Issue 12 2013

Remediation Australasia

OUT WITH THE OLD

A new way of measuring soil vapour

SOIL VAPOUR INTRUSION IN HOMES

Case study

ALSO: LANDFILL MINING PART 2

Recovering materials and energy

VAPOUR INTRUSION SPECIAL ISSUE

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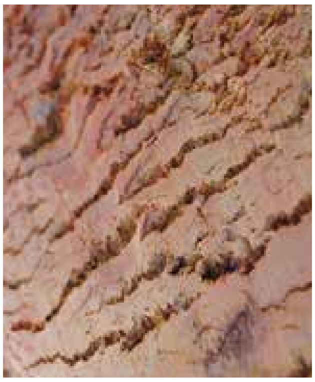

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editor's note

Welcome to Issue 12 of *Remediation Australasia*.

First, I'd like to wish you all a happy new year. I hope that things are off to an excellent start and that you're set for a productive, safe and enjoyable 2013.

The remediation sector is in for a very interesting year ahead. There are indications that contamination issues are gaining traction with political leaders. One promising sign is the appointment by Prime Minister Julia Gillard of Major General Michael Jeffery, former Governor General, as Australia's Advocate for Soil Health. In this role he will raise public awareness of the critical role soil plays in underpinning agricultural productivity, delivering high quality ecosystem services. This move shows leadership regarding Australian soils, which are generally old, leached and low in organic matter, and littered nationwide with contamination problems.

Also in 2013, work is continuing on both a petroleum vapour intrusion guidance document and the CRC CARE-led development of a national remediation framework.

Once finalised, the latter will complement the National Environment Protection (Assessment of Site Contamination) Measure, further strengthening the architecture of Australia's contaminated-site policy and regulation.

This issue of *Remediation Australasia* is the second of our themed editions, following last October's landfill special. In Issue 12, we shift our focus to the vexed subject of vapour intrusion (VI) and the myriad questions it raises. What is the best way to measure it? How accurate are the various methods of measurement? Are VI assessment guidelines too conservative?

Volatile organic compounds (VOCs), for example, are front and centre when it comes to VI issues. Of the millions of contaminated sites worldwide, two-thirds contain VOCs, which present a major risk to human health when they enter buildings where people live and work. *Remediation Australasia* investigates the need for reliable technologies that not only measure the presence of volatiles, but also identify what organic contaminants constitute the VOCs that may be present.

We also have VI case studies, along with our regular columns and the second article in our series on landfill mining (see issue 11 for the first instalment).

As always, please contact us via aric@crccare.com if you have any feedback or would like to contribute. We would love to hear from you.

Prof Ravi Naidu
Managing Director, CRC CARE
Editor, *Remediation Australasia*

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Cover photo: Using a glass syringe to take a soil gas sample for vapour intrusion assessment (See feature on pages 28-33). *Photo courtesy of Dr Blayne Hartman.*

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reMEDIAtion

Your guide to environmental contamination and remediation issues in the media

Brooklyn Bridge over troubled water: New York after Hurricane Sandy

She only took a day to blow through, but October's Hurricane Sandy has left a clean-up for the citizens of New York which is destined to take much longer.

Many canals and waterways broke their banks, including the Gowanus Canal, with the legacy of over a century of sewerage and industrial waste spilling onto the streets and into people's homes. Reported by the *New York Times* (nyti.ms/VRBBhc) to be on the USEPAs hit list as one of the most contaminated waters in the USA, the Gowanus Canal poses a difficult prospect for remediators.

Although the waters have now receded, the issues have not. In addition contaminants moving from water to land, the stormwater also aided the passage of land-based environmental contaminants into water supplies, an issue outlined by *Discovery News* (bit.ly/SHOgPg). According to the *Wall Street Journal* on.wsj.com/Rw67Yc) up to 45 of New York State's most hazardous toxic waste storage sites were within the storm surges and therefore pose a health risk. ■

Onion remediation

Phytoremediation using onion and garlic waste could provide a delicious new way to approach environmental contamination. A group in India have demonstrated that by-products of these members of the *Allium* genus are able to remove several heavy metals and metalloids, including arsenic, cadmium, iron, lead, mercury and tin. Optimised conditions for the remediation reactions have been published in the *International Journal of Environment and Pollution*. The process could prove viable for large-scale industrial decontamination projects.

Read more at *Asian Scientist* bit.ly/UAAYkA or *Science Daily* bit.ly/TSOYd2. ■

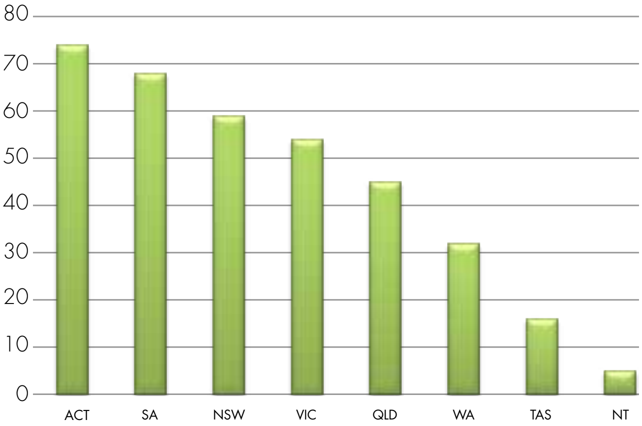
Queensland waste

Other Australian states are sending up to 165 tonnes of toxic waste per week to landfill in QLD reports the *Herald Sun* (bit.ly/WHFi7L), though industry sources estimate that the true figure could be much higher. Lead, arsenic, asbestos effluent, glues, resins and industrial oils are just some of the substances being transported. The need to transport these materials is due in part to the lack of suitable processing infrastructure in the other states.

NSW is credited with being the largest contributor to this mass influx, with some of the waste believed to be mined from landfill sites, taking advantage of the NSW waste levy rebate. The *Business Environment Network (BEN)* reports that the Waste Contractors and Recyclers Association is concerned that the disparity in regulation between NSW and QLD is leading to confusion and, potentially, the development of large-scale waste-transport facilities to move more waste into QLD landfills (bit.ly/X6od3G). ■

ACT winning the recycling race

The Department of Sustainability, Environment, Water, Population and Communities (DSEWPaC) recently released the *Waste and recycling in Australia 2011* report, prepared by Hyder Consulting. The report, which can be downloaded at bit.ly/WlhXxY, finds that waste generated in Australia continued to grow between 2006-07 and 2008-09, with per-capita waste generation of 2140 kg in 2008-09. On average, just over half of this (1090 kg, or 51%) was recycled, with the ACT the nation's clear leaders in this field. ■



Zero Waste SA zeroed

The state government of SA announced a number of cuts in the recent 2012-13 mid-year budget review, with Zero Waste SA at the receiving end of one of the blows. *The Advertiser* reports that the abolition of Zero Waste SA – to take full effect in the 2014-15 financial year – will save the government up to $8 million annually.

BEN reports that a nongovernment organisation is being proposed to continue the work of Zero Waste SA, with funding of $1 million per year (bit.ly/14RbB64). According to *Adelaide Now*, the redirection of the funds is being questioned by local government officials who are concerned that the taxes being paid by residents under their rates for recycling should be directed to the appropriate activities (bit.ly/Z8XglV). ■

Household asbestos risk

Home owners and electricians have been advised to wear masks and protective equipment while working on meter boards, reports the *Sydney Morning Herald* (bit.ly/TLhhwn). These precautions were advised after a number of houses built before 1988 – of which there are up to 2 million in the greater Sydney area – had asbestos disturbed during electrical work and solar panel installations. After Endeavour Energy issued a hazard warning to staff, the Electrical Trades Union banned its members from working on or near any of the potentially hazardous meter boards. Endeavour Energy subsequently commissioned asbestos assessor Noel Arnold and Associates to conduct air-monitoring tests. According to the accompanying report, available at bit.ly/V9diuV, the tests did not detect airborne asbestos fibres in air samples collected when opening pre-1988 electricity meter boxes. ■

news in brief

Bunny trees

Scientists have combined DNA from rabbits with that of the poplar tree, reports online news service *AZoCleantech.com* (bit.ly/13mgHav). Rather than creating some sort of giant tree bunny, marrying a rabbit gene that breaks down pollutants with the poplar DNA may result in a new form of phytoremediation. Early tests suggest that the transgenic tree could absorb more than 90% of trichloroethylene from contaminated water.

New chair for EPA SA

Mia Handshin, previously a candidate for the Australian Labor Party, has been appointed as chair of the South Australian Environmental Protection Agency. Ms Handshin told *Adelaide Now* that she is confident that with the strong regulatory frameworks already in place in SA she can direct the state to a positive future, including her main concern of reducing the use of non-renewable fossil fuels (bit.ly/12v3c53).

Port Stanvac demolition

After being decommissioned nearly a decade ago, the ExxonMobil oil refinery site at Port Stanvac, south of Adelaide, is being demolished. *Adelaide Now* reports that, although the site is not believed to be heavily contaminated, Mobil's representatives have acknowledged that following more than 40 years of industrial use, some remediation will be required. Site assessment is being overseen by the SA EPA to ensure that the remediation works are satisfactory (bit.ly/V2a7kj).

Australia's first advocate for soils

Erosion, salinity and productivity are just three of the soil problems that Major General Michael Jeffery – Australia's first official advocate for soils – is hoping to address. As a passionate campaigner for the importance of soil health, the former Australian defence chief and ex-governor general was appointed by Prime Minister Julia Gillard in October.

New landfill guidelines issued by EPA Victoria

Recent changes in the understanding of the risks associated with long-term landfill storage have prompted EPA Victoria to release new guidelines for licence holders and auditors who assess and manage landfill sites. A *BEN* report (bit.ly/VeAdCP) says the document outlines steps to be taken in landfill remediation projects and also notifies of changes to Post-Closure Pollution Abatement Notices to reflect the changes in the guidelines. The full document can be downloaded from the EPA Victoria website (www.epa.vic.gov.au/~/media/Publications/1490.pdf). See pages 38-41 of this issue of *Remediation Australasia* for part two of our look at landfill mining.

Greens call for Gladstone inquiry

Dredging Today reports that, following the release of a United Nations Educational, Scientific and Cultural Organization (UNESCO) report into contamination concerns in the Gladstone region of the Great Barrier Reef, the Australian Greens have called for an independent inquiry. Concerned about the risk of both destruction of the reef and loss of World Heritage status, the Greens believe that the state and federal governments are not doing enough to prevent damage from mining (bit.ly/Y7Fx7M).

Contaminated mine sites rife in NSW

An audit conducted by NSW Auditor-General Peter Achterstraat has revealed that more than 500 contaminated mine sites are present across NSW, the *Newcastle Herald* reports (bit.ly/VTk6rv). Twenty-seven sites were remediated in 2011-12 at a cost of $2.1 million. A new industry levy, which is expected to raise over $13 million, will be partially used to fund clean-up work.

Vapour intrusion into buildings: some things we know and some things we need to know

Dr Greg Davis, CSIRO Land and Water, Perth, Western Australia

What's the issue?

Organic chemicals that volatilise and move through soils can migrate into indoor air space and present a threat to people working or living in affected buildings. Potentially hazardous organic chemicals include petroleum hydrocarbons (e.g. gasoline, diesel, crude oil), industrial solvents and plastics precursors (e.g. trichloroethene, dichloroethane, vinyl chloride, tribromoethene, methylethylketone), and some pesticides. There is increasing interest in better understanding such chemicals' vapour behaviour and better defining regulatory criteria and guidelines related to vapour risks.

In the process of vapour intrusion, organic vapours migrate from groundwater or below-ground soil through to the ground surface and subsequently into buildings. Although simple in concept, the pathway of movement, and its assessment, is uncertain and complex. In many cases vapours may fail to reach the interior of buildings and hence pose no risk.

Complexities include: soil variability; uncertain migration pathways through a building foundation to indoor air; variability of the built environment; the size, shape and strength of the vapour source; and, across the vapour types, the different transport and attenuation behaviours. Such uncertainty and complexity requires caution when regulating sites where organic vapours may migrate into buildings. This is especially the case for sites set to undergo redevelopment, which may change surface conditions and, hence, potential exposures. Uncertainties necessarily lead to conservative regulatory guidelines and increased clean-up costs.

Recently, new knowledge has provided greater confidence and reduced uncertainty. Science-based outcomes and policy have been developed for vapour management at affected sites. Several reports published by CSIRO and the Cooperative Research Centre for Contamination Assessment and Remediation of the Environment (CRC CARE) have summarised knowledge and practice[1,2,3] and, to assist with management of contaminated sites, health screening levels have been proposed based on outcomes of the research[4]. These and suggested techniques for measurement of vapour distributions at affected sites have been incorporated into the draft variation of the National Environment Protection (Assessment of Site Contamination) Measure.

What do we know?

We understand that the depth of the vapour source below a building and its strength (maximum vapour concentration of the source) significantly affect the magnitude of the vapour concentration that moves upwards towards the base of a building foundation. These are the primary determinants of vapour migration into a building: the deeper a vapour source is below a built structure, or the lower its concentration, the less likely it is that the vapour will migrate to shallow depths and move into the building.

Modelling and field investigations have confirmed that the risk of vapours migrating into a building is significantly diminished the greater the distance a building is away from a source of vapours. This is critical to establishment of exclusion distances, whereby beyond a certain distance negligible (or no) exposure would occur.

Additionally, we know that not all vapours behave the same – petroleum vapours readily biodegrade in environments where oxygen is present, such as where the ground surface is open to the atmosphere. However, many industrial solvents, such as trichloroethene, do not biodegrade under oxygenated conditions. This is critical in determining potential exposures, as early guidance assumed no degradability for any types of vapours. Another factor to consider when designing buildings is that the behaviour of vapours in open-ground conditions is different to that beneath a building – so the effects of building foundation size and shape are important[5].This is true for all types of vapours but especially for petroleum vapours.

We also have greater insight into other factors that can influence vapour risks, including soil moisture, temperature and pressure variations caused by, e.g. wind or barometric changes. For example, an increase in soil moisture after recent rainfall can reduce the rate at which vapours move through the soil.

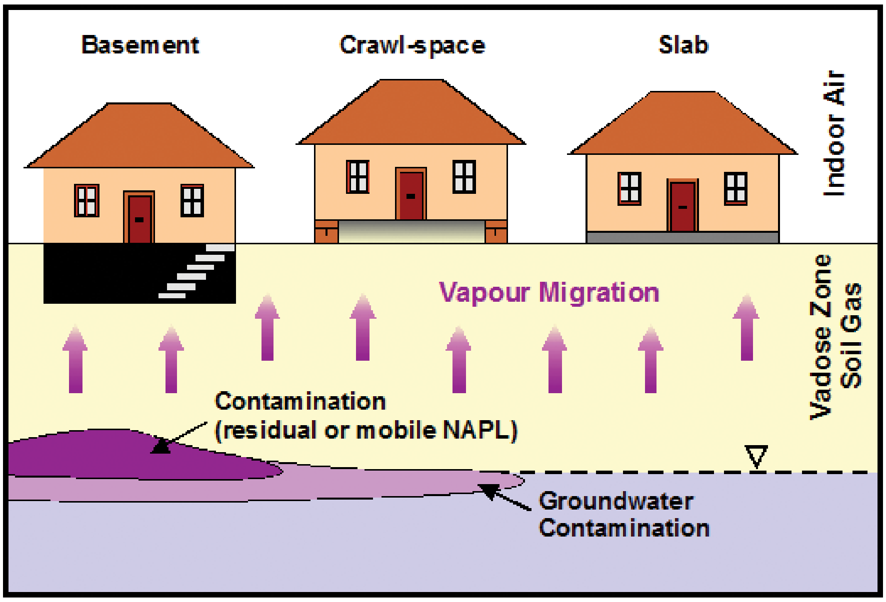


Figure 1. Potential vapour migration towards houses with different foundation types from vapour sources in groundwater or as residual or mobile non-aqueous phase liquid (NAPL).

