

SOCIETY OF BROWNFIELD RISK ASSESSMENT

**Vapour Intrusion –
Guidance Notes for Assessment in
Contaminated Land Scenarios in the UK**

Note 1B: Benefits of soil vapour sampling for assessment of vapour intrusion risks

Version 1.0

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PUBLICATION

This series of reports and tools is published by the Society of Brownfield Risk Assessment (SoBRA). It presents work undertaken by a SoBRA sub-group composed of volunteers listed in the acknowledgments below. This publication is part of a series of work packages designed to address various issues in data collection and evaluating risks associated with vapour intrusion.

The Society of Brownfield Risk Assessment (SoBRA) has produced a series of accessible and concise practitioners' guides to support informed decision making with respect to vapour intrusion (VI) risk assessment within the UK. In the context of these papers, "VI" is defined as:

"Vapour intrusion occurs when there is a migration of vapor-forming chemicals from any subsurface source into an overlying building" (US EPA).

These guides follow on from the publication of the SoBRA Groundwater Vapour Generic Assessment Criteria (GAC_{gwwap}) and from the recommendations of the SoBRA Summer 2017 workshop.

It is acknowledged that there is already an extensive portfolio of existing industry guidance available both within the UK and internationally in relation to VI risk assessment, nevertheless, these practitioners' guides aim to provide high level summaries of the existing guidance, covering key aspects of VI risk assessment and include signposting to the relevant published industry documents for more detailed information, where required.

The topics covered by the SoBRA practitioners' guides published so far comprise:

- 1A. Conceptual site model development for the assessment of VI contaminant linkages in the UK (this publication);
- 1B. Benefits of soil vapour sampling for assessment of VI risks; and
- 1C. VI data collection considerations.

This second document in the series considers the limitations in assessing VI risks from volatile organic compounds (VOCs) concentrations in soil and groundwater, in order to highlight when soil vapour phase sampling is beneficial.

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1. INTRODUCTION

This guidance document promotes the use of soil vapour sampling when assessing VI risk and highlights good practice. VI risk assessment is generally regarded as more reliable when based on the results of soil vapour sampling rather than relying solely on the results of soil and/or groundwater sampling. Soil vapour sampling is beneficial because:

1. It reduces uncertainty when modelling VI as it removes the uncertainty around the application of literature vapour phase partition coefficients when estimating soil and groundwater vapour phase partitioning;
2. It is therefore a more accurate estimation of potential VI risks that can, on occasion, reduce conservativeness and avoid unnecessary intervention and assist in providing the most sustainable response to the situation; and
3. It can identify VOCs (especially chlorinated hydrocarbons, CHCs) that may not otherwise be detected in soil and groundwater samples, therefore providing an important line of evidence such that a robust conceptual site model (CSM) can be built, in turn supporting robust risk-based decision making.

Currently however, the estimation of VI risks typically relies on the use of soil and groundwater sample data. Therefore, this paper presents the limitations inherent in that approach in order that practitioners can understand where it might be beneficial to undertake soil vapour sampling to improve the understanding of a potential VI risk.

Assessment of VI risks is a complex process. It is not the intention that this guide provides prescriptive rules or conclusions for that process, but instead, by way of a workflow and supporting notes, provides a road map to highlight detailed information for practitioners to consider in their assessments.

There are various limitations inherent in estimating VI risk from soil and groundwater data. This guide distils detailed information on those limitations into three broad topics, summarising these into a workflow, with a view to making the presented information as accessible as possible. The three topics comprise:

- Notes on sampling limitations;
- Notes on parameter uncertainty; and
- Notes on modelling limitations.

The objective of the workflow and explanatory notes is to provide concise information for practitioners to demonstrate why it might be beneficial to a VI risk assessment to undertake soil vapour sampling. The workflow is presented in Section 3 and the explanatory notes are presented in Tables 1 to 5.

The reader is strongly encouraged to read the source publications referenced herein for a more in-depth understanding of the subject matter.

Further guides in this series address conceptualisation, how best to undertake soil vapour sampling and how to evaluate the VI risks from the results of that sampling.

2. CONTAMINANT TYPES

The potential for vapour phase contamination should be identified by the CSM, informed by lines of evidence including (but not limited to); the historical uses of the site / surrounding area, ground conditions, groundwater conditions, soil and/or groundwater chemical test results etc. Because of the importance of developing a robust CSM, this is addressed in detail in a separate paper in this series. However, the CSMs specifically relating to potential VI risks upon which many of the considerations herein are based can be broadly summarised by Figures 1 and 2:

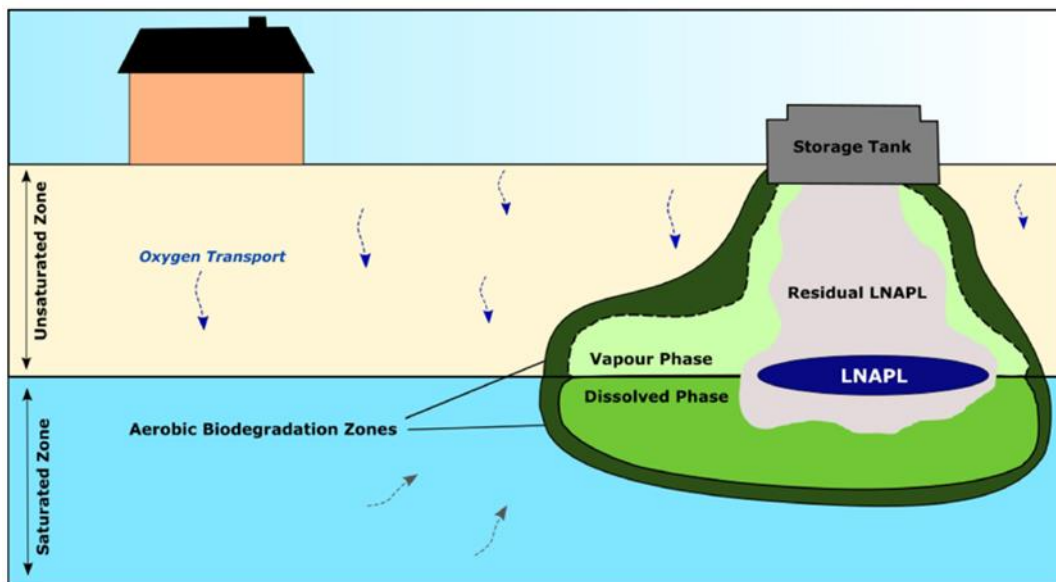


Figure 1: Example contaminant scenario for petroleum hydrocarbons (PHCs)

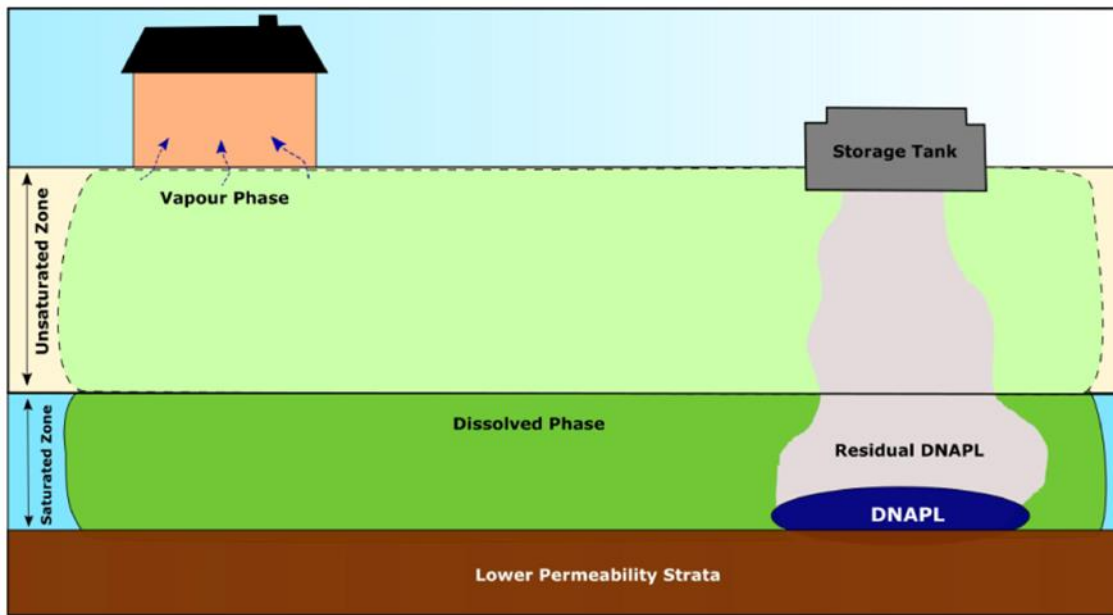


Figure 2: Example contaminant scenario for chlorinated hydrocarbons (CHCs)

The explanatory notes to the workflow in this document focus on two prevalent contaminant types, namely **chlorinated hydrocarbons (CHCs)** and **petroleum hydrocarbons (PHCs)**, which have been chosen to highlight key CSM considerations.

[Throughout the subsequent sections of this paper CHCs and PHCs are identified by the colours purple and orange to assist the reader]

These hydrocarbons display extremes of behaviours in sub-surface environments, primarily due to differences in their densities relative to water and due to significant differences in biodegradation rates in shallow aerobic soil environments. CHCs are typically Dense Non-Aqueous Phase Liquids (DNAPL), with low rates of aerobic degradation in both groundwater and the soil unsaturated zone, whereas PHCs are typically neutral to Light Non-Aqueous Phase Liquids (LNAPL), with dissolved-phase and vapour-phase aerobic biodegradation rates that may significantly limit VOC flux and the potential for VI risk (USEPA, 2012).

