or LNAPL lateral migration), although (by definition) it is not sufficiently mobile to migrate into borehole response zones. Residual-NAPL may easily be missed unless boreholes are suitably drilled and cores are carefully logged.

The vapour potential from residual-NAPL and NAPL are roughly the same (over the short- to medium-term). Lack of suitable identification of residual- NAPL may therefore lead to an under-estimation of VI potential.

Changes in groundwater level can significantly affect measured concentrations of VOC in both groundwater and soil vapour, particularly where residual NAPL is present in the groundwater smear zone. In these circumstances rising groundwater levels may re-mobilise (dissolve) residual NAPL and result in increased dissolved-phase VOC but reduce soil vapour VOC concentrations due to lower vapour flux in higher moisture content soils. Conversely, lower groundwater levels may result in a decrease in dissolved-phase VOC and an increase in soil gas VOC concentrations.

<p><i>Significance of GAC exceeding saturation limits</i></p>	<p>GAC for VOCs in soil, groundwater and soil vapour may exceed the soil saturation, solubility limits and saturated vapour limits, respectively. How do we use such criteria in the assessment of VI?</p> <p>Fate & transport models (such as CLEA, RBCA, etc.) may calculate VI risk-based criteria that exceed the saturation limits for individual (single, pure) compounds (with criteria then typically set at the saturation limit). Theoretically, in such cases the presence of free product (indicative of exceedance of the saturation limits) is not sufficient to pose a significant VI risk.</p> <p>However, precaution should be given in such cases for the following reasons:</p> <ul style="list-style-type: none"> • Models do not take account of the presence of NAPL, but may flag when concentrations exceed saturation conditions (some models take account of Raoult's Law to flag saturation limits for mixtures of compounds). The presence of NAPL may invalidate modelling results. • Models typically calculate partitioning of VOCs to the vapour-phase based on the assumption of low contaminant concentrations (e.g. Henry's Law for partitioning from groundwater to vapour). Such calculations may underestimate the vapour-phase concentration where NAPL is present and vapourisation directly from free-phase to vapour-phase occurs. <p>The presence of NAPL (particularly residual-NAPL or LNAPL) typically defaults a VI assessment to require direct measurement of the unsaturated zone vapour-phase VOC concentrations to address the modelling uncertainty highlighted above.</p>
<p><i>Assess the presence of preferential vapour entry routes into properties</i></p>	<p>Preferential entry routes are rapid vapour migration pathways into buildings, such as large foundation cracks (caused by subsidence for example), unsealed service entries (e.g. sewerage, water, electricity), etc.</p> <p>The presence of both a VOC source and preferential entry routes must be considered as a high risk VI scenario.</p> <p>Fate and transport models (such as CLEA, RBCA, etc.) do not take account of preferential entry routes (entry is via foundation joints and fine, dust-filled cracks), and GAC will therefore be under-conservative where preferential entry routes exist.</p>

<p><i>Current GAC may not be suitable for assessing VI into modern housing or older housing stock with suspended timber floors</i></p>	<p>GAC (soil, groundwater, soil vapour) assume vapour migration through a ground-bearing slab (or basement), with standard assumptions for VOC ingress rates and building ventilation rates (providing indoor dilution of VOC).</p> <p>Consideration should be given to the appropriateness of GAC for evaluation of VI into modern buildings, which may have passively ventilated foundation sub-floor voids or which may be designed to be more air tight (lower building air exchange rates and less dilution).</p> <p>GAC may be under-conservative for assessment of VI through suspended timber floors, particularly where passive air vents have been either removed or blocked (reduced sub-floor dilution).</p>
<p><i>The presence of LNAPL and a shallow water table presents a potentially acute or high risk for indoor air quality</i></p>	<p>Shallow LNAPL (or elevated concentrations of VOC in shallow groundwater) has the potential to enter a building through impregnation of the foundation fabric, rather than via typical VI (vapour-phase) pathways. In many real-life cases indoor air quality has been acutely affected by substances not typically associated as having a high VI potential (e.g. heating oil / kerosene) through such direct contact pathways.</p>