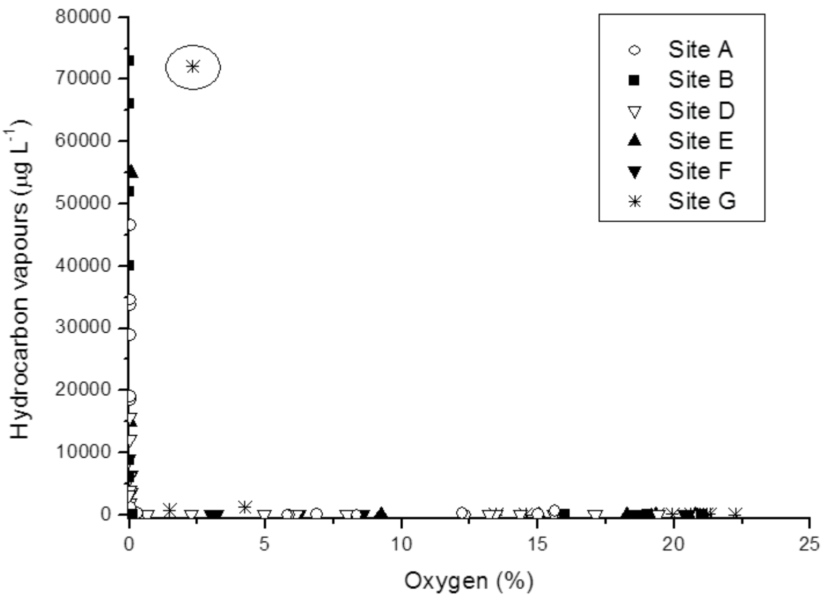
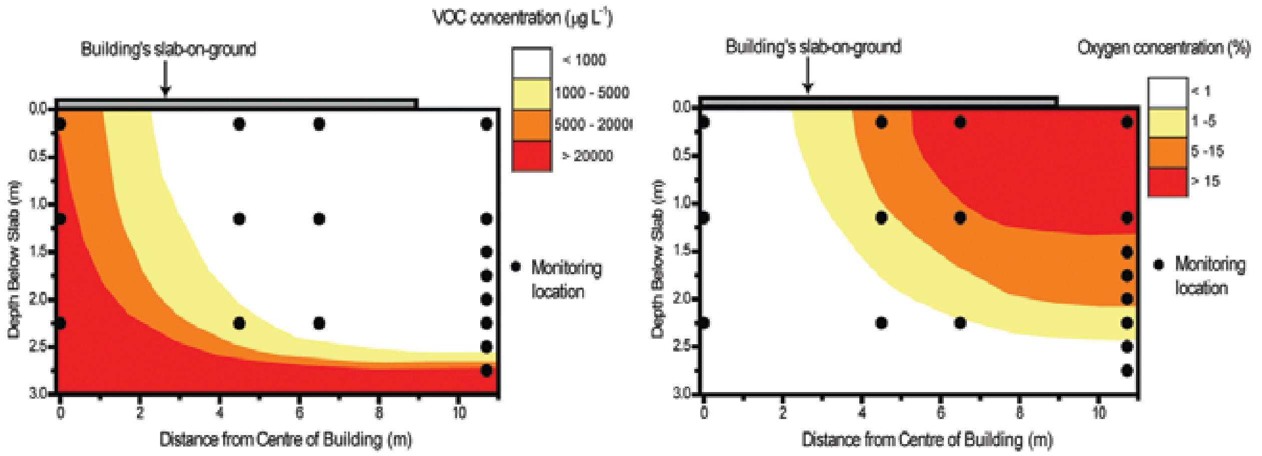


Figure 2. The presence of oxygen often stimulates biodegradation of hydrocarbons. This graph shows little oxygen at all sites where hydrocarbon vapours are observed, and low hydrocarbon vapour levels at all sites where oxygen is observed[3]. At one location (circled) it was found that significant pressure fluctuations generated overlapping concentrations of vapours and oxygen.

Figure 3. Vapours migrate vertically upwards from a source about 3 m below ground. Oxygen penetrates beneath the slab and induces aerobic biodegradation of vapours under the edge, but not at the centre, of the slab, where vapours come in contact with the slab's underside (Patterson and Davis 2009).



What don't we know (and what are we doing about it)?

Efforts are under way to further expand and consolidate US and Australian databases containing information on vapour concentrations and associated data from contaminated sites. This not only enables better conceptualisation of vapour migration, but also helps to establish relationships between such factors as soil, type of volatile contaminant and type of built environment. A better understanding of these relationships will allow researchers to establish empirical correlations for potential vapour risks across a range of environments. Such databases are being used to differentiate vapour behaviours according to degradability, ground conditions (open or covered), and building type (slab on ground versus basement versus crawl space).

For petroleum-affected sites, there are current efforts supported by CRC CARE to document the steps required to determine if further action and investigation is warranted. This involves measuring such variables as the extent of the petroleum vapour source present at a site, what distance the source is from the building foundations, whether oxygen is present in the soil profile, and if the vapours biodegrade. The documentation is currently in draft form and includes recommended measurement and investigation techniques that might best determine these data.

To better quantify the potential for biodegradation of vapours, there is also further research to better define the migration of oxygen through surface soils and near building foundations. Because buildings cover part of the ground surface, they will inhibit oxygen from penetrating the ground surface naturally. However, buildings can also create pressure differentials that enhance the flow of air and allow more oxygen into the subsurface. Surplus oxygen can yield high levels of biodegradation, which in many cases may be sufficient to significantly reduce or eliminate vapour exposures and hence risk.

It is clear that much work remains in piecing together the complexities of vapour movement around and into buildings. Fortunately the research is moving quickly, and is yielding knowledge that will help ensure that the built environment is as safe for people as it can be.

FURTHER READING

1. Davis, GB, Trefry, MG & Patterson, BM 2004, Petroleum and solvent vapours: quantifying their behaviour, assessment and exposure. CSIRO Land and Water Report to the Western Australian Department of Environment.
2. Davis, GB, Wright, J & Patterson, BM 2009, Field assessment of vapours. CRC CARE Technical Report no. 13, CRC for Contamination Assessment and Remediation of the Environment, Adelaide, Australia, August 2009, 88 pp.
3. Davis, GB, Patterson, BM & Trefry, MG 2009, Evidence for instantaneous oxygen-limited biodegradation of petroleum hydrocarbon vapours in the subsurface. Ground Water Monitoring & Remediation 29(1), 126–137.
4. Friebel, E & Nadebaum, P 2011, Health screening levels for petroleum hydrocarbons in soil and groundwater. Part 1: Technical development document. CRC CARE Technical Report no. 10, CRC for Contamination Assessment and Remediation of the Environment, Adelaide, Australia, September 2011, 278 pp.
5. Patterson, BM & Davis, GB 2009, Quantification of vapour intrusion pathways into a slab-on-ground building under varying environmental conditions. Environmental Science and Technology 43(3), 650–656.

A WMS-LU passive sampler recovered from sub-slab sampling point and removed from protective gauze.
Photo courtesy of Adrian Heggie, Parsons Brinckerhoff

Out with the old

A new method for measuring soil vapour concentrations in vapour intrusion risk assessments

Adrian Heggie, Principal Scientist, Parsons Brinckerhoff Australia

With increasing awareness of the risks to human health of vapour intrusion, soil vapour sampling, is being used more and more to define vapour intrusion risks. Until now, this procedure has been expensive and relatively complex. Recently, development of new passive soil vapour samplers and validation of the method to quantify concentrations of analytes in soil vapour have overcome these drawbacks.

Passive sampling, or to give it its more technically descriptive title, passive diffusion-absorptive sampling, has been used for decades in occupational hygiene monitoring to quantify air concentrations for a wide range of organic and inorganic compounds. More recently passive sampling has been applied to ambient air monitoring, particularly to measure indoor air concentrations and to define spatial variations, such as in the validation of air dispersion models, and indeed in vapour intrusion investigations. For reasons explained in this article, the contaminated land industry has been slow to adapt passive samplers to provide quantitative measurements of soil vapour concentrations for human health risk assessment. However, following an appreciation of the principles of passive-diffusive absorption sampling, in the last year or so in Australia passive sampling has been recognised as a legitimate method to quantify soil vapour concentrations within the soil profile.

Perhaps the most significant factor leading to the recognition of the effectiveness of passive samplers in the quantification of soil vapour concentrations has been the development of a sampler suitable for that specific application. The Waterloo Membrane Sampler (WMS) utilises a poly-dimethyl siloxane (PDMS) membrane at one end of a glass vial through which organic compounds diffuse and are subsequently adsorbed on a carbon medium.

This article looks at the theory behind this new method, its advantages and disadvantages, and a few examples of data comparisons with traditional active sampling.

Principles of passive absorptive samplers

In simple terms, the principle governing the determination of vapour in air (or soil gas) concentration by a passive sampler is governed by Fick's first law of diffusion, which defines the diffusional mass transfer rate of a gaseous compound. The concentration (C0) of a compound in air, including in soil vapour pore space, can be determined from the mass (M) of the analyte collected on the passive sampling tube, provided that the sampling time (t) and the uptake rate (k-1) are known. This relationship is expressed as:

$C0 = M/(k\text{-}1t)$ eqn 1

Typically, the uptake rate (k-1) for any given compound must be determined experimentally. However, most of the volatile organic compounds of interest to contaminated land vapour intrusion investigations have already had sampling rates determined for the PDMS-membrane-equipped passive samplers.

As indicated in equation 1, concentration of an analyte collected in the sampler can be calculated after the mass is determined following laboratory extraction of the adsorbed volatile compounds on the carbon pack in the sampling tube. Extraction and analytical methods are essentially the same as those used for active sampling.

Analytical detection limits on passive samplers are a function of the sampling time for a given compound, and a function of the compound's uptake rate into the sampler, for a given sampling time. In practice, for areas of low to moderate contaminant impacts, samplers are deployed for one to three weeks. Detection limits for most of the commonly required volatile analytes lie between 1 µg/m3 and 4 µg/m3. Such levels are sufficiently low to resolve risks in vapour intrusion investigations and to delineate the extent of impacts.

As the quantification of soil vapour concentrations relies on the maintenance of equilibria in concentrations in the borehole void and the soil formation, it is important that the sorption rate of the sampler is not greater than the potential flux into the borehole void from the formation. Otherwise, the sampler may reduce concentrations in the borehole void – the so-called starvation effect – and in so doing, reduce the uptake rate.

The WMS-LU sampler is designed to produce low uptake rates to avoid starvation effects under most conditions, but to allow reasonable sampling durations of typically one to three weeks. Examples of calibration constants (uptake rates) listed by the manufacturer are: benzene 0.67 L/min; toluene 0.99 L/min; naphthalene 1.0 L/min; and trichloroethene 0.88 L/min. These rates are quite low, as seen by comparison with established passive samplers such as the Draeger ORSA-5 and the Radiello, which have respective sampling rates for benzene of 6.44 L/min and 80 L/min.

Deployment methods for passive soil vapour samplers

Typically, the passive soil vapour sampler is suspended on a wire to the required depth in a soil bore hole. Wire gauze can be wrapped around the sampler to provide protection and prevent soil lodging on the PDMS membrane. With the sampler suspended in the void at the base of the borehole, a temporary plug is created to seal the void above the sampling tube. To prevent water and air ingress, a further seal is created at the ground surface. At the time of sample recovery, the seals are removed to allow removal of the sampling tube.

Quantifying concentrations relies on potential flux of contaminant vapours into the sampling bore void greater than the sorption rate of the sampler (the sampler's uptake rate). Because of this, at sites where soil contaminant concentrations may be low, it is wise to construct

Passive sampling apparatus is small, light and easily transported compared with, for example, Summa canisters (pictured).
Photo courtesy of Massachusetts Dept. of Environmental Protection

A WMS-LU passive sampler being installed into a soil bore.
Photo courtesy of Adrian Heggie, Parsons Brinckerhoff

the borehole of sufficient diameter to allow for a suitably large surface area of the borehole void (typically 60–100 mm) and create a void depth of 300–500 mm.

The pros and cons of passive samplers

Outlined here are the advantages and disadvantages of using passive samplers for quantifying soil vapour concentration.

Advantages

Passive methods have two key advantages over active sampling methods. Firstly, passive sampling usually costs much less than active sampling. Secondly, passive sampling produces a much longer-term time-weighted average concentration, thus removing uncertainty over the possibility of short-term fluctuations in soil vapour concentrations.

A further advantage arises from the fact that passive samplers collect the sample via molecular diffusive fluxes. No advective air movement is involved in the collection of a soil sample. In any active soil sampling method, an unnatural flow within the profile is produced by the vacuum canister or the sampling pump as it draws air from the soil bore. Tight soil formations may result in a vacuum that is too strong to allow for the collection of an adequate sample. And, in any formation, particularly when a significant vacuum is created, the steady state of the adsorbed-to-vapour-phase partitioning ratio is altered, leading to 'stripping' of volatiles off the adsorbed and into the vapour phase in the pore space. This leads to an unnatural increase, or overestimation, of the soil vapour concentrations. A passive sampler on the other hand does not change the phase equilibrium within the soil pore space, and does not create any advective flow. On that basis the passive sampler collects a more representative sample of the soil pore space concentrations.

Because the passive sampler does not use any advective flows (no air is drawn from the soil bore), it eliminates the potential for leakage from atmospheric air down the soil bore through imperfect sealing during construction. Additionally, the process of active soil bore sampling can draw soil vapours from shallower depths, whereas sampling depths for passive sampling are restricted entirely to the depth of the bore void.

A further advantage of passive soil vapour sampling is that it is technically simpler for the field operator, thus reducing the chance of sample collection errors. Passive sampling apparatus is also small, light and easily transported, particularly compared with the use of Summa canister sampling.

Disadvantages

Because passive samplers are sealed only temporarily within a bore, the sampling tube must be readily accessible for later collection and at the same time effectively sealed from the atmosphere and rainwater. At some locations this can be difficult if the deployment period coincides with heavy rain, although active sampling bores may also be compromised in such conditions.

Another potential disadvantage is that if subsequent sampling rounds are required, new sampling tubes must be purchased, deployed and recovered for each sampling event, and sometimes the soil bores must be reconstructed.

Finally, uptake rates are not currently available for some less commonly targeted analytes, so the concentrations for those compounds cannot be quantified. However, reasonably close estimates may be made using uptake rates of compounds with similar physicochemical properties. Similarly, to measure the collective concentrations of groups of compounds, such as total petroleum hydrocarbon fractions, an uptake rate of a single representative compound must be used.