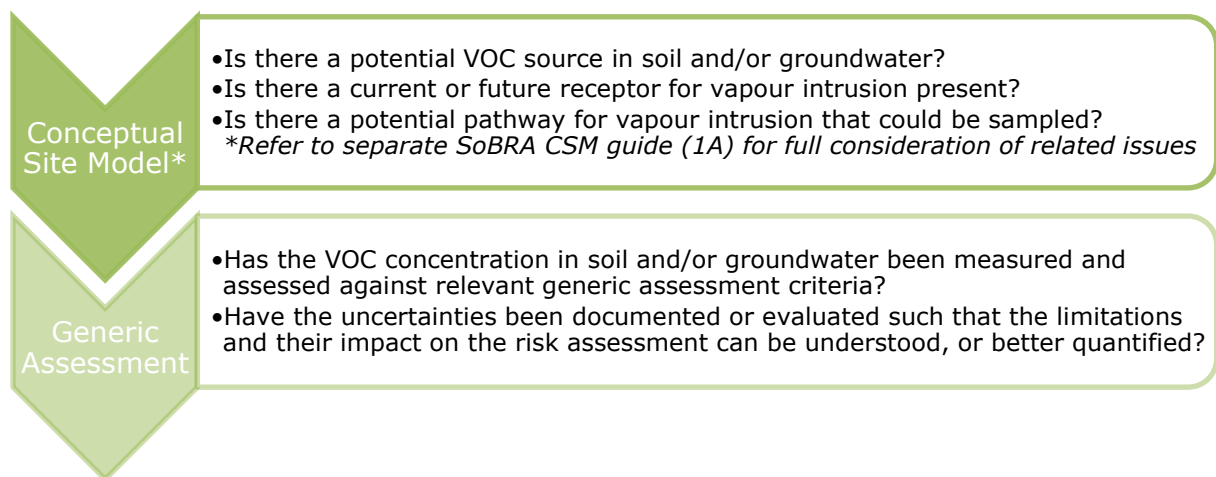
Figures 1 and 2 represent simplified, idealised situations, and it should be noted that more complicated conditions such as mixed or fractured bedrock geology and the potential for multiple VOC sources and co-dissolved plumes (NAPL and dissolved) are possible. Whilst volatile CHCs and PHCs are the focus of this paper, potential VI risks are not limited to these contaminant types.

There is different common terminology to represent the presence of VOCs in the soil vapour phase. The terms soil vapour and soil vapour-phase VOCs are used throughout this paper and are synonymous with other terms such as soil gas VOCs.

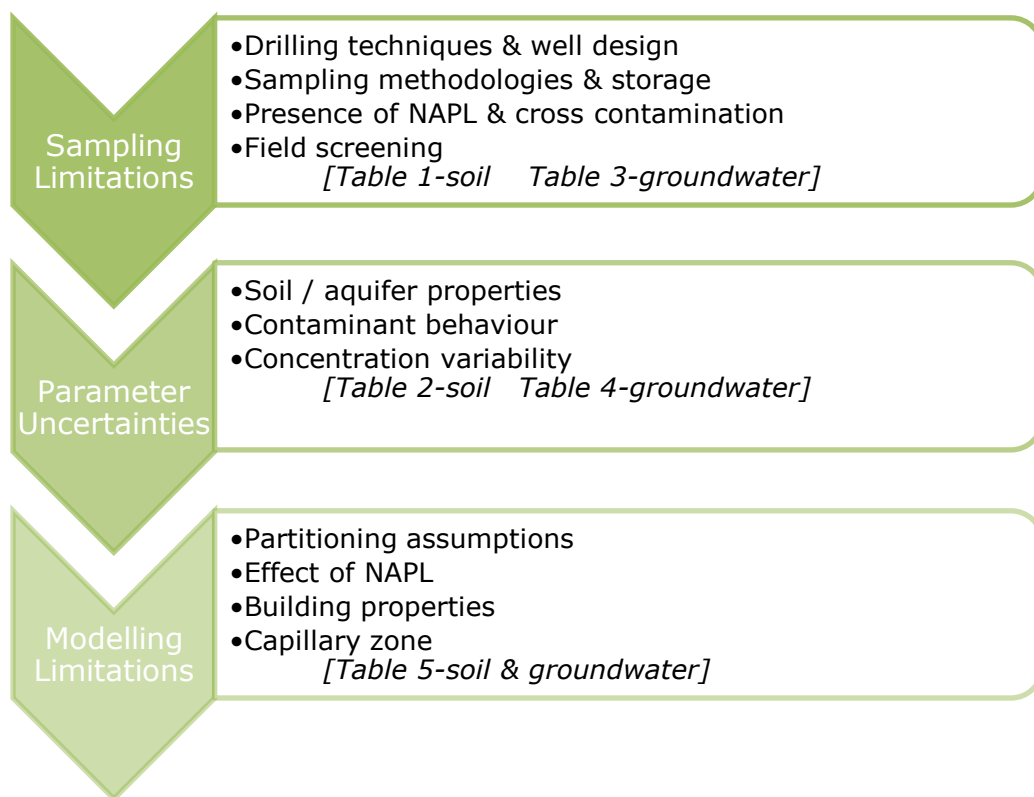
In the UK there is often a hierarchy of data collection for VI assessment (e.g. VOCs in soil and groundwater prior to undertaking direct soil vapour sampling) whilst in other jurisdictions the hierarchy is different. However, it should be noted that the detailed descriptions of uncertainty listed in the following workflows represent an amalgam of ideas and considerations and, whilst having potentially different contributions to overall uncertainty, are not listed in any order of importance. For each conceptual scenario all potential sources of uncertainty should be addressed.