REFERENCES

- British Standards Institute (BSI), 2013. BS 8576:2013 Guidance on investigations for ground gas. Permanent gases and Volatile Organic Compounds (VOCs), British Standards Institution, Apr 2013. [Available at <https://knowledge.bsigroup.com/products/guidance-on-investigations-for-ground-gas-permanent-gases-and-volatile-organic-compounds-vocs?version=standard>]
 - BSI, 2020. BSI 10176:2020: Taking soil samples for determination of volatile organic compounds (VOCs), May 2020. [Available at <https://knowledge.bsigroup.com/products/taking-soil-samples-for-determination-of-volatile-organic-compounds-vocs-specification?version=standard>]
 - CIRIA, 2009. The VOC Handbook. Investigating, assessing and managing risk from inhalation of VOCs at land affected by contamination, C682, Nov 2009. [Available at https://www.ciria.org/CIRIA/CIRIA/Item_Detail.aspx?iProductCode=C682&Category=BOOK]
 - Environment Agency, 2015. Contaminated land exposure assessment (CLEA) tool. Handbook and software to help assess the risks of contaminated land exposure for human health, Sept 2015. [Available at <https://www.gov.uk/government/publications/contaminated-land-exposure-assessment-clea-tool>]
 - Environment Agency, 2009. Updated technical background to the CLEA model. Science Report : SC050021/SR3. [Available at <https://www.gov.uk/government/publications/updated-technical-background-to-the-clea-model>]
 - GSI Environmental. Risk Based Corrective Action (RBCA) Toolkit for chemical releases, v2.6. [Available at <https://www.gsienv.com/software/rbca-tool-kit/rbca-tool-kit-for-chemical-releases-version-2-6/>]
 - Johnson and Ettinger, 1991. User Guide for the Johnson and Ettinger Model for Subsurface Intrusion into Buildings. Updated version Johnson and Ettinger Model Spreadsheet Tool, Version 6.0. [Available at <https://www.epa.gov/vaporintrusion/epa-spreadsheet-modeling-subsurface-vapor-intrusion>]
 - Lahvis M., et al, 2013. Vapour intrusion screening at petroleum UST sites. Groundwater Monitoring & Remediation 33 (2):53-67. [Available at <https://ngwa.onlinelibrary.wiley.com/doi/full/10.1111/gwmr.12005>]
 - Parker, T., et al, 2017. Real-world uncertainties during a site assessment of vapour migration into a residential house from soil and groundwater, Quarterly Journal of Engineering Geology and Hydrogeology. [Available at <https://doi.org/10.1144/qjegh2016-129>]
 - SoBRA, 2017. Development of Generic Assessment Criteria for Assessing Vapour Risks to Human Health from Volatile Contaminants in Groundwater, Version 1.0, Society of Brownfield Risk Assessment (SoBRA), Feb 2017. [Available at <https://sobra.org.uk/resources/reports/>]
 - SoBRA, 2018. Vapour Intrusion to Support Sustainable Risk Based Decision Making, Society of Brownfield Risk Assessment (SoBRA), Summer Workshop, Jun 2017. [Available at <https://sobra.org.uk/resources/reports/>]
 - SoBRA, 2022. Guidance Notes for Assessment of Vapour Intrusion in Contaminated Land Scenarios in the UK, Society of Brownfield Risk Assessment (SoBRA), Sept 2022 [Available at <https://sobra.org.uk/resources/reports/>]
- 1A. Conceptual site model development for assessment of VI contaminant linkages in the UK
 - 1B. Benefits of soil vapour sampling for assessment of VI risks
 - 1C. VI data collection considerations

- US EPA, 2013. Evaluation of Empirical Data to Support Soil Vapour Intrusion Screening Criteria for Petroleum Hydrocarbons (EPA 510-R-13-001), United States Protection Environmental Protection Agency (US EPA), Jan 2013. [Available at https://www.epa.gov/sites/default/files/2014-09/documents/pvi_database_report.pdf]
- US EPA, 2015. Technical Guide for Assessing and Mitigating the Vapour Intrusion Pathway from Subsurface Vapour Sources to Indoor Air. OSWER Publication 9200-2-154, Office of Solid Waste and Emergency Response (OSWER) United States Environmental Protection Agency (US EPA), Jun 2015. [Available at <https://www.epa.gov/vaporintrusion/technical-guide-assessing-and-mitigating-vapor-intrusion-pathway-subsurface-vapor>]
- US EPA, 2017. Documentation for EPA's Implementation of the Johnson and Ettinger Model to Evaluate Site Specific Vapour Intrusion into Buildings. United States Environmental Protection Agency (US EPA) Office of Superfund Remediation and Technology Innovation. Version 6.0, Sept 2017. [Available at <https://www.epa.gov/vaporintrusion/epa-spreadsheet-modeling-subsurface-vapor-intrusion>]
- Wilson, S., 2008. Modular approach to analysing vapour migration into building in the UK. Land Contamination and Reclamation, 16 (3), 223-236. [Available at <https://www.eppublications.com/home/land-contamination-reclamation/>]
- Wilson, J.T., et al., 2014. Groundwater Issue Paper: An Approach that Uses the Concentration of Hydrocarbon Compounds in Soil Gas at the Source of Contamination to Evaluate the Potential for Intrusion of Petroleum Vapours into Buildings (PVI). US EPA Groundwater Issue, EPA/600/R-14/318, Dec 2014. [Available at <https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P100N87X.TXT>]