A commonly perceived limitation of passive soil vapour sampling is that the method does not allow the quantification of concentrations of target analytes. This idea arises from the mistaken belief that it is not possible to accurately apply an uptake rate for any compound when the sampler is placed in a soil bore void because the experimentally determined rate may not be consistently achieved within the void due to the starvation effect. Certainly, if the air in the sampling void is stagnant and contains low concentrations of contaminants, the passive sampler may uptake the target compounds at a faster rate than they can be replenished by diffusive flux into the void from the soil profile. In such a case the sampler may reduce the concentration of those compounds within the sampling void. However, with a sampler of low uptake rate and a suitably designed soil bore, the starvation effect should not arise. This is demonstrated by the examples of field sampling provided (see Table 1).

When to use passive sampling

Despite the generally equivalent results of passive and active sampling, and the cost savings achieved through use of the passive method, there will be circumstances where active sampling may be preferable – and perhaps less costly. When multiple rounds of sampling are envisaged, passive sampling may be less practicable as passive samplers would need to be reinstalled for each sampling event. And, when a

	Location 1		Location 2		Location 3	
Analyte	**Passive**	**Active**	**Passive**	**Active**	**Passive**	**Active**
benzene	9.4	<8.3	13	6.7	<4	<5
toluene	4.0	9.6	2.7	5.6	<2.7	<5
ethylbenzene	9.1	<8.3	<1.3	<5	<2.2	<5
xylene	77	27	7.1	<5	5.4	<5
trimethylbenzene	85	16	1.6	<5	2.7	<5
tetrachloroethene	<1.5	<8.3	18	10	<2.4	<5
trichloroethene	<1.9	<8.3	28	15	<3.1	<5
cis-1,2-DCE	<3.1	<8.3	4.4	11	<5.1	<5
vinyl chloride	<12	<8.3	38	8.1	<19	-
Units: $\mu g/m^3$						

Table 1. Comparative concentrations of volatile organic compounds in three soil bores from co-located passive and active soil vapour bore implants.

calibration constant (uptake rate) for a particular target compound is not available, active sampling may be the best option.

Placement of passive soil vapour samplers in soil bores greater than about 2 m deep may present challenges in borehole construction and sampler deployment and recovery methods. Nevertheless, innovative methods of deployment in deep bores will undoubtedly be developed as the method gains wider use.

'Tight' soil formations, where permeability is low, present major challenges for active soil sampling because of the induced vacuum caused by the vacuum canister or the sample pump. In such conditions, passive sampling offers a distinct advantage.

In most cases where soil vapour assessments are used to evaluate the potential for vapour intrusion, or to characterise and delineate contaminant impacts, either active or passive sampling methods are suitable and selecting one method or the other would depend on cost considerations or convenience.

Comparisons from local field data

In Australia to date there are limited data available with which to compare co-located passive and active sampling In table 1, which presents a sample of the data available, Locations 1 and 2 are at a site impacted by both petroleum and chlorinated hydrocarbon compounds, while Location 3 was believed to be 'clean' on the basis of active sampling. However, passive sampling, by virtue of lower detection limits, identified trace amounts of some petroleum VOCs at Location 3.

At all three locations, soil vapour concentrations were low or at trace levels. Of particular note is the fact that at very low concentrations, when the starvation effect (depletion of concentrations in the soil bore void) would be expected to occur using passive samplers, it is the passive samplers rather than active sampling that detected very low-level vapour concentrations. Overall there is very good alignment between the results of the two methods despite the values being in the parts per billion range.

The recent development of an environmental passive absorption sampler designed, at least in part, for soil bore sampling, and the availability of empirically determined uptake rates, has provided an alternative method with which to quantify soil vapour concentrations down to trace levels. The value of the new methodology is enhanced by virtue of its relatively low cost and greater simplicity compared with active sampling.

FURTHER READING

Zabiegala, B, Gorecki, T & Namiesnik, J 2003, Calibration of Permeation Passive Samplers with Silicone Membranes Based on Physicochemical Properties of the Analytes. Anal.Chem. 75, pp. 3182–3192.

McAlary, TA, Groenevelt, H, Gorecki, T, Seethapathy, S & Hayes, H 2009, 'PDMS Membrane Samplers for Quantitative Passive Monitoring of Soil Vapor Intrusion to Indoor Air', Vapour Intrusion, Air and Waste Management Association, January 27–30, 2009, San Diego CA.

Assessing vapour intrusion – how do assessment technologies compare?

Kenneth L. Kiefer, Environmental Resources Management (AUS); Chuck E. Schmidt, Environmental Consultant, USA; Mark K. Jones, Environmental Resources Management (USA) and Ranajit (Ron) Sahu, Basic Remediation Company, USA

As awareness of vapour intrusion increases, there is greater demand for effective remediation of sites prior to building. Along with this comes a need for effective assessment technologies to estimate the risk of vapour intrusion. This work demonstrates the utility, strengths and weaknesses of selected assessment technologies in assessing potential vapour intrusion into future structures.


Borders of the test site for comparison of VI technologies

There are three basic approaches for assessing vapour infiltration into established buildings: soil vapour or groundwater testing with vapour transport modelling; comparative measurement of compounds in indoor air versus outdoor air; and direct flux chamber measurements on the land surface using the United States Environmental Protection Authority (USEPA) flux chamber assessment technology. If there are no structures or buildings on site, however, assessment presents more of a challenge, with the available technologies limited to soil or groundwater testing with vapour transport modelling, and direct measurement of volatile organic compounds (VOCs) flux at the land surface.

Comparing assessment technologies

- Surface flux chamber sampling involves isolating an area of ground within a flux chamber and deliberate introduction of air to assist in mixing and transport of the gasses emitted from the ground to a collection chamber for measurement. In the field study described here, sampling was performed using the USEPA flux chamber technology from five locations (a central point and four radial points located 6.1 m from the centre).
- Soil vapour sampling uses a probe to collect vapour *in situ* in the soil, rather than waiting for it to be released at ground level. Probes can be installed at different levels and collect different volumes of vapour. In this study, two probes were installed to depths of 1.5 m and 3 m below ground surface (bgs).
- Soil profiling and sampling is the practice of taking a core, or columnar piece of soil, and analysing what is collected. In this study, soil samples at each location were collected every 0.6 m down to a depth of 3 m. The samples were analysed for particle density, percentage moisture, porosity and bulk density.
- Surface flux estimation was performed using the Johnson and Ettinger (J&E) vapour intrusion model[1] and site-specific soil parametric data, allowing a direct comparison between measured surface flux and modelled surface flux using multi-depth soil vapour data at each location. The modelling was conducted using the soil vapour measurements as well as chloroform groundwater concentrations as source inputs.

A recent comparative field study aimed to meet this challenge by assessing the efficacy of direct flux chamber measurements and soil vapour sampling/modelling to measure potential vapour infiltration levels into future buildings on a development site containing groundwater contaminated with chlorinated VOCs. This site provided a rare opportunity to compare the capability of these preferred technologies to assess potential exposure to vapours from subsurface groundwater contamination before and during building.

The study was designed and implemented on a parcel of land in the development area, with comparative testing at multiple locations using soil vapour sampling and direct flux chamber measurement. By using soil vapour data in a vapour transport model to estimate surface flux of study compounds at the surface, it was possible to compare the techniques. In addition, soil parameter data (coring and sampling) were also collected and used to inform site-specific modelling.

The study's several sampling locations were characterised by relatively uniform groundwater plume concentration and known lithology. The depth to groundwater in the study area was approximately 18.3 m, and the range of chloroform concentration in the groundwater was 250 µg/L to 900 µg/L. These selection criteria allowed specific testing of the efficacy of the technologies, rather than an environmental assessment of the area (see above for a brief description of each technology).

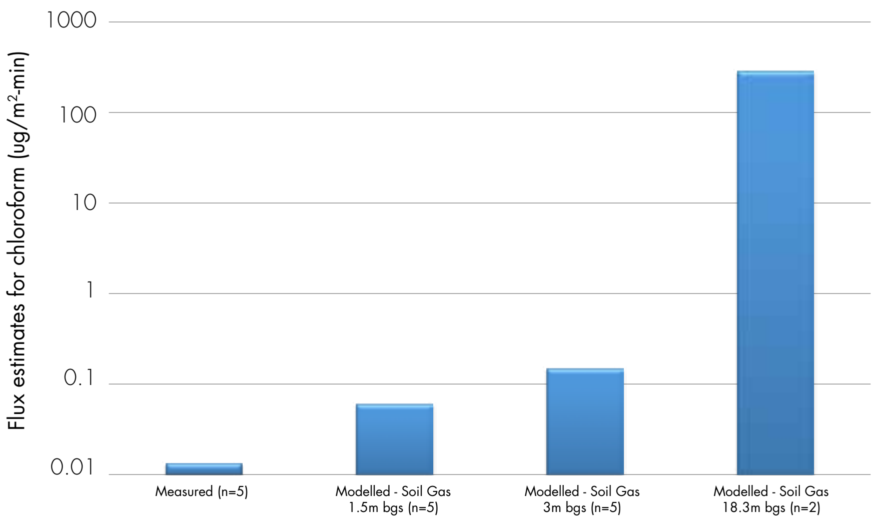


Figure 1. Comparison of flux estimates modelled versus measured.

In total, seven VOC compounds were dominant in both data sets. Chloroform, which was found in the highest concentration in the study area groundwater, was used for the comparison study. Measured surface flux data (USEPA flux chamber technology) and modelled surface flux data (soil vapour data modelled using J&E equation), and the comparison between measured and modelled surface flux are shown in Figure 1.

The results show that the modelled flux for chloroform using soil vapour data is consistently higher for both of the measured soil vapour depths as compared to the measured surface flux.

Supportive of other reports in the literature, this study saw modelled estimates exceeding the measured values, despite the possibility of variation with site-specific soil input parameters for the vapour transport modelling.[2-9] The modelled flux values are on average 15 times higher than the measured surface flux values for chloroform, and both benzene and 2-butanone also saw similar variation when comparing the ratio of modelled to measured flux. These data show very good agreement between three of the seven compounds indicating that the methodologies have high reproducibility.

The modelled surface flux from groundwater demonstrates the conservative estimate of surface flux using transport modelling and groundwater data (18.3 m bgs) compared with soil vapour/predictive modelling (1.5 and 3.0 m bgs) and measured surface flux. Using the maximum value soil vapour/predictive modelled estimate and maximum measured surface flux estimate, these estimates are within an order of magnitude (factor of 8.5) of the modelled estimate using groundwater data, which is 1,300 times higher than the soil vapour/predictive model estimate and about 11,000 times higher than the measured surface flux estimate.

Designing vapour intrusion tests

The comparison of surface flux data with soil vapour data illustrates the utility and challenges of these source assessment technologies. Further, some points to keep in mind when designing predictive vapour intrusion testing for future buildings are:

1. Both measured and modelled technologies are spatially sensitive and it is important that the subsurface source be adequately characterized and that a sufficient number of test locations used to reduce uncertainty and variability.
2. Variability can occur as the method detection limit is approached, including increased frequency of false positive and negative analyses.
3. The common misconception regarding underestimation of flux level using the USEPA flux chamber direct measurement method for assessing for health risk assessment was not supported in this field study. Note that the USEPA has recommended limited validation of the Jury vapour transport model using the USEPA surface flux chamber technology.[10]
4. Although both technologies require expertise in sample collection and specialized equipment, direct surface flux chamber testing may be more cost and time effective when compared with soil vapour and column data collection methods.
5. Consistent with other case studies, more advanced techniques require less conservative analysis of results, ranging from one order of magnitude when comparing soil vapour to two orders of magnitude for modelling from groundwater.[2, 8, 9]
6. Direct measurement of surface flux does not rely on transport modelling and therefore has this advantage over indirect technologies that do. However, despite this, the soil vapour sampling and transport modelling approach holds favour over direct flux measurement since this approach is generally considered to be more conservative.

The measurement of potential for vapour intrusion from surface flux – and thus potential exposure to occupants – in existing or future structures is possible using a number of different techniques, all of which have advantages and disadvantages in application.

Installing a USEPA flux chamber

Assessing vapour transport and potential exposure to subsurface contamination continues to present challenges. Whichever assessment approach is selected, multiple lines of evidence – including assessing the indoor air quality data when possible – are suggested in order to obtain representative exposure data. In the future building scenario, investigators must rely on either (a) transport modelling using groundwater or soil vapour input data, or (b) direct surface flux measurement using the USEPA surface flux chamber technology. As such, both direct measurement technology, and predictive assessment technologies (transport modelling using groundwater data or soil vapour data) are capable of generating useful surface flux data for exposure assessment as related to subsurface VOC sources, including compounds found in groundwater.

USEPA surface flux chamber *in situ* at a test site

All photos courtesy of Chuck Schmidt

REFERENCES

1. Johnson, PC, & RA Ettinger 1991. "Heuristic Model for Predicting the Intrusion Rate of Contaminated Vapors into Buildings," Environmental Science and Technology vol 25, no. 8, pp. 1445–1452.

2. Schmidt, C.E.; Teri L. Copeland; Rich Pesin. "Comparison of Measured and Modeled Emissions from Subsurface Contamination at an Industrial Site in a Residential Neighborhood"; Presented at the Annual 1998 AWMA Conference, 98-TA9C.01; San Diego, California, June 1998.

3. Schmidt, C.E., et.al., "Comparison of Measured Versus Modeled Surface Flux of VOCs from Contaminated Groundwater", Paper No. 447, 93rd Annual Meeting of the Air and Waste Management Association, Salt Lake City, Utah, June, 2000.

4. Copeland, Teri, C.E. Schmidt, Jim Van de Water, Michael Manning, "Predicting Potential Exposure from the Occupants in Future Buildings Using Direct Measurement and Predictive Modeling Techniques," Paper No. 43141, 95th Annual Meeting of the Air and Waste Management Association, Baltimore, MD, June, 2002.

5. Robles, Heriberto, C.E. Schmidt, Teri Copeland, Jim Van de Water, Michael Manning, "Measured Infiltration Flux as the Preferred Input to Indoor Exposure Assessment," Paper No. 70, Air and Waste Management Association Symposium on Air Quality Measurement Methods and Technology, San Francisco, California, November 13-15, 2002.

6. Menatti, John, Ed Fall, "Measured Versus Modeled Exposure from Petroleum Groundwater Plumes," Paper No. 74, Air and Waste Management Association Symposium on Air Quality Measurement Methods and Technology, San Francisco, California, November 13-15, 2002.

7. Copeland, T., J. Van de Water, CE Schmidt, "Reducing Uncertainties in Health Risk Characterization, Part II: Methodologies for Assessing Indoor Air Exposures to Carcinogens," Paper No. 361, Proceedings of the 97th Annual Meeting of the Air and Waste Management Association, Indianapolis, Indiana, June, 2004.

8. Schmidt, CE et al. 2005 "Evaluating Direct Measurement Approaches Used for Assessing Potential Air Pathway Impacts to Occupants in Structures Over Subsurface Sources", AWMA Symposium on Air Quality Measurement Methods and Technology, San Francisco, California, USA.

9. Schmidt, CE & Kick R 2006 Use of Flux Chambers and Indoor Air Measurements to Evaluate Vapor Intrusion, AWMA Specialty Conference on Vapor Intrusion, Los Angeles, California, USA.

10. USEPA 1995 Limited Validation of the Jury Infinite Source and Jury Reduced Solution Finite Source Models for Emissions of Soil-Incorporated Volatile Organic Compounds, Environmental Quality Management, Inc., Janine Diana, Work Assignment No. 1-55, Subcontract No. 95.5, PN 5099-4, USEPA Office of Solid Waste and Emergency Response.