3. WORKFLOW AND KEY CONSIDERATIONS

Assessment of VI risks is a complex process. This workflow and the supporting notes below provide a road map to highlight information for practitioners to consider in their assessments, rather than prescriptive rules or detailed conclusions for that process.



Identify if the generic (risk) assessment, as referred to above, is sufficient by considering the following potential limitations / uncertainties:



Where the CSM and/or generic assessment identifies a potential VI risk, and/or where the above uncertainties and limitations are considered too great:

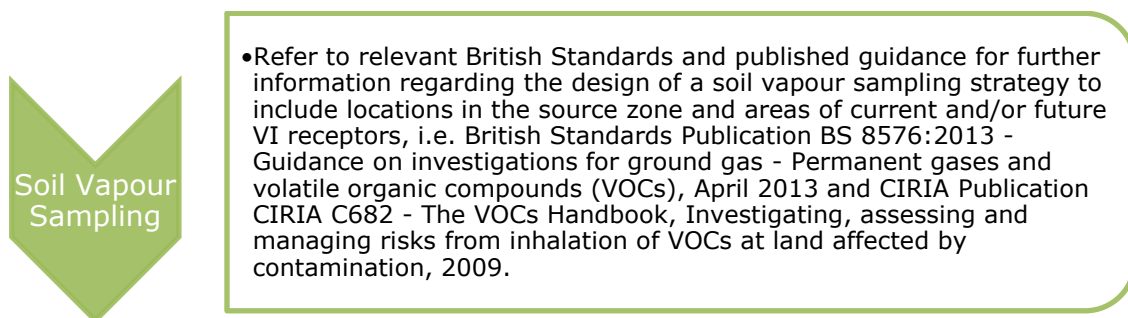


Table 1 – Key considerations regarding potential sampling limitations - Soil

Note: This is not intended to be an exhaustive list of limitations, and additional considerations may be relevant depending on the CSM and site-specific constraints.

Potential Sampling Limitations	Discussion
<p>Sampling methodology</p>	<p>There is potential for volatilisation losses of VOCs whilst sampling, transport and during laboratory analysis, resulting in inaccurate results. Follow relevant guidance including BS 10176:2020 (where soil types are appropriate) and adopt sampling methods which minimise loss of volatiles i.e. ensure no headspace remains when filling sample jars etc.</p> <p>Weather conditions (particularly high temperatures) during sampling can also cause volatilisation of VOCs whilst sampling.</p> <p>The collection of disturbed soil samples for VOCs analysis will usually underestimate the concentrations present due to volatilisation. Similarly, the use of a photo-ionisation detector (PID) to target sampling can also mean that VOCs have already been lost via volatilisation.</p> <p>There are some advantages to using field screening techniques such as membrane interface probes (MIPs) as these provide in-situ real time results. However, it should be noted that these results will require confirmation by physical sampling. Field screening techniques will differentiate between volatile PHCs and CHCs but will not provide details of specific compounds. Correlation with laboratory results may not be clear and will be qualitative only due to detection limits of equipment, samples not being obtained from same horizon (due to volume of sample) or inappropriate detector for the contaminants of potential concern (i.e. inappropriate bulb used in PID).</p> <p>Heterogeneity in soils can lead to uncertainties in level of impact and poor repeatability in results (CIRIA, 2009). Discrete soil samples may not be representative of the soil mass being evaluated. In this regard, the quality of site investigation and logging is particularly critical, for example sampling in a specific 'lens' of contamination may give different results depending on where it is taken in that lens and that may not be clear if associated logs are not sufficiently detailed – this links back to selection of appropriate sampling / drilling techniques.</p> <p>Cross contamination due to poor decontamination procedures adopted during the site investigation and sampling works may result in unrepresentative results.</p>