Drilling through a housing slab to test for vapour intrusion.
Photo courtesy of SA Health

Soil vapour intrusion into homes: a case study

Ian Delaere, Richard Evans and Kateryna Babina. Public Health, SA Health, Government of South Australia

Disclaimer
This article is a modified version of the public health report: Evans et al. 2010 Vapour intrusion in suburban dwellings. *Public Health Bulletin SA 7*(1), pp. 48–52 (www.dh.sa.gov.au/pehs/publications/public-health-bulletin.htm). More information can be found in the further reading list at the end of the article.

Whenever exposure to volatile organic compounds (VOCs) is suspected, the soil and groundwater surrounding the potentially hazardous site must be assessed. In the mid-to-late 1980s it became increasingly common for such assessments to include as potential exposure pathways both potable use of groundwater and inhalation of indoor air. These assessments revealed that VOCs could migrate through air pockets in the soil (referred to as soil gas) and into structures above or near contaminant plumes through a process known as soil vapour intrusion, which is analogous to that of radon gas intrusion.[1, 2]

Identifying the issues

In Australia, as elsewhere in the industrialised world, commercial, manufacturing and heavy industries in urban areas are often situated in close proximity to residential development. The historical release of chlorinated hydrocarbons into soil and groundwater as a result of past disposal practices, spills, or leaks from storage tanks from industrial and commercial sites presents a persistent public health issue for some communities. Affected sites require ongoing investigation, mitigation or remediation.

An Adelaide suburban public-housing residential area was investigated following an environmental site assessment (ESA) describing elevated levels of volatile chlorinated hydrocarbons (VCHs) in shallow soil vapour and groundwater on a neighbouring former vehicle manufacturing plant site. The contaminant of concern was trichloroethene (TCE), an industrial solvent mainly used in Australia for vapour degreasing and cold cleaning of fabricated metal parts. No attempts were made in the ESA to determine the precise boundaries of the solvent in groundwater or soil gas within the residential area.

Noting the regulatory limitations associated with enforcement of additional environmental assessment activities on orphan sites in South Australia, SA Health in conjunction with the South Australian Environmental Protection Agency (EPA) identified an immediate need to conduct a screening assessment for the presence of TCE in shallow soil gas within the adjacent residential area. The magnitude of TCE mass adsorbed onto the passive samplers, used to collect soil gas samples for chemical analysis, and the close proximity to occupied residential properties quickly led to an indoor air investigation within the residential area.

Description of the site

The area under study was bound to the north and northeast by a former vehicle manufacturing plant and to the east by a vehicle parts manufacturing plant in Adelaide, South Australia. The decommissioning ESA indicated significant contamination in the soil gas and groundwater with VCHs, specifically TCE to the north and northeast of the residential neighbourhood. Groundwater flow was generally in a westerly direction with the residential area down-gradient from the historical manufacturing precinct. The depth to groundwater was approximately 14-18 m.

Residential structures in the study area are of slab-on-grade construction. Reference to the Soil Association Maps of the Adelaide region indicates that the most likely soil profile in this particular site is red/brown earth (RB3-RB5). These soils contain highly to extremely reactive clays within the upper layers, which expand when moisture content rises and shrink when moisture falls.

During the hot, dry summer months, these expansive clays are prone to forming large vertical fissures, which may extend below the surface for 1 to 2 m. Such fissures would allow any gas to penetrate and travel laterally within the soil profile over a considerable distance. Given these soil characteristics, the absence of residential groundwater bores in the region, and the proximity of residential properties to contaminant sources, the vapour intrusion pathway was expected to be an exposure pathway of concern.

Soil vapour intrusion to residential properties

A prominent route of TCE release into the atmosphere of cities is via evaporation of the used or stored solvent from factory premises. If disposed to soil, the portion of TCE not lost to the atmosphere can migrate into porous subsurface soils and be transported by diffusion, advection (the bulk movement of vapour) or dispersion of the pure liquid, as a solute in water or by gaseous diffusion throughout the soil spaces.

Given the potential duration and magnitude of the onsite contamination and direction of groundwater flow, it was postulated that substantial percolation to subsurface regions had occurred within the affected site and that the subsurface contamination was no longer confined within the boundary of the industrial site.

The regulatory issue

In Australia, at the time of conducting this investigation there was no National Environment Protection Measure guidance on how jurisdictions should manage vapour intrusion contamination issues associated with VOCs such as TCE. Therefore SA Health was compelled to review the scientific literature and derive an interim inhalation guideline value to inform potential risk management actions

For the purpose of managing this site, SA Health developed a pragmatic interim guideline for TCE in indoor air of residential properties based on health criteria as well as other factors. These other factors included detection limits of TCE, variability in indoor air analysis, variability in analytical methods, gaps in the Australian understanding associated with environmental TCE exposure, and uncertainties in the toxicological database. In essence the interim guideline developed was a 'ceiling' air concentration to guide decision making and efforts to manage and reduce TCE exposure.

An interim guideline for indoor air TCE levels of 37 µg/m^3 or 'action level' was proposed with an 'investigation level' set at 3.7 µg/m^3.

Passive vapour sampler on location at the testing site.
Photo courtesy of SA Health.

Figure 1. Locations of passive soil vapour sampling sites within the residential study area. The colours of the sample locators indicate the mass-range of TCE adsorbed onto the Radiello® passive samplers at a sample depth of 2 metres.

Air concentrations above the interim guideline indicate a need to manage and reduce exposure, with the need for action becoming more urgent as concentrations increase. The values were based on pharmacokinetic and toxicological data derived principally from chronic exposure studies that found small but significant changes to central nervous system functions in humans and animals. The interim guideline was written in terms of a graded response, with practical actions that would reduce exposure still recommended below the interim guideline value.

Passive soil vapour testing

The first phase of the field investigation consisted of the placement of passive samplers (Radiello®) into boreholes up to 2 m deep, 50 mm in diameter, which were drilled in publicly accessible areas in close proximity to residential properties (boreholes were subsequently backfilled with sand). The qualitative soil vapour data, obtained using this simple method, confirmed that VOCs were present in soils at three depths (2 m, 1 m and 0.5 m). On this basis it was considered likely that TCE vapour in soil was in contact with building foundations and the in-ground services typical of the area (e.g. sewers, pipes and cables).

The data were of sufficient spatial resolution to show the presence of a significant soil vapour plume of TCE beneath approximately 50 dwellings in the study area (Figure 1). Given the magnitude of the TCE mass absorbed onto the samplers and their proximity to residential properties, the decision was made to progress directly to indoor air testing so as to clarify, within an acceptable timeframe, the potential for vapour intrusion into nearby homes.

Indoor air testing

Traditionally an investigation of site contamination such as this proceeds through a variety of stages, such as a full delineation of the groundwater and soil vapour plume, derivation of a risk estimate, followed by consultation with the community and, generally, as a last step in the data collection process, indoor air testing of residential properties. The rationale for this approach is that the 'weight-of-evidence' should be sufficient to provide a reasonable suspicion that residents may be at risk prior to undertaking indoor air testing, which can be very stressful to the community.

However, in the case described here, regulatory and financial constraints led to an expedited indoor air investigation within the residential area. All residential property owners within the defined zone were given

REFERENCES

1. Hodgson, AT, Garbesis, K, Sextro, RG & Daisey, JM 1988. Evaluation of Soil-Gas Transport of Organic Chemicals into Residential Buildings. Indoor Environment Program Lawrence Berkey Laboratory, LBL25465.
2. World Health Organisation (WHO) 2009. WHO handbook on indoor radon: a public health perspective. Zeeb, H. and Shanoun, F. eds. http://whqlibdoc.who.int/publications/2009/9789241547673_eng.pdf

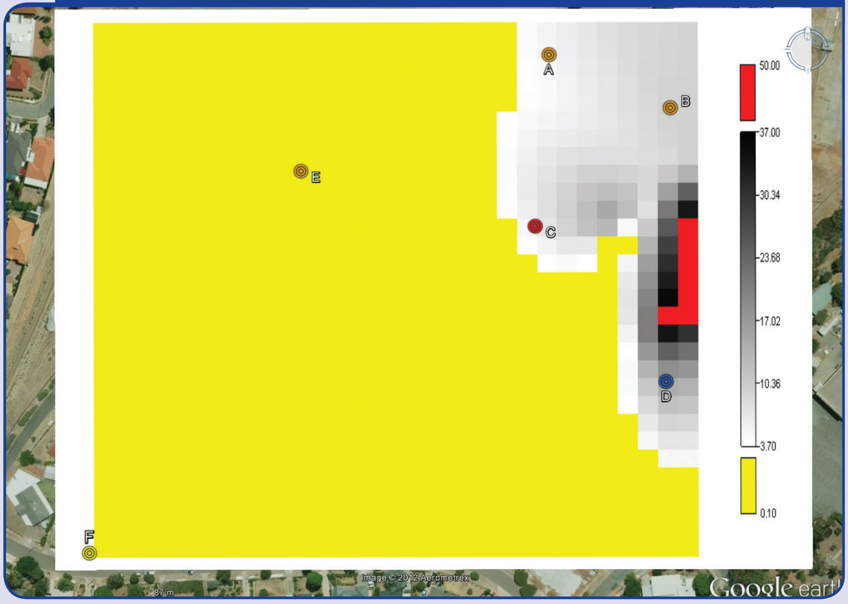
FURTHER READING

Forand, SP, Lewis-Michl, EL & Gomez, MI 2012. Adverse Birth Outcomes and Maternal Exposure to Trichloroethylene and Tetrachloroethylene through Soil Vapor intrusion in New York State. Environmental Health Perspectives, 120(4), pp. 616–621.

McDonald, GJ & Wertz, WE 2007. PCE, TCE and TCA Vapors in subslab soil gas and indoor air: A case study in upstate New York. Ground Water Monitoring & Remediation, 27(4), pp. 86–92.

NSW DECCW (New South Wales Department of Environment Climate Change and Water) 2010. Vapour Intrusion : Technical Practice Note, Sydney, NSW.

Figure 2. Interpolation of indoor air sampling results overlaid on the locations of passive soil vapour sampling sites within the residential study area. The red colour indicates indoor air TCE concentrations (µg/m^3) in residential properties in excess of the interim guideline value.



the opportunity to have their indoor air quality assessed with respect to the levels of common VOCs including TCE (Figure 2). These measurements were repeated for equivocal results, poor detection limits or where TCE was detected in excess of the investigation level. Over three-months and two rounds of testing, using both 24-hour active sampling and integrated seven-day passive sampling, 38 dwellings were tested, along with a number of 'control' homes located in other suburbs of Adelaide. Results clearly indicated that the TCE was intruding into the living spaces of some dwellings located on the immediate boundary of the industrial complex.

Risk communication

At the commencement of the investigation within the region, approximately 300 property owners adjacent to the affected area where informed of potential groundwater contamination associated with the TCE. It was recommended that householders refrain from extracting groundwater unless the water had been tested and shown to be fit for purpose. This is standard advice for much of Adelaide in areas that sit above shallow unconfined aquifers that are invariably contaminated with TCE and other chemicals.

Prior to the commencement of indoor air testing, it was necessary to further consult with the community, media and relevant local officials. To operate effectively, organisations such as SA Health and the EPA need to gain the trust of the community and become respected intermediaries. An extensive community engagement process in the study area helped to achieve this. The process involved letter drops and face-to-face meetings with residents in their homes, along with briefing community leaders and the media. The success of the engagement confirms the need for effective two-way communication with residents and other stakeholders in all environmental investigations that have a direct impact on residents in a community.

Risk characterisation and management

Results of the indoor air testing demonstrated a clear dichotomy of results – either very low (or not detectable) or high. For a majority of dwellings TCE concentrations were found to be well below the interim 'investigation level' of 3.7 µg/m^3 (Figure 2). However, several dwellings located on or near the boundary of the industrial site exceeded the interim 'action level' for TCE in indoor air, which necessitated relocation of residents. With the assistance of Housing SA these residents were provided with alternative accommodation.

Conclusions

The use of passive soil gas and indoor air sampling enabled the South Australian Government to rapidly collect information to inform a human health risk assessment and manage exposure. The immediate management of exposure to high levels of TCE in residential dwellings was addressed, with some residents needing relocation. This was fortunately relatively easy to achieve since the dwellings were not privately owned and the residents were within the South Australian public housing system.

This investigation required expert judgement, inter-organisational cooperation and extensive community engagement. Strong organisational support was critical for the investigation to proceed.

Major themes:

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- Risk assessment and characterisation
- Human health effects of exposure to contaminants
- Soil and sediment assessment and remediation
- Groundwater assessment and remediation
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John E. Boyer
ITRC Petroleum Vapor Intrusion Team Co-Lead, New Jersey Department of Environmental Protection, USA
Presentation topic: Petroleum Vapor Intrusion: The Current Science of Investigation and Mitigation

Ian Thompson
University of Oxford, UK
Presentation topic: Exploiting the potential of nano-scale iron for environmental clean-up

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University of Nottingham & Land Quality Management Ltd, UK
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The need to advance existing models for vapour risk assessment

Dawit Bekele and Ravi Naidu, CRC CARE

The number of contaminated sites currently runs into the millions. Of these, two-thirds contain volatile organic compounds (VOCs) whose volatile vapours are a major toxic risk, especially when they enter buildings where people live and work. The widespread production and use of organic solvents and hydrocarbon fuels have made VOCs the world's most widely occurring environmental contaminants. VOC contamination occurs primarily in urban areas, especially those next to or overlapping industrial areas where chemicals are used. The VOC vapours emanating from contaminated subsurface soil can contaminate indoor air through joints, cracks or other openings in foundation slabs and basement walls of a building.

Human exposure to VOC-contaminated soil and groundwater – usually via skin contact or ingestion – presents significant potential health hazards. As a result, risk assessment criteria from exposure to contaminated soil and groundwater have been well studied. Recently much attention has focussed on the health risks associated with inhalation exposure in indoor air arising from VOC-contaminated sites. Vapour intrusion (VI) into buildings is a major exposure pathway at such sites. Commonly, health risks of contaminant exposure via VI are evaluated using the fate and transport models. Although popular, such models take a simplistic approach to simulate complex processes of the vadose zone (the area between the land surface and the water table), often resulting in inaccurate outcomes.

Given the increasing costs and slow pace of remediation, and the potential liabilities associated with ineffective screening of contaminated sites, a more accurate screening tool has long been needed by both legislators and remediation consultants. However, as VI is a relatively new field of research – with a history of just two decades – regulatory documents are largely still being developed. Currently, final reviews on VI guidance documents for Australia (National Environmental Protection Measure, the review of which is being led by CRC CARE) and the United States (US EPA Vapour intrusion guidance) are underway.

Quantifications of VI have been a challenge for scientists and engineers because of the complexity of fate and transport processes involved in the migration of vapour from the subsurface into indoor air. To address the need for decision-support tools that accurately assess health screening levels (HSLs), many attempts have been made to develop mathematical models that minimise both the uncertainty and costs associated with inaccurate VI assessment, as well as establishing the extent of clean-up required at remediation sites.

Dawit Bekele measures VOCs at a CRC CARE test site.

These models range from simple analytical and semi-analytical mathematical algorithms to numerical three-dimensional simulation models. However, there is no consensus among environmental managers as to which model to use. The lack of a comprehensive model that effectively simulates biochemical processes and heterogeneous physical characteristics of soils in the vadose zone – which connects indoor air with the contaminant source – results in conservative risk predictions. Despite this, these models are widely used by environmental practitioners and regulators globally.