Potential Sampling Limitations	Discussion
Sample storage	<p>If holding time for samples is exceeded results may not be representative. Samples need to be kept cool during storage and transport to the laboratory, which should be done as quickly as possible.</p> <p>Preservation of the sample can lead to higher detection limits (methanol), up to 1 to 2 orders of magnitude (EPA, 2014).</p> <p>Note specific requirements for sample preservation, storage and transport as detailed in BS 10176:2020.</p>
Presence of NAPL / residual phase	<p>Presence of NAPL / residual phase needs to be confirmed in order to identify an appropriate CSM. NAPL/residual phase sampling should be undertaken if present. Risks during sampling may include insufficient NAPL to adequately fill sample jars and mixing of NAPL/residual phase and soil.</p> <p>If NAPL is present in groundwater, then the smear zone can affect soil concentrations.</p>
Site investigation methodology	<p>Action of site investigation – heat, vac-ex, air flush etc caused by the methods employed could alter concentrations if easily volatilisable.</p> <p>Risk of drilling water introducing VOCs into the sample matrix especially with recirculation or where NAPL is present.</p>
Poor correlation between sample and material remaining in-situ	<p>Correlation between collected disturbed sample and undisturbed material cannot adequately assess potential VI exposures for most VOCs in undisturbed soil or in soil remaining after excavation (EPA, 2014).</p>

Table 2 – Key considerations for potential parameter uncertainties - Soil

Note: This is not intended to be an exhaustive list of uncertainties, and additional considerations may be relevant depending on the CSM and site-specific constraints.

Potential Parameter Uncertainties	Discussion
Concentration variability in soils	<p>The degree of VOC concentration variability in soils may be great due to preferential partitioning of VOCs into organic rich horizons, collection on top or in the upper horizons of less permeable strata or may be present in the smear zone at the top of the groundwater table (CIRIA, 2009).</p>
Poor correlation of CHCs between soil data and soil vapour	<p>No clear correlation has been identified between the concentrations of CHCs in soil and soil vapour (better correlation identified between groundwater and soil vapour (CIRIA, 2009).</p>

Potential Parameter Uncertainties	Discussion
Change in contaminant composition during degradation and migration	Increasing concentrations of CHC compounds may be seen during migration of the vapour phase through the vadose zone through reductive de-chlorination. This is a particularly important consideration due to the toxicity of chlorinated solvent degradation daughter products, e.g. vinyl chloride.
Biodegradation & attenuation	Assessment of VI risk from identified concentrations of PHCs in deeper soils may be overly conservative where unsaturated zone vapour-phase biodegradation occurs. The level of attenuation between source and receptor is considerably lower for CHCs due to reduced potential for biodegradation or, in some cases, increase in concentrations of compounds during migration in the vadose zone (see above).
No consideration for potential lateral migration of soil vapour	Reliance on soil samples for potential VI risk does not allow for the possible presence of preferential vapour migration pathways. Vapours may migrate from other source areas along preferential pathways such as utility corridors (backfill material in utility corridors is often more porous and permeable than surrounding soils), more porous zones of soils / bedrock or beneath potential surface barriers such as areas of hardstanding. As such, the potential presence of soil vapours beneath a site may be missed by soil sampling alone.

Table 3 – Key considerations regarding potential sampling limitations – Groundwater

Note: This is not intended to be an exhaustive list of limitations, and additional considerations may be relevant depending on the CSM and site-specific constraints.

Potential Sampling Limitations	Discussion
Monitoring well design and installation	Groundwater monitoring wells need to be designed for the purpose of sampling VOCs in terms of the depth and length of screens. Multi-level sampling may be required to identify the vertical contamination profile. The CSM will require review in order to design the monitoring wells and identify potential source areas and receptors, particularly in fractured rock where NAPL is present for example. Borehole response zones should be suitable to allow entry of LNAPL and/or DNAPL taking account of possible groundwater level fluctuation and observed ground conditions. Response zones should also be designed to meet CSM data objectives (e.g. targeted groundwater horizon and avoiding cross installation). Long response zones are generally not preferred for groundwater sampling, however specific horizons may be targeted using low flow sampling methods.