Uncertainties surrounding site characterisation – such as the nature and extent of contamination, along with overly conservative risk assessment – can result in unnecessary remediation, or ineffective risk-management actions, which can severely constrain the sustainable redevelopment of contaminated sites.

The often conservative predictions of existing VI models can occur for a number of reasons. These include a lack of detailed site characterisation data, the assumption of homogeneous soil or sediment through which vapour migrates, and omission or simplified representation of the complex natural attenuation process. Among the list of assumptions applied by the most widely used VI models are a uniform subsurface soil environment and uniform soil properties between the source and foundation slab. At best, users of such models assume averaged parameters for the vadose zone based on information generated elsewhere.

Further to this, the lack of trained professionals with sufficient understanding of both VI models and VOC contaminants increases the uncertainty associated with model predictions. For instance, practitioners often fail to distinguish between petroleum hydrocarbons and chlorinated hydrocarbons that differ in both bio- and physico-chemical properties in the vadose zone.

In short, unsaturated subsurface soil has heterogeneous properties, and biogeochemical reactions and physical processes are complex. However, the applications of mathematical algorithms to simulate processes in the vadose zone require simplifications and assumptions that limit the model or result in inaccurate predictions of the fate and transport of VOCs.

Identifying sensitive and critical input parameters (for which small variations in input values greatly influence the predictive output) of VI models is complicated and dictated by site-specific factors. Estimating a range of values for critical parameter analysis (i.e. using probabilistic modelling) would provide decision-makers at contaminated sites with an idea of the range of possible outcomes and where the best estimated values are located.

Vapour intrusion risk assessment for improved decision making requires continuing research to accommodate non-equilibrium and transient conditions and conceptual site model scenarios representing the actual subsurface. Research areas for improving the VI models include a two-dimensional subsurface algorithm that can model heterogeneity of soil properties and the soil environment of vadose zone conditions, and can be combined with a transient-condition model.

A robust model simulating volatile transport in the vadose zone is crucial for accurate and effective health risk assessment and screening of VOC contaminated sites. Such a model must take into consideration a range of parameters, including hydrocarbon vapour attenuation due to biodegradation, the transient nature of vapour migration, the finite source of contamination, and heterogeneous subsurface moisture contents and soil temperatures along the soil profile. A model that achieves this would be a great asset for researchers, consultants and, ultimately, the community at large.

The vapour intrusion pathway

Guidance for and issues with petroleum hydrocarbons

Blayne Hartman, PhD

Using a glass syringe to take a soil gas sample for vapour intrusion assessment. *Photo courtesy of author.*

In the US and Australia alike, the vapour intrusion pathway is a 'box-office blockbuster' throughout the environmental community. Although guidance documents have been released by numerous US state and federal agencies, few of these make any clear distinction in assessing the vapour intrusion pathway for chlorinated hydrocarbons (CHCs; these include solvents such as trichloroethylene and perchloroethylene) versus petroleum hydrocarbons (PHCs). As a result, costly vapour intrusion assessments are being conducted at many PHC sites despite recent evidence that suggests such assessments may not be necessary or are being conducted inappropriately for PHCs. So what to do?

Preparing to sample for sub-slab vapour intrusion. *Photo courtesy of author.*

Regulatory updates

USEPA – Office of Solid Waste & Emergency Response (OSWER)

www.epa.gov/oswer/vaporintrusion

The United States Environmental Protection Agency (USEPA) is currently updating their draft 2002 guidance for release in the first half of 2013. This guidance is primarily applicable to CHCs, although large petroleum sites (such as refineries and transfer terminals) fall under this guidance. This is problematic, because many of the methods recommended in this guidance, such as soil gas and indoor air sampling methods, are not designed for PHCs (see main article for further discussion on this).

USEPA – Office of Underground Storage Tanks (OUST)

www.epa.gov/oust/cat/pvi/index.htm

OUST has convened a technical workgroup to prepare guidance specifically for PHCs. The workgroup consists of EPA-OUST staff, regulators from several states, and representatives from industry. Draft guidance is currently in final review and a final version will be released at the same time as the revised OSWER guidance. However, this guidance states that it should be applied only to underground storage tank sites.

Interstate Technology and Regulatory Council (ITRC)

www.itrcweb.org

A multinational consortium of regulators, consultants, industry, military and stakeholders, ITRC released in 2007 a vapour intrusion guidance document focusing primarily on CHCs. Recognising that the new EPA-OUST guidance would not apply to non-underground storage tank PHC sites, and fearing that the OSWER guidance would then be used at these sites, a new ITRC workgroup formed in 2011 and is currently writing guidance for all types of PHC sites, including underground storage tank sites and larger petroleum release sites. The document is in preparation and expected to be released in late 2013 or early 2014.

Australia

In 2012, CRC CARE developed a draft vapour intrusion guidance document for PHCs, which is scheduled to be published as a Technical Report in 2013. Although every effort has been made to ensure the report is well-written, concise and easy to follow, as with all guidance, there are nuances that must be understood so as to avoid errors in implementation.

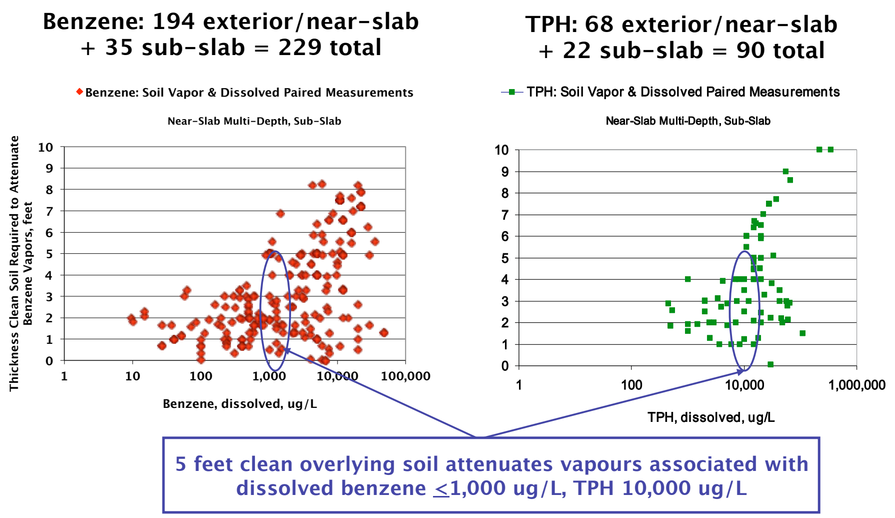
The guidance consists of a decision framework using flow diagrams that reference decision boxes and appendices. There are three petroleum vapour intrusion (PVI) assessment stages: (1) Preliminary, (2) Screening, and (3) Detailed. Each stage provides step-outs to determine:

- if PVI risks are significant (acute or chronic)
- if there is no PVI risk and no further assessment required
- if further assessment (stages) are required.

Sites can be screened out initially using distance exclusion criteria (see page 30) and/or health screening levels. If the site cannot be screened out, a detailed assessment is necessary, preferably on the basis of soil gas data, although crawl space or indoor air data can also be collected.

Appendices provide details on soil gas probe installation, soil gas sample collection, crawl-space and indoor air sample collection, analytical methods, quality assurance and quality control of vapour data, field record templates, and checklists for review.

Figure 1. Thickness of clean soil required to attenuate benzene vapors from dissolved benzene in groundwater and to attenuate TPH vapors from dissolved TPH in groundwater (Davis 2010).



Benzene: 194 exterior/near-slab + 35 sub-slab = 229 total

TPH: 68 exterior/near-slab + 22 sub-slab = 90 total

5 feet clean overlying soil attenuates vapours associated with dissolved benzene ≤1,000 ug/L, TPH 10,000 ug/L

Differences between CHCs and PHCs

PHCs behave differently from CHCs in the vadose zone (the area between the land surface and the water table) for two primary reasons. First, volatile petroleum compounds biodegrade readily in the presence of oxygen and soil moisture (a process known as bioattenuation), whereas chlorinated compounds are typically more resistant to biodegradation. The biodegradability of volatile petroleum compounds provides an effective, naturally occurring contaminant-removal mechanism that inherently limits the migration of subsurface petroleum vapours in most cases. Second, PHC 'free product' (i.e. mobile liquid-phase PHC) is lighter than water, while CHC free product is denser. These two key properties (i.e. biodegradability and density) lead to significantly different subsurface source and transport behaviours that greatly influence whether vapours reach the near surface and intrude into structures.

One final difference to keep in mind: PHC fuel products are mixtures of many hundreds of compounds, many of which are also present in other common consumer products other than fuel. Chlorinated solvents are typically only one primary compound with perhaps some degradation compounds. USEPA has prepared a technical document with a more comprehensive treatment of this subject, which can be found at the USEPA-OSWER website (see the Regulatory updates box).

Exclusion criteria

A primary problem we face with PHC sites is determining which criteria to use to decide if a site needs a vapour intrusion assessment in cases lacking an obvious indicator, such as fuel in basements or petroleum odours in structures. Applying typical screening distances of 30 m both vertically and spatially, combined with extremely low screening concentrations, results in the vast majority of sites being included for assessment and few sites excluded. While these criteria may be appropriate for recalcitrant CHC compounds, they are not appropriate for PHCs in most scenarios.

Jackie Wright of enRiskS, Robin Davis of the Utah Department of Environmental Quality, Ian Hers of Golder & Associates, and Matt Lahvis from Shell Global solutions have independently analysed a database from hundreds of petroleum sites from the US, Canada and Australia with the goal of determining screening criteria for PHC sites. Their intent was to determine what thickness of clean soil is necessary for various source concentrations to decrease to levels of no concern as a result of bioattenuation. All three concluded that 1.5 m of clean soil is all that is required between the contaminant source and receptor to fully attenuate benzene vapours for dissolved concentrations of benzene up to 1,000 µg/L and to fully attenuate total petroleum hydrocarbon (TPH) vapours for dissolved TPH concentrations of up to 10,000 µg/L (Figure 1). Compare this benzene screening value of 1,000 µg/L to the value that you would get from the USEPA-OSWER screening value of 1.5 µg/L – a factor of nearly 700! This is why ITRC convened their workgroup to provide alternative guidance to the OSWER guidance for non-tank petroleum sites.

The evaluations of the database also show that benzene vapours volatilising from free-product on groundwater are completely attenuated with as little as 5 to 10 m of clean soil between the source and the receptor (Figure 2).

In the past year, several states in the US have adopted distance exclusion criteria and it is likely that all other states will do the same in the near future. The OUST guidance will also contain exclusion criteria. The Australian petroleum vapour intrusion (PVI) guidance has also adopted exclusion criteria similar to those given above, although if

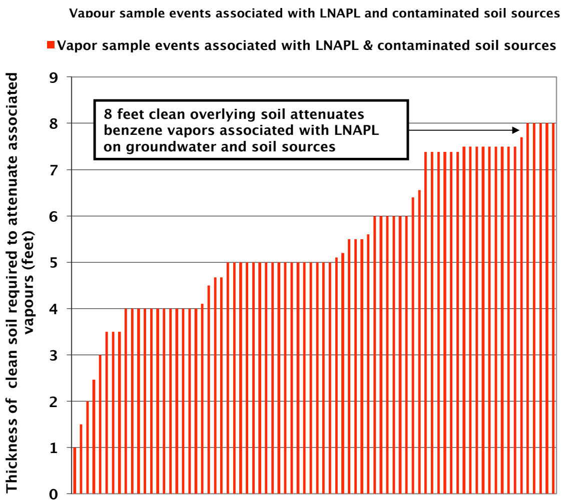


Figure 2. Thickness of clean soil required to attenuate benzene vapors from sites with LNAPL (Davis 2010)

free product is present, a two-fold uncertainty factor gives rise to an exclusion distance of 10 m (this uncertainty factor will hopefully be removed as more database evaluations are published and regulators and auditors become more familiar and confident with the underlying science and supporting data).

Sampling issues for PHC sites

Indoor air sampling

Indoor air sampling for PHCs is likely to be problematic and will confuse, not clarify, the vapour intrusion pathway. This is due to two primary reasons:

1) Ambient (outdoor air) levels of benzene exceed the screening levels in most urban areas and can exceed the residential risk levels in many non-urban areas. It is challenging, to say the least, telling a resident that although their indoor air exceeds the allowable cancer risk value by 10 times, it is acceptable because it is coming from the outside air.

2) The indoor sources for benzene and other PHC compounds are ubiquitous and nearly impossible to identify. A great example of this is a currently available toy that children use to make balloons. It contains alarming amounts of acetone, ethanol, benzene and other PHCs, and you would never think to remove it from a house if it was lying on the counter.

Currently, USEPA-OSWER is recommending longer indoor air sample collection periods of 7 to 30 days based upon lessons learned from the radon literature. This, however, is not a good idea for PHC sites because of the many potential indoor air sources. It will therefore produce numerous false positives and unnecessary time and expense deciphering the actual source of the detections.

The above reasons make it prudent to keep to a minimum residential indoor air sampling for PHCs. The Australian PVI guidance agrees. For commercial or industrial receptors, collecting indoor air samples may be more suitable depending on the allowable indoor levels, which can be 10 to 50 times higher than allowable residential levels.

Groundwater sampling

Because the existing models and default attenuation factors do not account for bioattenuation, groundwater data are likely to over-predict the risk for PHC compounds if there are no sources in the vadose zone. Hence, groundwater samples should not generally be collected for vapour intrusion assessment of PHC if soil gas data are available (although sometimes a shallow water table precludes the collection of soil gas data). However, if groundwater data already exist and indicate there is no risk, then it is very likely that the pathway is not of concern and no further assessment is needed.

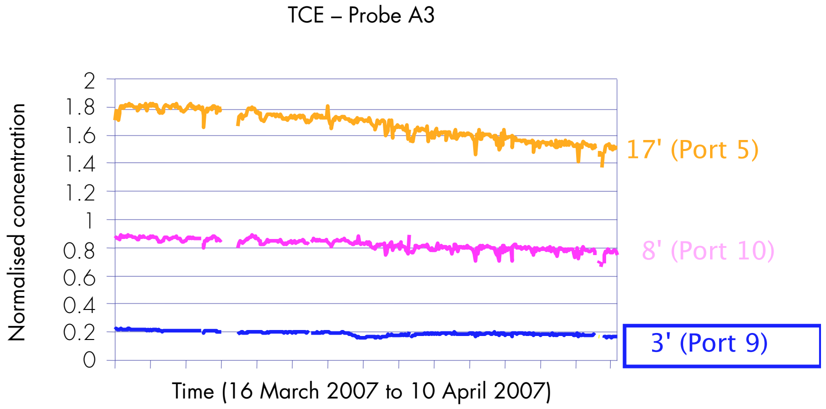
Soil gas sampling

Sample depth

Soil gas sampling locations for PHCs differ from those of CHCs owing to their different fate and transport behaviour. For PHCs, if samples at deeper depths (>1.5 m below ground surface) exceed allowable values, shallower samples (<1.5 m bgs) can be collected since bioattenuation may be active in the upper few feet and reduce values below acceptable levels, provided the assessment does not need to include large slabs (currently defined in Australian guidance as >7.5 m from centre to edge). Thus, a recommended approach is to collect additional samples shallower than 1.5 m bgs in the event the deeper sample exceeds allowable levels. The incremental cost of collecting the additional samples is relatively low. The shallower sample need not be analysed until and unless the results from the deeper sample indicate if there is a need to analyse it.

As far as the representativeness of shallow (<1.5 m bgs) soil gas

Figure 3. TCE concentrations in soil gas for a period of 4 weeks for three probes at 3′ bgs, 7′ bgs, and 17′ bgs (EPA 2007).



concentrations, the USEPA Office of Research and Development has conducted three studies documenting that the temporal variation of soil gas concentrations as shallow as 0.6 m bgs are less than 50% (Figure 3; also see www.epa.gov/nerlesd1/cmb/pdf/270cmb07.pdf).

When sampling soil gas, oxygen data should always be collected to document the presence of the aerobic zone. Carbon dioxide and methane are also useful to confirm the presence of bioattenuation. Soil phase data may also be needed to document the presence of a bioattenuation soil zone.

Sub-slab versus near-slab samples

For CHCs, the current thinking is that shallow soil gas data (1.5 to 3 m bgs) collected outside the building slab may not adequately represent sub-slab soil gas concentrations for many situations. This thinking is based upon modelling simulations as well as data from many CHC sites. For PHCs, however, field data and modelling simulations suggest that exterior shallow soil gas values are representative, so long as sufficient oxygen is present (>5%), 1 to 1.5 m of clean soil exists under the receptor (Figure 4), and the building slab is not large. Thus, near-slab sampling for PHCs is a viable approach at most sites, unless contaminated soils or low oxygen are suspected under the structure (because of the size of the building or the presence of very shallow groundwater).

The two most common errors in vapour intrusion

Vapours and vapour intrusion are an unfamiliar territory for many practitioners in this field, including regulators, stakeholders, consultants, subcontractors and lawyers. Two of the most common errors are:

1. Confusion with units

One common error made with soil-gas data is assuming that parts per billion by volume (ppbv) is equivalent to a µg/L or a µg/m^3. The units are not equivalent, and the conversion depends on the molecular weight of the compound. Converting between units (e.g. µg/L to µg/m^3, percent to ppmv) also causes problems. Consultants can overcome these problems by instructing their lab on their preferred units and detection levels, and using a unit conversion spreadsheet such as that available at www.handpmg.com/resources/links.html.

2. Required soil gas target levels

All too often, regulators or consultants use incorrect soil-gas screening levels. Residential values are erroneously applied at commercial sites, incorrect attenuation factors are used to determine target values, or values determined from predictive models are incorrect. The soil-gas target level ultimately determines the required analytical method and the need for additional assessment. Determining the proper value is often an unfamiliar exercise for regulator, auditor and consultant.

Experience: the key ingredient

The most important ingredient for cost-effective vapour-intrusion investigations is the experience of the consultant and subcontractors (e.g. the sampling firm or laboratory). This problem continues to grow as many inexperienced practitioners enter into vapour intrusion due to the large opportunities available.

Sampling errors borne of inexperience include such basics as not opening containers, incorrect seals or tubing, over-tightening swage lock fittings, using contaminated parts and sealants, and more. Laboratory issues include, but are by no means limited to, incorrect or faulty hardware, using the wrong method for the required detection levels (typically at higher cost). These mistakes result in bad data that only further confound the interpretation. Although the sampling appendices in the Australian PVI guidance give detailed sampling instructions, there is still a long way to go.

Parties seeking vapour intrusion assessment are well advised to seek experienced consultants. In turn, those consultants should use to use firms experienced in soil-gas collection and labs experienced in indoor air and soil-gas analyses. With vapour intrusion, the stakes are simply too high to do anything else.

Want to know more?

In the US:

- The American Petroleum Institute is offering free training on “Assessing vapor intrusion at petroleum hydrocarbon sites” at the Association for Environmental Health and Sciences (AEHS) conference in San Diego in March 2013. The training will cover the topics discussed in this article and more; see www.aehsfoundation.org/west-coast-conference.aspx.
- USEPA-OSWER will be holding a one-day workshop on vapour intrusion at the same AEHS conference in San Diego in March 2013.

In Australia:

- A one-day vapour intrusion workshop and a vapour intrusion session will be held at the Cleanup 2013 Conference in Melbourne in September 2013; see www.cleanupconference.com.

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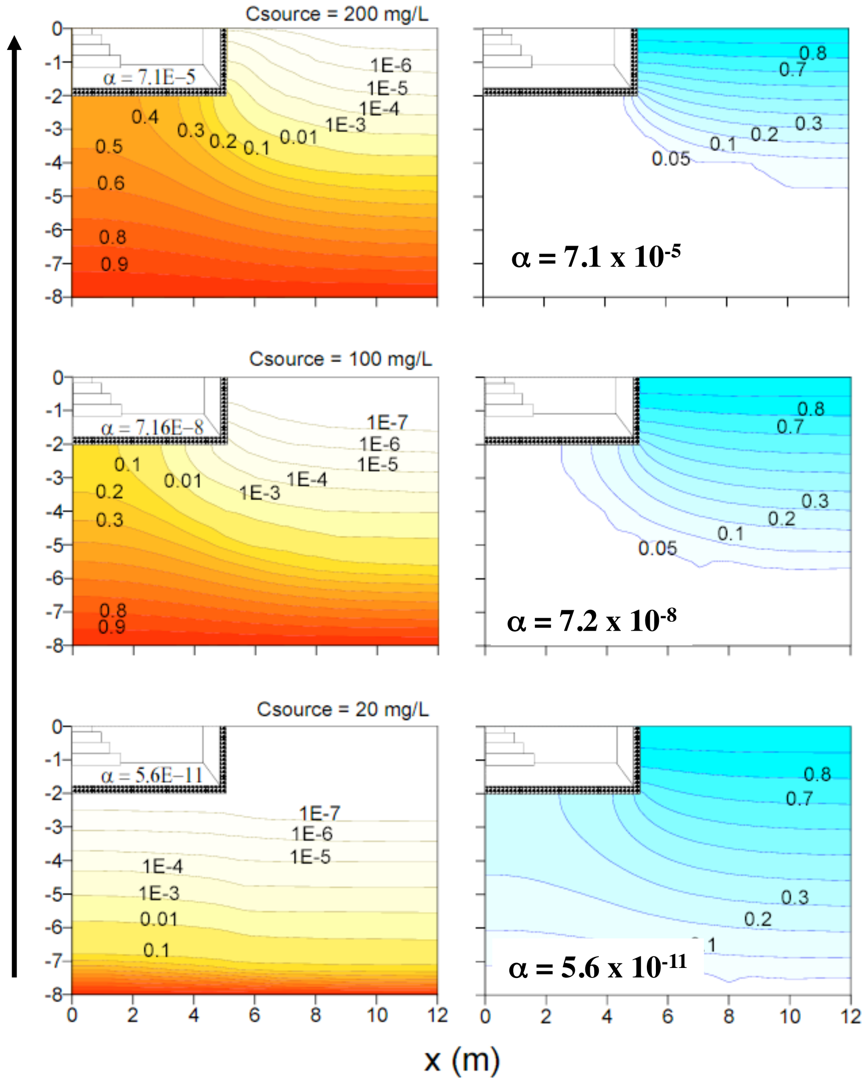
The author wishes to thank Jackie Wright (Environmental Risk Sciences) and G. Todd Ririe (BP) for reviewing this article and their constructive comments.

Figure 4. 3-D modeling of hydrocarbon vapors showing the effects of bioattenuation (Abreu & Johnson 2006)

Effect of source soncentration

[λ= 0.18 h^{1}]

There may be source vapour concentrations that are of little concern if soil gas beneath the foundation is well oxygenated (e.g. groundwater plume sources).



REFERENCES

Abreau & Johnson 2006, Simulating the effect of aerobic bioattenuation on soil vapor intrusion into buildings: Influence of degradation rate, source concentration, and depth. Env Sci Tech 40, pp. 2304–2315

Davis, R 2010. Slides from presentations at the American Petroleum Institute's Assessing Vapor Intrusion at Petroleum Hydrocarbon Sites training course, AEHS conference, San Diego, March 2010.

USEPA 2007, Final project report for investigation of the influence of temporal variation on active soil gas/vapor sampling. EPA/600/R-07/141, December 2007

Mass transport of oxygen within the vadose zone: Evidence for aerobic degradation under a slab

Victoria Lazenby, URS Australia Pty Ltd

Understanding oxygen transport and consumption in the vadose zone (the area between the land surface and the water table) at a contaminated site can be an important factor in the assessment of vapour intrusion from petroleum hydrocarbons. The presence of oxygen within the subsurface can substantially decrease measured concentrations of petroleum hydrocarbons (and various other compounds such as vinyl chloride), with the majority of volatile petroleum compounds aerobically degrading rapidly within a very narrow soil horizon once oxygen is encountered.

Obtaining site-specific soil vapour data that enable characterisation of the oxygen profile under future site conditions can be challenging. This is particularly true when assessing sites that have been decommissioned, are unsealed, or are proposed for large-scale or high-density redevelopment.

Site screening for vapour intrusion risk

There is a consensus regarding the approach to identifying the conditions where aerobic degradation of contaminated vapours is likely to occur, with the key factors including:

- degree of contamination
- distance of the source from the receptor point being assessed (often defined by exclusion distances)
- size of building or slab footprints overlying contamination source
- oxygen concentration measured within profile.

With these points in mind, guidance to quantify minimum exclusion distances has been prepared by a number of agencies, including various US state agencies[1] and CRC CARE (currently in Draft).[2] These guidance documents set out specific conditions for identifying sites where vapour intrusion will not be a significant issue, with the exclusion distances defined based on large empirical datasets.

For sites that cannot be omitted from further assessment based on exclusion distance criteria, a site-specific vapour investigation may be required. The last two factors listed above are of key interest when designing such a vapour assessment program, as obtaining representative site data that can adequately address both of these issues while producing a reasonable approach to risk assessment can be problematic.

This situation often arises when assessing vacant, cleared and/or decommissioned sites with future redevelopment likely to include a large slab or building footprint. If soil vapour data obtained from an area of open ground reports oxygen greater than 5% v/v, it may be necessary to further consider whether these data are representative of likely future conditions under a slab.

Modes of oxygen transport

The presence of oxygen within a soil vapour bore (installed within the vadose zone to allow sampling of contaminated vapours) – particularly in an unimpacted location where the oxygen is not being consumed through the hydrocarbon degradation process – provides the first line of evidence that oxygen can penetrate into the subsurface at the site. If the bore is located in an unsealed area, the presence of oxygen is likely to be largely due to passive diffusion from ambient air into the soil.

While the presence of a concrete slab is often assumed to inhibit the diffusion of oxygen into the subsurface, this isn't always the case. Experimental studies have been conducted to identify the vapour-phase diffusion coefficient of various molecules through cement for a range of chemicals. These studies have indicated that diffusion rates for oxygen and volatile organic compounds (VOCs) in concrete can be within two orders of magnitude of the diffusion rates of these compounds within low moisture soils. In addition, cracks or joins in the slab could provide pathways for diffusion of vapours through the slab. It follows that, if contaminant vapours are able to diffuse upwards through a concrete slab, smaller molecules of oxygen are likely to be able to diffuse downwards through that same slab.

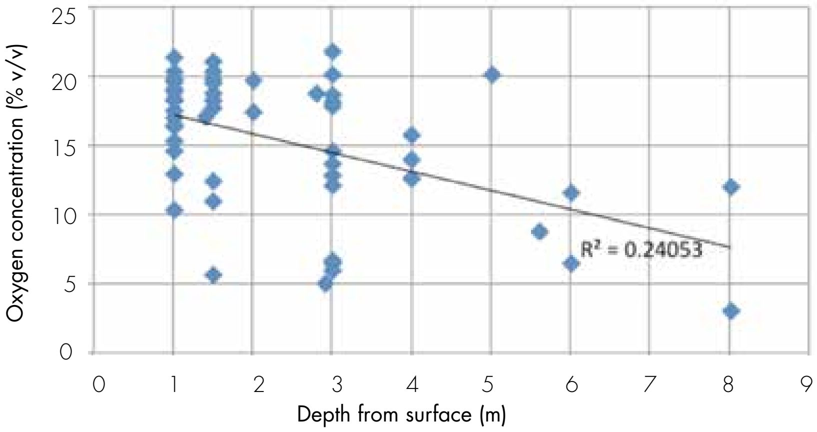
For situations where there is advective (active) vapour flow from the subsurface into a building, passive diffusion of oxygen downwards through a slab may be inhibited. However, these active flows within the subsurface will promote the migration of oxygen from the edges of the slab into the subsurface, further promoting aerobic degradation. This process is well presented in the BioVapor modelling tool.[3]

For many large buildings, both advective and diffusional transport of oxygen into the subsurface may occur through the sand pad beneath a slab, or along the shallow preferential pathways present around services and drains installed through the slab. Luo *et al*, [4] for example, collected sub-slab data below a large concrete foundation that clearly showed an increase in oxygen at the centre of the slab in the vicinity of a wastewater trench.

Oxygen flux into the vadose zone from ambient air or from within buildings may also be promoted due to the aerobic degradation process itself. This may occur through both diffusion and advective processes. The biological oxygen demand of the hydrocarbon degradation will result in decreased oxygen within the degradation zone. This will increase the concentration gradient between ambient air and the subsurface, promoting diffusion of oxygen into the vadose zone.

Additionally, hydrocarbon biodegradation consumes more molecules from the vapour phase than are produced by the degradation process, which would result in potential pressure-driven flows from ambient air into the subsurface in areas where aerobic degradation of hydrocarbons is occurring. Some site-specific evidence of this can be seen through oxygen enrichment in surface soils beneath a slab, as discussed below.

Figure 1. Oxygen concentrations relative to depth in unimpacted soil vapour wells



Field measurements of oxygen in the vadose zone

Field measurements of oxygen, carbon dioxide and methane were collected from a number of permanent soil vapour wells installed by URS Australia at multiple depths across 12 sites located in Victoria and South Australia. Data were collected from each location using a portable landfill gas meter, with evacuated stainless steel canisters used to collect samples for VOC analysis. These data were compiled into a database, which allows an estimation of the likely oxygen migration distances into the subsurface, based on passive diffusion only.

The compiled data indicated that oxygen levels from unimpacted soil vapour locations penetrated considerable depths into the vadose zone (Figure 1). The depth of penetration is potentially to greater than 8 m at concentrations exceeding the target of 5% v/v.

This 5% criterion is generally established as the maximum concentration of oxygen measured at a data point, for the data point to be considered representative of under-slab conditions. However, diffusion from the atmosphere alone is shown to result in higher levels at some distance from the unsealed surface. It should be noted that this diffusion can be limited in some situations, such as where contamination sources are present at shallow depth, or within fractured rock.

In the case of fractured systems, trends in oxygen concentrations with depth were inconsistent. Oxygen concentrations at near-atmospheric levels were reported relatively deep into the vadose zone at some locations, while negligible levels were reported at shallow depths in others. Therefore, soil vapour data from bores installed within basalt were excluded from the data represented in Figure 1 due to the complexities of vapour migration within fractured basalt.

As a comparison, Figure 2 shows the relationship of oxygen relative to depth according to the surface cover above the soil vapour well, with data grouped as unsealed, asphalt or concrete surface covers. These data show that the concentration gradient of oxygen relative to depth is a stronger relationship beneath sealed surfaces, particularly concrete, with no correlation between oxygen levels and depth in the unsealed bore locations. The graphs show that oxygen at close to atmospheric levels was still recorded in shallow soils (less than 1.5 m below ground surface) underneath the slab at the sites reviewed here. Of particular note is that oxygen levels were above atmospheric concentrations in the vadose zone in three locations, with all three wells installed beneath a concrete slab. This elevated oxygen provides evidence that oxygen is being drawn into the subsurface through processes other than diffusion at contaminated sites, even when a slab is present.