Potential Sampling Limitations	Discussion
<p>Sampling methodology - dissolved phase</p>	<p>Follow relevant guidance including BS ISO 5667-11:2009 and adopt sampling methods which minimise disruption during purging and agitation during sampling are preferred, e.g. low flow purge and sample methods rather than bailer sampling.</p> <p>Weather conditions (particularly high temperatures) during sampling can also cause volatilisation of VOCs whilst sampling.</p> <p>Use of bailers and high flow pumping methods can cause any NAPL present to mix with the water column resulting in inaccurate data. In low yield wells, complete dewatering can cause aeration and volatilisation of VOCs. The use of bailers can also cause aeration and loss of vapours and they are not recommended for VOCs sampling.</p> <p>Low flow sampling is preferable for VOCs as it extracts groundwater at a rate comparable to ambient groundwater flow, so drawdown is minimised and also allows monitoring from a designated depth in the water column. Low flow sampling of VOCs using a peristaltic pump is acceptable for groundwater heads of up to 7 to 7.5 m. Sampling at greater head depths may lose significant VOCs and a bladder pump or static sampling is recommended. Low flow sampling is not recommended in wells with long screen sections unless samples are taken at discrete depths in the water column to identify vertical variations and will not work in low yield wells.</p> <p>Practitioners must design the sampling strategy to reflect the potential VOC source on a site-specific basis. For example, where PHCs are anticipated samples will typically be collected toward the top of the water column. Conversely, where CHCs are anticipated samples will typically be collected toward the base of the well.</p> <p>Passive sampling (diffuse sampler or hydrosleeve) is good for sampling VOCs as it requires no purging and there is no purged water to dispose of. Use in long screened wells is not recommended (USEPA, 2012).</p> <p>There is the potential for volatilisation of VOCs whilst filling sample jars resulting in inaccurate results. It is essential to ensure no headspace when filling sample jars.</p>
<p>The presence of NAPL and residual NAPL</p>	<p>The presence of NAPL in groundwater needs to be confirmed in order to provide key information into a VI CSM. Sampling of groundwater using bailers or high flow meters is not appropriate if NAPL is present as NAPL may become entrained in the groundwater sample resulting in exaggerated dissolved-phase concentrations of VOC.</p>

Potential Sampling Limitations	Discussion
The presence of NAPL and residual NAPL (contd.)	<p>Often, groundwater is not sampled when NAPL is present, however, a VOC dissolved-phase concentration profile in groundwater may be useful to measure to inform the VI CSM.</p> <p>For example, with DNAPL the dissolved-phase concentration at the top of the water table is most important for VI assessment, whereas for LNAPL the presence of free- or residual- phase is important as well as potential presence in the capillary/smear zone.</p> <p>Low flow groundwater sampling should be undertaken, with care given to the potential loss of VOC sampled from deeper groundwater using peristaltic pumps (in such cases down-hole bladder pumps should be considered).</p> <p>By definition, residual NAPL will not flow into borehole response zones, and so its presence may be missed during borehole monitoring and groundwater sampling. See also Table 1.</p> <p>NAPL sampling and analysis should be undertaken if present and should occur before borehole purging. Concentrations of VOC measured in groundwater should be compared with appropriate solubility limits.</p>
Sample storage	<p>If holding time for samples is exceeded, then results may not be representative. Samples need to be kept cool during storage and transport to the laboratory.</p>
Presence of VOCs in unsaturated zone	<p>Groundwater sample results will give an indication of concentrations of VOCs present in the dissolved phase, however, if there is also a source within the unsaturated soils at the site, assessing soil vapour concentrations from groundwater results in isolation may not provide realistic results.</p>

Table 4 – Key considerations for potential parameter uncertainties – Groundwater

Note: This is not intended to be an exhaustive list of uncertainties, and additional considerations may be relevant depending on the CSM and site-specific constraints.

Potential Parameter Uncertainties	Discussion
<p>Vertical contamination gradient in groundwater</p>	<p>Due to the process of volatilisation at the groundwater/ vadose zone boundary, the concentrations of VOCs in groundwater can vary with depth. Lower concentrations may be present at the top of the water column with an increase in concentrations with depth. When a vertical concentration gradient is present in groundwater near the soil vapour interface, then vertical diffusion and dispersion through groundwater may control the migration of VOCs from deeper groundwater to soil vapour (McHugh et al., 2009).</p> <p>Use of deeper groundwater VOC data to assess VI risk may therefore be overly conservative, particularly where DNAPL is present and contained within groundwater samples.</p> <p>The uppermost horizon of groundwater is key for sampling for PHC and is the best indicator (in the absence of LNAPL or residual NAPL) for vapour-phase PHC (i.e. boundary conditions). Sampling at depth may underestimate PHC concentrations and therefore VI potential. Consider the potential for a PHC depth-concentration profile in groundwater.</p>
<p>Presence of freshwater lens</p>	<p>If infiltration downgradient of a VOC contaminant plume is sufficient, it can form an uncontaminated layer of water above the contaminated groundwater, significantly reducing the ability of VOCs to partition into the soil vapour phase. Where infiltration rates are high relative to the magnitude of seasonal water table fluctuations, a sustainable freshwater lens can develop which can be an effective barrier to off-gassing of VOCs from groundwater to the vadose zone (McAlary et al., 2004 as cited in McHugh et al., 2009).</p>
<p>Falling groundwater table</p>	<p>If the groundwater table falls, contaminated water is trapped by capillary forces in the vadose zone. When this happens the partitioning of VOCs from groundwater to soil vapour will increase as water is replaced by air in larger pore spaces. The water saturation of well-drained soils is 20% to 80%, depending on soil type (McHugh et al., 2009).</p>