There are a range of other variables that can influence the likelihood of oxygen penetration or of aerobic degradation occurring. Some factors that may reduce the likelihood of aerobic degradation include elevated organic matter in the soils, methanogenesis (formation of methane by microbes) resulting in elevated biological oxygen demand, direct contact of contamination with a slab, the potential for localised vacuums induced by hydrocarbon biodegradation, or very narrow separation distances. As with all environmental investigations, each site must be considered individually

REFERENCES

1. Eklund, B., Beckley, L., Yates, V. and McHugh, T. E, 2012. Overview of state approaches to vapour intrusion. Remediation 10.1002/rem, 7-20.
2. Wright, J. 2012. Draft Petroleum Vapour Intrusion (PVI) Guidance . CRC for Contamination Assessment and Remediation of the Environment Technical Report.
3. API, 2008. BioVapor: A 1-D Vapor Intrusion Model with Oxygen-Limited Aerobic Biodegradation.
4. Luo, H., Dahlen, P., Johnson, P.C., Peargin, T. and Creamer, T, 2009. Spatial variability of soil-gas concentrations near and beneath a building overlying shallow petroleum hydrocarbon-impacted soils. Ground Water Monitoring and Remediation 29, 1, 81-91.

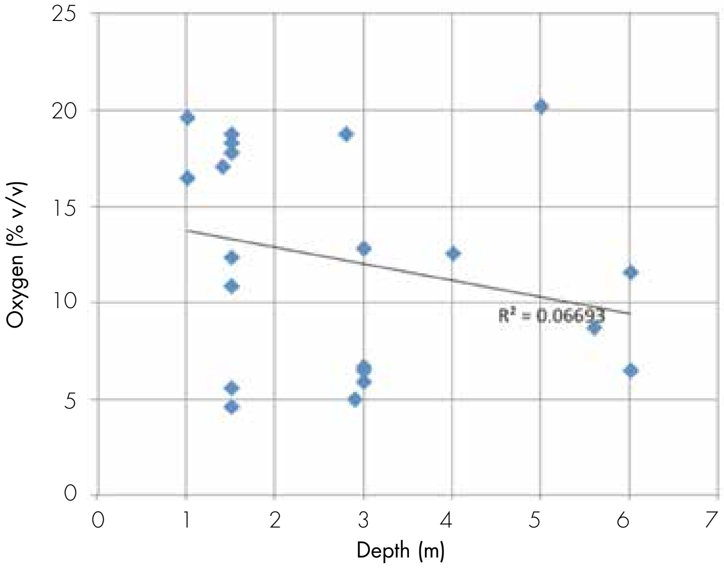
to ensure appropriate assumptions regarding contaminant behaviour.

For sites where significant petroleum contamination is present, or if impacts are at very shallow depths, mass transport of oxygen may not be significant enough to promote sufficient aerobic degradation of petroleum hydrocarbons to entirely mitigate the vapour intrusion pathway. However, if soil vapour data indicate that oxygen will migrate into the vadose zone at a site, and petroleum impacts are shown to be attenuating with distance from the source, aerobic degradation will limit the likelihood of vapour intrusion issues occurring following site redevelopment. This will occur due to oxygen transport occurring through a combination of processes as discussed above, including diffusion from ambient air, diffusion across a slab and through cracks, advective flows into the building, and advective and diffusive flows into the zone of aerobic degradation.

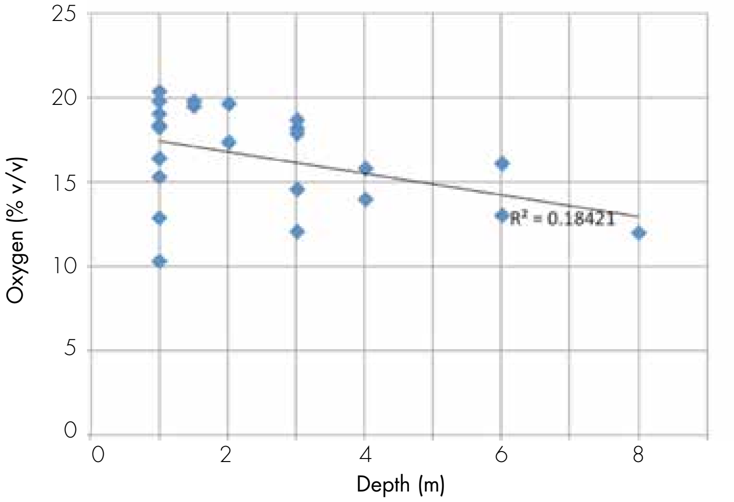
By using multiple lines of evidence, soil vapour data collected from an undeveloped site with oxygen levels greater than 5% v/v in the soil vapour may still be appropriate for assessing larger-scale future redevelopment scenarios.

Figure 2. Oxygen concentrations relative to depth under asphalt, concrete and unsealed surfaces

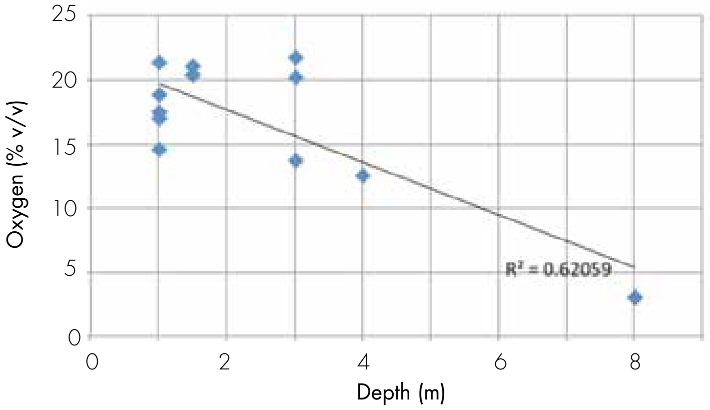
Unsealed



Asphalt



Concrete



Landfill mining technologies: part 2

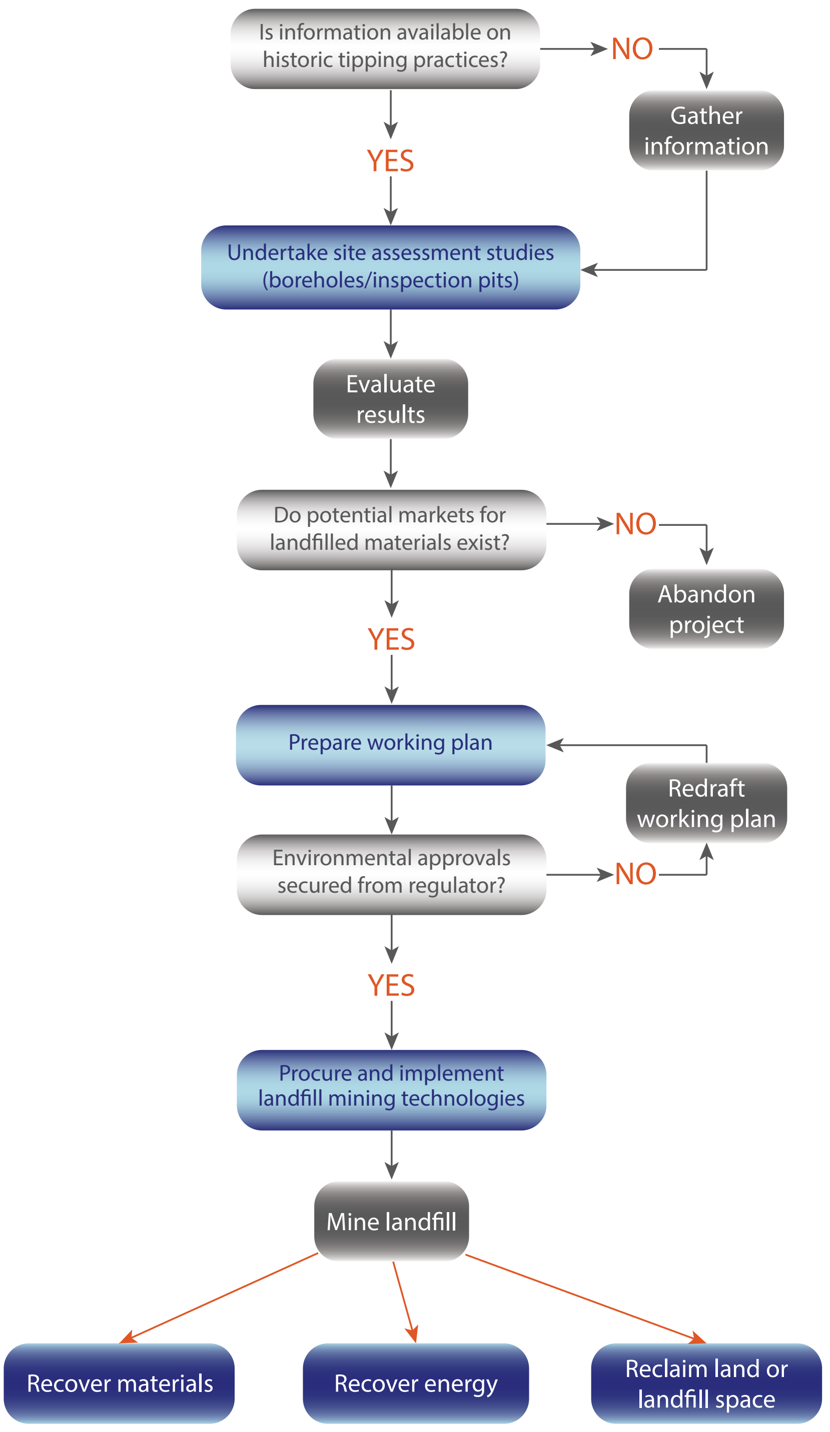
Paul Clapham, Sinclair Knight Merz

The second in a series on landfill mining focuses on the technologies and approaches that can be taken to recover materials and energy from closed and working landfills.

Although landfills have traditionally been viewed as repositories for society's waste, they are increasingly being seen as potential reserves of materials and energy. While landfill gas extraction is now accepted as mainstream technology, landfill mining is a relatively new concept and can be defined as the removal of materials already in landfill and their use for beneficial purposes.

The US Environmental Protection Agency has estimated that approximately 30% of materials by weight in a municipal landfill are paper and wood products and 17% are plastics. In 2009, the Australian Federal Government reported that 30.5% of the municipal solid waste (MSW) stream (i.e. waste collected from households and similar properties) that was being sent to landfill comprised paper and paper board, garden and park waste, and wood and wood waste. By comparison these waste types represented 32% of the commercial and industrial waste stream being landfilled; but only 11% of the construction and demolition waste that was being sent to landfill. For the same waste streams (i.e. MSW, commercial and industrial, and construction and demolition), inert waste (including concrete, metal, plastic and glass) represented 28%, 37.5% and 89%, respectively. In energy terms the calorific value of these materials range from zero for concrete, metals and glass, to about 8 MJ/kg for park and garden waste, and more than 25 MJ/kg for plastics. Economic recovery of the higher calorific value waste types would allow them to substitute for fossil fuels, with the biogenic component (i.e. that derived from the wood, paper and card) potentially qualifying as renewable energy production.

A decision tree to help with planning safe and cost-effective landfill mining.



Although material and energy recovery has become the Holy Grail of landfill mining, there can be other drivers. Reinhard Goeschl of Innovation und Technik AG has identified three reasons:

- concerns about pollution being caused by a landfill (the environmental reason)
- an opportunity to create space for new infrastructure (the commercial reason), and
- a shortfall in void space at a particular landfill (the new volume reason).

A brief history

One of the earliest examples of landfill mining comes from Israel where, nearly 50 years ago, the City of Tel Aviv's municipal dump was excavated and the material sorted to recover the organic and sediment fractions to help reclaim land for agriculture. Waste was extracted from the landfill using a front-end loader that deposited the material on to conveyors before it was passed through a trommel. The technology limitations of the time meant that the soil amendment that was manufactured from the recovered material was heavily contaminated with glass and could only be used for surface dressing in citrus groves. Nevertheless, the soil amendment had a total nitrogen, phosphorus, and potassium (NPK) concentration of 1.4%, providing a much needed nutrient boost to the reclaimed desert lands.

Since the 1970s, small-scale attempts have been made to mine landfills in the USA. Cells constructed in a private sanitary landfill in Barre, Massachusetts, were almost completely impervious to penetration by precipitation and the waste in the cells was virtually in its original state 30 to 40 years after being deposited in the landfill. By comparison, field tests at the Collier County landfill in Florida found that the recovered ferrous and plastics fractions contained substantial levels of contamination which adversely effected their value as recyclable materials: an illustration of the fact that local landfilling practices, as well as climate, can have an impact on the degree of decomposition and the quality of the materials that can be recovered from landfills.

Managing risk

Whatever the local reason for mining a landfill, it should be recognised at the outset that the excavation of waste from a closed or active landfill can have its own environmental consequences. Chief among these are issues of uncontrolled release of landfill gas and leachate. Methane-rich landfill gas can pose serious environmental and health and safety issues (methane is explosive at concentrations between 5% and 15%); while leachate can contaminate surface and ground water bodies. Other concerns include slope stability at the working face as material is removed from the landfill, and the release of odours and bioaerosols from the waste during the extraction and processing phases. Given these issues, it is likely that an operational plan will need to be prepared and submitted to the regulatory authorities before permits can be issued and work started.

With these inherent risks, a working plan should be drafted before commencement of any landfill mining project. The working plan and its supporting documentation should contain information about the waste that is contained in the landfill and the methods that were used to deposit the material – for example whether the waste was ‘loose-tipped’ or deposited in engineered cells. Site records may exist that provide much of this information (such as old photographs, survey data, waste deposit records, borehole data and monitoring records), but in their absence, interviews with existing and former site managers and operatives may yield eyewitness accounts of former working practices. It is also likely that the regulator will require site-specific data on the current state of the waste, which can be obtained by digging test pits at locations across the landfill.

Prior to the extraction of the waste from the landfill, it may be necessary to implement infrastructure including access roads, the creation of leachate or surface runoff retention cells, and the removal of cover material. Problems associated with landfill gas can be addressed through two mechanisms. The first is increased pumping of landfill gas to create a ‘negative pressure’, provided a landfill gas extraction system is already in place. The second method – so-called aerobisation of the landfill – is designed to kill off the methane-producing microbes within the landfill and stimulate aerobic decomposition conditions leading to the production of carbon dioxide as opposed to methane. At its simplest, aerobisation can be achieved by inserting 3.5-metre-long lances into the landfill in a grid array at 5- to 6-metre intervals. Air is forced through the lances and aerobic conditions can be achieved in as little as 200 minutes.

The excavation of the waste material from the landfill can be achieved through the use of front-end loaders or backhoes. The extracted waste is typically deposited on to a series of conveyors and processed through a combination of trommels (rotary sieves); shredders; overband magnets (to remove ferrous metals); and eddy current separators (to remove non-ferrous metals). In many instances the degradation processes within the landfill will have adversely affected the quality of plastics, so reprocessing of polymers is unlikely to prove attractive. Thus the plastic fraction is typically combined with the wood, paper and card to produce a refuse-derived fuel to be combusted in a dedicated waste-to-energy facility or co-combusted in a power station. The recovered glass, aggregate and soil fractions can be used to refill the void or as daily cover at the landfill.