Potential Parameter Uncertainties	Discussion
<p>Unsaturated zone biodegradation</p>	<p>Assessment of VI risk from identified concentrations of PHCs (as opposed to CHCs) in groundwater may be overly conservative where unsaturated zone vapour-phase biodegradation occurs.</p> <p>Biodegradation of VOCs can occur in the shallow (typically <1 m) unsaturated zone where atmospheric oxygen is introduced by diffusion and by pressure-driven flow, resulting in an inverse depth-concentration profile relationship between PHCs and oxygen. The depth profile of PHCs and oxygen may need to be measured in order to show that vapour-phase biodegradation is occurring and to what degree (note, this may be complicated by soil/sorbed-phased sources of PHCs).</p> <p>In aerobic conditions the vapour-phase biodegradation of PHCs is often sufficient to mitigate VI risk. Therefore, an assessment of VI potential using groundwater data alone may significantly overestimate VI.</p> <p>Biodegradation further reducing the concentration and flux of PHCs by four orders of magnitude is not atypical.</p> <p>Biodegradation rates depend on PHC type and concentration/fluxes and on oxygen flux. Biodegradation rates are typically rapid with sufficient oxygen flux but are commonly slow where LNAPL PHC is present and oxygen flux is insufficient to maintain high biodegradation rates. Where oxygen flux is limited (such as in clay soils or beneath hardstanding/buildings), conditions can potentially become anoxic with lower rates of PHC biodegradation.</p> <p>When considering biodegradation rates, and the impact of this on PHC risk, it is important that practitioners consider any changes which may alter the CSM, e.g. site redevelopment. This is particularly key where large span buildings may limit biodegradation due to the inhibited downward diffusion of oxygen. It is also an important consideration when using data collected from open (non-hard surfaced) sites, which are to be subsequently developed. Site redevelopment may also cause preferential pathways to be created, and hence the importance of a robust CSM is critical.</p> <p>CHCs typically biodegrade much more slowly than PHC and often incompletely (e.g. PCE biodegradation to TCE, DCE and vinyl chloride), and principally in anaerobic environments. For some CHCs, such as vinyl chloride, aerobic degradation may be sufficient to limit VI risks). Slow biodegradation (combined with high toxicity) is the principal reason for typically higher VI risk with CHCs vs PHC.</p>

Table 5 – Key considerations regarding potential modelling limitations – Soil and groundwater

Note: This is not intended to be an exhaustive list of limitations, and additional considerations may be relevant depending on the CSM and site-specific constraints.

Potential Modelling Limitations	Discussion
<p>Specific information required for modelling</p>	<p>As per any soil and groundwater investigation, the design and collection of appropriate data should be considered at the initial stages of the project during preliminary risk assessments and site investigation design. Beyond reliable and representative source data, key information required for modelling includes (but is not limited to):</p> <ul style="list-style-type: none"> • Atmospheric and weather conditions at the surface in the days leading up to the modelling (potentially including ambient air concentrations and / or background air concentrations); • Sufficient groundwater level data including seasonal fluctuations; • Groundwater flow direction; • Properties of the unsaturated zone including bulk density, moisture content, soil organic matter, structural geology and particle size distribution; • Low flow in situ groundwater parameters, including pH, temperature, oxygen, carbon dioxide, methane, REDOX • Unsaturated zone parameters (including oxygen levels) • Source location, plume area and depth profile; • Presence of NAPL / residual NAPL; and • Details of the building's foundation construction and internal construction/height (if present) including preferential pathways.
<p>Behaviour of soil vapour in the vadose zone</p>	<p>The models will predict the concentrations in soil vapour directly above the soil or groundwater source based on simple partitioning relationships and equilibrium conditions. Three-phase partitioning (sorbed, dissolved and vapour (four phases where NAPL is present) is complex, difficult to predict with accuracy and may be disturbed by the process of investigation itself. Partitioning calculations do not take account of potential unsaturated zone biodegradation and so the prediction of vapour phase concentrations from soil / groundwater data is often over-estimated, particularly for PHC. For these reasons conclusions for significant VI risk based on soil and/or groundwater VOC data alone should not be made without detailed knowledge of the VI CSM.</p> <p>Whether soil vapour data are measured directly or modelled (from soil / groundwater data) and understanding of the temporal and spatial variation, as well as migration and degradation mechanisms in the unsaturated zone and mechanisms for intrusion into buildings is required to inform a detailed VI CSM.</p>

Potential Modelling Limitations	Discussion
<p>Capillary fringe</p>	<p>CLEA does not specifically model VOC in groundwater but takes account of partitioning to soil pore water, which can be used as an approximation for dissolved-phase concentrations in groundwater (e.g. SoBRA GAC_{gwwap}). The flux of VOC from groundwater to the soil vapour phase requires migration via the capillary (semi-saturated) soil zone, which is not taken into account in CLEA and caution is therefore advised.</p> <p>Based on individual chemical properties, diffusion of VOCs through water is approximately 1000 - 10,000 times slower than in air.</p> <p>Soil moisture content is therefore a critical parameter for vapour-phase migration from groundwater, i.e. through the capillary zone ranging in moisture content from saturation to field soil capacity.</p> <p>Assessment of VI from groundwater without considering a capillary zone is therefore conservative (e.g. SoBRA GAC_{gwwap}).</p> <p>Capillary zone effects on VI will be greater for fine soils (cf coarse soils) due to a larger capillary zone (e.g. 0.25 m for sand cf 0.4 m for sandy loam) and higher volumetric water content (calculated at 0.35 for sand cf 0.42 for sandy loam).</p>
<p>Partitioning</p>	<p>Commonly used models assume that the partitioning reaches chemical equilibrium and do not take account of NAPL.</p> <p>Partitioning calculations assume that the chemical concentrations and soil properties are homogenous across the site. This is often not the case in reality.</p> <p>The CLEA model, used to derive soil assessment criteria, uses Henry's Law constant to model partitioning into the soil vapour phase.</p> <p>Field data (McHugh et al., 2009) indicates that equilibrium partitioning based on Henry's law is a poor predictor of the relationship between VOC concentrations measured in groundwater and deep soil vapour. This paper includes results of a study on a site contaminated by TCE in groundwater in New York where measured soil vapour concentrations were less than those predicted using groundwater data by more than 80%.</p> <p>Using Henry's constant to predict vapour phase PHC concentrations from groundwater data may overestimate by 10 to 1,000 times, most likely a function of non-equilibrium and non-ideal conditions in the field compared with the laboratory.</p>

Potential Modelling Limitations	Discussion
Partitioning (contd.)	<p>Further differences in measured vs predicted can be caused by potentially rapid vapour-phase biodegradation as previously discussed (Table 4).</p> <p>This section highlights the importance of over-reliance on VOC source measurements for the assessment of VI that rely on partitioning calculations to estimate the soil vapour phase concentrations, which may contribute to significant over-conservatism. One clear example of this would be to conclude a positive VI based on analysis of PHE in soil (also recognising the potential for VOC loss during sampling) and groundwater without undertaking direct vapour-phase VOC measurements.</p>
Consistent Strata	<p>Models assume consistent strata properties through the depth of the vadose zone which may result in an under or overestimate of vapour concentrations.</p>
Groundwater Variation	<p>Models do not generally account for variations in groundwater level, however, the potential implications of groundwater level variation on model results can be assessed via sensitivity analysis.</p>
Vapour Phase Biodegradation	<p>Most models do not account for vapour-phase biodegradation in the unsaturated zone, which may reduce the potential for significant VI (e.g. for PHCs but not for CHCs).</p>

4. CONCLUSIONS

In conclusion, soil vapour sampling is considered beneficial because:

1. It reduces uncertainty when modelling VI as it removes the uncertainty around the application of literature vapour phase partition coefficients when estimating soil and groundwater vapour phase partitioning;
2. It is therefore a more accurate estimation of potential VI risks that can, on occasion, reduce conservativeness and avoid unnecessary (and potentially costly) intervention and assist in providing the most sustainable response to the situation; and
3. It can identify VOCs (especially CHCs) that may not otherwise be detected in soil and groundwater samples, therefore providing an important line of evidence such that a robust CSM can be developed, in turn supporting robust risk-based decision making.

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6. GLOSSARY

Acronyms	Description
ASTDR	Agency for Toxic Substances and Disease Registry
BS	British Standard
CHCs	Chlorinated hydrocarbons
CIRIA	Construction Industry Research and Information Association
CLEA	Contaminated land exposure assessment
CSM	Conceptual site model
DCE	Dichloroethene
DNAPL	Dense non-aqueous phase liquids
GAC	Generic assessment criteria
LNAPL	Light non-aqueous phase liquids
MIP	Membrane interface probe
NAPL	Non-aqueous phase liquids
PCE	Perchloroethene or tetrachloroethene
PHCs	Petroleum hydrocarbons
PID	Photo-ionisation detector
REDOX	Reduction and oxidation
SoBRA	Society of Brownfield Risk Assessment
TCE	Trichloroethene
USEPA	United States Environmental Protection Agency
VI	Vapour intrusion
VOCs	Volatile organic compounds

LIMITATIONS

This publication has been developed by members of the SoBRA VI sub-group acting in a voluntary capacity, and details the views of the individual members, not those of their employers. It is provided freely on the SoBRA website to help promote discussion on what should constitute good practice in assessing the potential health risks associated with vapour intrusion into buildings in the UK. Users of the paper must satisfy themselves that the content is appropriate for the intended use and no guarantee of suitability is made.

FEEDBACK

Feedback on this publication is welcomed and should be submitted to SoBRA at info@sobra.org.uk.