Energy recovery

Over the last two decades, attention has been focused on energy recovery as well as recycling of previously landfilled material. In the USA in 1990, the municipal authority in Lancaster County, Pennsylvania, USA completed a three-train, 1100 tonnes per day mass burn incinerator. When combustion operations started it was discovered that the incinerator had excess capacity. To fill the gap, wastes that had previously been landfilled at the county’s Frey Farm landfill were excavated and added to the fresh MSW in a ratio of approximately 1:3 (by weight). Although the addition of the mined waste decreased energy yields at the incinerator by about 160 kWh per tonne of fuel burnt, the benefits were substantial: the energy value of the mined material was estimated to be US $33 per tonne and mining the landfill has conserved landfill space for future use.

In 2010, UK company Advanced Plasma Power (APP) formed a joint venture with the Belgian waste management company Group Machiels to mine 16.5 million tonnes of municipal waste dumped since the 1960s at a landfill site near Hasselt in eastern Belgium. The project is scheduled to become operational by 2014 and is designed to generate 60 MW of power, enough to supply 60,000 homes. APP's gas plasma process subjects the waste to temperatures in excess of 10,000 °C. The organic material (wood, paper, card, and plastics) in the waste dissociates to produce a hydrogen- and methane-rich 'syngas' (synthesis gas) which can be burnt to produce power. The metals present in the waste become molten and can be tapped off and recovered; whereas the remaining inorganic material becomes fused as a slag, which APP proposes to convert into a building material called Plasmarok.

The Belgian landfill mining and energy generation project is an exciting opportunity for recovering value from landfilled materials. As with so many novel technology processes, however, the devil will come in the detail and it may be salutary to remember the experience in St. Lucie County, Florida. In 2007 the county signed a contract with Atlanta-based Geoplasma to construct, operate and finance a plasma gasification facility to treat MSW from Fort Pierce and Port St. Lucie. The contract was cancelled in 2012 because of economic conditions, a lack of money and the decision by Fort Pierce to pull out of the scheme. Despite such occasional failures, landfill mining provides an alternative to more conventional waste management solutions and has a role to play in delivering what has been termed the 'circular economy' where discarded materials are either remanufactured into new goods or converted into energy.

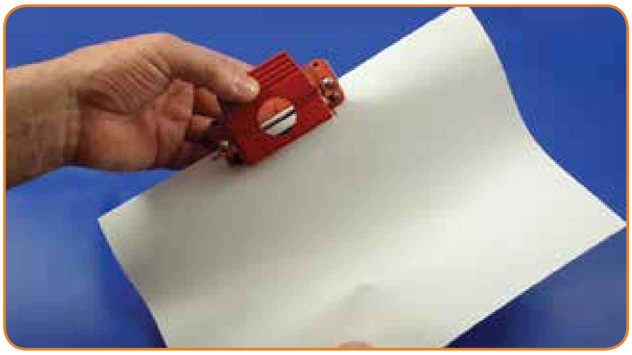
The final article in this series will look at the potential role of landfills as designated, temporary repositories of discarded materials, which can be reprocessed when suitable economic conditions prevail and more appropriate technologies are available.

FURTHER READING

For an introduction to landfill mining, see Mining landfills for energy and more on pages 13–15 of Remediation Australasia issue 11.

Research RoundUp

Identification of existing guidance for a National Remediation Framework



In 2011 the National Remediation Framework Steering Group was established to provide strategic advice and to oversee the development of the National Remediation Framework (NRF). Bringing together high level representatives from government, industry, academia and the community sector, the group is endeavouring to build upon the resources that are already available, with the aim of developing a 'harmonised guidance on the practicalities of cleaning up contaminated sites'. The production of this guidance document involves the synthesis of many smaller projects, some of whose objectives include:

- identifying existing guidance on site remediation (Australian and international) that may be adopted or adapted by the NRF.
- reviewing the guidance to assess whether it meets the needs of the proposed framework, and providing recommendations for adoption or adaptation, focusing on:
    a. development of remediation and management plans
    b. implementation of remediation plans, and
    c. post-remediation considerations.
- conducting a data gap assessment to determine whether there are omissions in the existing guidance.

As part of this project, the NRF team identified, from both Australian and international jurisdictions, 122 documents that may have content appropriate for inclusion in the NRF. Of these, 38 were rejected, with 84 documents remaining for detailed review.

In addition, data gaps in the available guidance were identified for the following requirements:

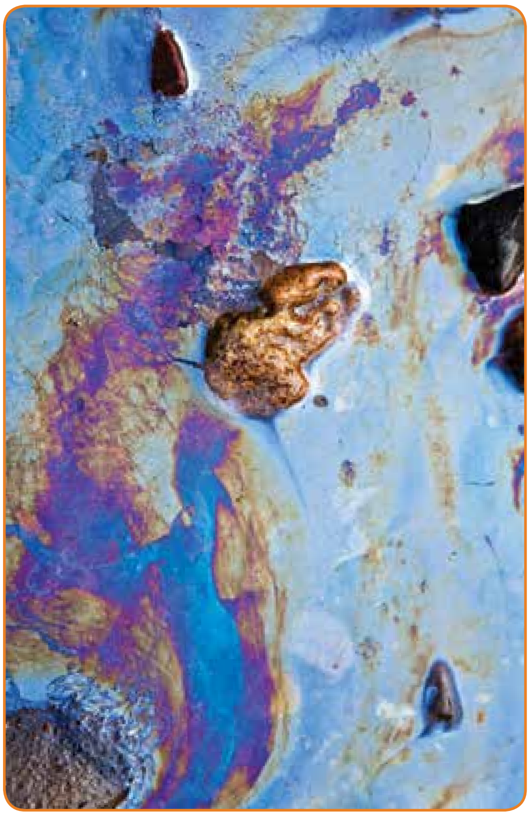
- treatability studies (high significance)
- cost–benefit and sustainability analysis (medium)
- stakeholder consultation and decision making (medium)
- health and safety considerations – worker and public (low)
- environmental considerations (low)
- community consultation and risk communication (low)
- remediation validation (medium)
- long-term monitoring and contingency plan (high)
- institutional controls (high).

To address the data gaps, CRC CARE researchers are developing Australian national guidance on these topics. ■

Bioremediation of hydrocarbon-contaminated soils in arid regions

Hydrocarbon soil contamination is one of the most common contamination issues faced by the mining sector in Australia. Much hydrocarbon contamination occurs in Australia's arid regions, where remediating soil presents unique and challenging problems. In the past, a range of treatment methods have been used with limited success, but to date there has been little investigation of the efficacy or sustainability of these practices. Biological treatment (bioremediation) is often used to remediate hydrocarbon-contaminated soils, as it is viewed as a sustainable and cost-effective option. However, arid regions are often subjected to such environmental extremes as extreme differences between maximum and minimum temperatures, fluctuating soil moisture, and native microbial flora that may be ineffective hydrocarbon degraders. To aid in better planning and management for the bioremediation of arid soils, CRC CARE, in collaboration with BHP Billiton, is leading research focusing on the effect of these diverse conditions on bioremediation in Australia. The primary focus of this research is to delineate the soil conditions that may inhibit bioremediation of hydrocarbon-contaminated soils subjected to arid climatic conditions, and to determine soil parameters that enhance the microbial mineralisation of such contaminants. ■

Modelling practical LNAPL recovery – remediation endpoint and risk longevity



The assessment and remediation of light, non-aqueous phase liquids (LNAPLs) is one of the greatest challenges to corrective action and clean up at petroleum manufacturing, storage, and handling facilities. Nearly half of Australia's contaminated sites – including refineries, bulk product terminals, gas stations, airports, and military bases – contain petroleum hydrocarbons. Difficulties with assessment and recovery of LNAPLs mean that they are often implicated as a long-term source of risk and exposure issues (e.g. vapour, groundwater and soil contamination), acute-risk concerns (e.g. explosive conditions), and LNAPL mass concerns (e.g. regulations that require recovery of 'free-product,' 'free-phase hydrocarbon,' or 'liquid-phase hydrocarbon'; for aesthetics or mass reduction reasons; or for potential LNAPL migration).

To address the issue of LNAPL management, CRC CARE has brought together companies and regulators to develop strategies and policies for assessing and recovering LNAPL in the subsurface. The current research project involves the use of known quantities of release, subsurface and recovery volumes to test methods to estimate volumes when one or more of these states is unknown. With this information, this project aims to develop a model that predicts the remaining volume of LNAPL and its subsequent fate characteristics over the long term as a means of assessing its ongoing risk profile (i.e. the longevity of the source of risk). ■

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Remediation Australasia is a quarterly magazine for the Australasian remediation industry.

Remediation Australasia includes a range of full technical articles, regulator updates, case studies, training events, publications, and news relating to new technologies and research developments, keeping the reader ahead of the public debates and scientific advances within the industry. It informs people working in the remediation industry about new research and outcomes that may impact on their business, and helps them to better respond to the challenges of dealing with contamination. To subscribe, fill out the form below and return it to us, or email us with your details.

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Training and events calendar

March

11–15 Global Mineral Industry Risk Management training course

JKTech/Brisbane

www.jktech.com.au/g-mirm

19–22 Practical Monitoring for Improved Environmental Performance for the Resources Sector

JKTech/Rockhampton

www.jktech.com.au/practical-monitoring-improved-environmental-performance-resources-sector-qld

April

15–19 Global Mineral Industry Risk Management training course

JKTech/Perth

www.jktech.com.au/g-mirm

22–23 The Fundamentals of Acid and Metalliferous Drainage

JKTech/Brisbane

www.jktech.com.au/fundamentals-acid-and-metalliferous-drainage-qld

June

10–13 Groundwater Pollution and Remediation

SRIT/Sydney

www.srit.com.au/course_details.php?id=31

August

6–8 Australian Mine Rehabilitation Workshop

JKTech/Adelaide

www.jktech.com.au/amr2013

September

15 -18 CleanUp Conference

CRC CARE/Melbourne. See www.cleanupconference.com and pages 24 – 25 of this issue for more information.

CRC CARE workshops

CRC CARE is currently scheduling a range of training workshops for 2013, including the following (dates to be confirmed soon):

- LNAPL remediation – April/May
- Assessment of Site Contamination NEPM Training Roadshow – May/June – this 2-day course will visit all states to update attendees on the NEPM's new elements.

Save the Date

We've searched the world for some of Australia's most exciting exports. Join us in March 2013 to meet them.

The 2013 Advance Global Australian Awards Forum and Ceremony will bring together some of Australia's leading global talent for an inspiring lunchtime event.

12pm for lunch

Thursday 21 March 2013

Museum of Contemporary Art, Sydney

Join current and emerging leaders as we reveal our second annual Award winners and the winner of our 2013 Advance Global Australian Award.

Our Advance Global Australian Award mentees will also be exclusively revealed at the event.

Tickets go on sale shortly. For more information, please visit: **www.globalaustralianawards.com**

Australian Government

Advance receives funding support from the Australian Government

Publications update

This section contains publications that have been published in the last 3 months (since the last edition of *Remediation Australasia*). The publications may originate from research institutions, regulators or industry groups. Let us know if you have any appropriate publications (no promotional material) for inclusion by emailing **victoria.leitch@crccare.com**.

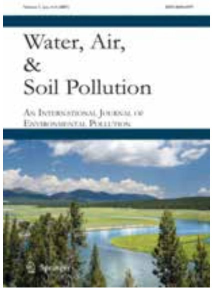
Cadmium contamination and its risk management in rice ecosystems

Bolan, Makino, Kunhikrishnan, Kim, Ishikawa, Murakami, Naidu & Kirkham 2013, in Advances in Agronomy vol. 119 pp: 184–273.

Clean coal technology combustion products: properties, agricultural and environmental applications, and risk management

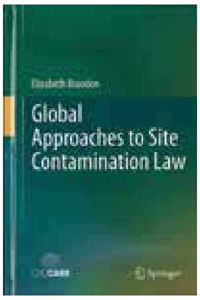
Seshadri, Bolan, Naidu, Wang & Sajwan 2013, in Advances in agronomy vol. 119 pp: 310–370.

Available for purchase at www.sciencedirect.com/science/bookseries/00652113



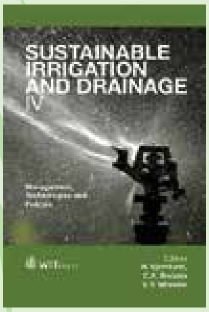
A comparison of water treatment sludge and red mud as adsorbents of As and Se in aqueous solution and their capacity for desorption and regeneration

Zhou & Haynes 2012, Water, Air and Soil Pollution 223, pp. 5563–5573.



Global approaches to site contamination law

Brandon 2013, Springer Science and Business Media, Dordrecht.



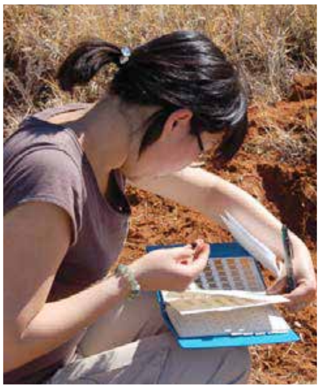
Nutrient management in effluents derived from agricultural industries

Matheyarasu, Seshadri, Bolan & Naidu 2012, in Bjornlund, H., Brebbia, C.A., Wheeler, S. (eds), Sustainable Irrigation and Drainage IV – Management, Technologies and Policies. WIT Transactions on ecology and the environment, vol. 168, pp. 213–224.

Greenhouse gas emission from wastewater irrigated soils

Thangarajan, Kunhikrishnan, Seshadri, Bolan & Naidu 2012, in Bjornlund, H., Brebbia, C.A., Wheeler, S. (Eds), Sustainable Irrigation and Drainage IV – Management, Technologies and Policies. WIT Transactions on ecology and the environment, vol. 168, pp. 225–236.

In 2013, CRC CARE will launch Associate Membership for businesses, industry bodies and government agencies. Associate Members will have access to the latest developments in contamination research, technology, policy and regulation, as well a suite of other exclusive benefits. For more information contact Michy Kris at michy.kris@crccare.com



Enhance your career with a research degree in environmental remediation.

CRC CARE is offering three PhD scholarships, valued up to $28,500 p.a. (tax free) for three years, for potential candidates to undertake projects focussed on light non-aqueous phase liquids (LNAPLs).

Australian petroleum industry and regulatory agencies wish to support improved understanding of the sustainable remediation of LNAPLs, such as petroleum fuels in groundwater environments. Such improved understanding will be developed through better field-scale quantification of the effectiveness of remediation strategies in removing LNAPLs from aquifers, thereby reducing exposures and risks. There are currently 3 research projects available:

- Field evaluation of the inter-comparison of petroleum (LNAPL) remediation technology efficiencies in complex fractured and/or porous media
- Multiphase modelling of petroleum (LNAPL) remediation options in aquifers with complex geologies
- Quantifying the transient risk due to petroleum (LNAPL) removal from impacted sites

The PhD students will work closely with project investigators, consultants and other specialist staff on this well funded, industry linked project. The projects will be conducted at CSIRO Land and Water, Floreat Western Australia in partnership with the University of Technology Sydney (UTS), and jointly with industry partners where field investigations are undertaken and applications tested.

For further project related information, please contact:

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Visit **www.crccare.com** for more information on these and other scholarship opportunities.

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