SoBRA
The Society of Brownfield Risk Assessment

SOCIETY OF BROWNFIELD RISK ASSESSMENT

2016 Summer Workshop Outputs

Site Investigation and Risk Assessment for Historic Landfill Redevelopment

PUBLICATION

This report is released by the Society of Brownfield Risk Assessment (SoBRA). It presents a written record of the discussions held during the Summer 2016 workshop. Attendees for each workshop are listed in the relevant section. Any views expressed in this report are not necessarily those of SoBRA or any of the contributing individuals or their employers.

It is imperative that readers consider this information in conjunction with the presentations and do not rely solely on the text presented herein.

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1 INTRODUCTION

The Society of Brownfield Risk Assessment (SoBRA) was established in December 2009 with the principal aim of promoting technical excellence in land contamination risk assessment in the United Kingdom (UK). As part of achieving this aim, SoBRA undertook to host regular conferences and workshops on technical subjects of interest to UK risk assessors and to facilitate and widen access to the dissemination of knowledge regarding land contamination risk assessment.

SoBRA held a one day workshop in June 2016 entitled "*Site Investigation & Risk Assessment for Historic Landfill Redevelopment*". The morning comprised a series of presentations from experts in the field as listed below.

- "*Achieving the successful redevelopment of a former landfill through the innovative application of real-time Volatile Organic Compounds (VOC) boundary air monitoring*" from David Jacob (RSK) and Aldona Rahman (Royal Borough of Windsor and Maidenhead);
- "*Controlled Waters Detailed Quantitative Risk Assessment (DQRA)*" from Charlotte Wakefield and Thersea Cory (Environment Agency);
- "*Use of Leaching Tests in Controlled Waters (CW) DQRA*" from Brian Bone (Bone Environmental Consultants);
- "*Landfill Gas Case Study*" from Sarah Mortimer/Steve Wilson (EPG) & James Clay (Campbell Reith);
- "*Remediation: Helpston landfill case study (Part 2A Special Site)*" from Lee Wood (Hydrock); and
- "*Feasibility of landfill mining and approaches to risk assessment*" from Simon Burr (Campbell Reith).

Readers are referred to the SoBRA website for pdf copies of the expert speaker presentations.

The afternoon comprised workshop sessions on four themes:

- Conceptual Site Models and Site Investigation;
- Controlled Waters Risk Assessment;
- Landfill Gas; and
- Landfill Mining.

This document provides a record of the discussions held in the four workshops. The conclusions and recommendations will be considered further by the SoBRA and the Executive Committee and used to potentially shape future SoBRA reports, projects and events.

Those individuals who were registered to attend each workshop are presented in Appendix 1. The preparation material for each workshop (provided to participants in advance of the workshop day) is presented in Appendix 2.

2 CONCEPTUAL SITE MODELS AND SITE INVESTIGATION

2.1 Introduction

The Conceptual Site Model (CSM) and Site Investigation group attendees included consultants (large and small), Local Authorities (urban and rural), academia, contractor-consultants, ground investigation companies and the Environment Agency. Delegates were present from throughout the UK. Discussion was led by Craig Hampton of the Environment Agency as facilitator with Jane Thrasher of Jacobs as rapporteur.

2.2 Objective

The objective of the workshop was to consider key issues associated with the CSM and site investigation for landfill sites. Delegates were asked to consider a wide range of issues to identify those representing accepted scientific understanding and/ or good practice, and those which require further work to extend, improve or clarify current understanding or practice.

A number of pre-defined questions formed the basis of the discussion. However, prior to addressing these specific questions, a more general discussion was held with regard to issues which were considered important to cover. These were then picked up as relevant through the workshop.

2.3 Key Issues

2.3.1 Conceptual Site Model

It was agreed that a good conceptual model was fundamental to landfill site investigation design, and should be based on a desk study using information from as wide a range of sources as possible.

Definition of the source term is important, particularly when identifying the contaminants of concern. Where available, landfill operators should be consulted. However, for older landfills the operators are seldom available. Even where records have been kept they may be very generic and the meanings of descriptive phrases may have changed over time (for example, 'inert' waste in the 1940s could include foundry sand). Local knowledge can be invaluable, but anecdotal information can be of dubious quality (*e.g.* the ubiquitous 'lorry' or 'steam engine' alleged to have been buried in many landfills). Some sources now considered significant were just not recorded, *e.g.* asbestos insulating boards. Even radiological disposal (*e.g.* laboratory waste) may not initially be identified in a standard desk study.

A good understanding of the expected geology and hydrogeology and any engineering or containment measures is important. This is particularly important in considering the safety of the design and minimising the risk to sensitive receptors, *e.g.* an underlying aquifer.

2.3.2 Assessment requirements

The motive and objectives of any site investigation need to be clearly understood. It should be expected that site investigation is an iterative process. For the redevelopment of a former landfill site, it would be expected that there would be multiple phases of investigation as the conceptual model was refined and risk assessment and site design was developed.

2.3.3 Most appropriate drilling techniques for former landfill sites

It was agreed that the most appropriate drilling techniques depend very much in the circumstances - including the CSM and the objectives, site access, safety considerations and other constraints. The need for geotechnical information should also be taken into account, to make the ground investigation cost effective. With regard to specific methods, some practitioners had found dynamic cone penetration testing useful for characterisation. The availability of guidance with regard to drilling methods was discussed and it was agreed that in practice the experienced drilling contractors were best placed to advise on suitable methods. In many cases it was beneficial to have the option of alternative drilling methods available during the site investigation to meet different needs.

2.3.4 How to account for the heterogeneous and unpredictable nature of waste in intrusive investigation (number of sample locations/ gas/ leachate/ groundwater wells)

The discussion turned to the use of statistics in landfill investigation. It was agreed that the statistical methods normally applied to contaminated land were unlikely to be applicable to landfill investigation, as the amount of data required would be unfeasibly large.

The benefits of using trial pits to expose a larger surface area of waste and thus improve characterisation, was discussed. It was recognised that there are no consistent agreed methodologies for recording the description of landfill made ground and landfill waste making logging very subjective and log interpretation difficult.

When investigating landfills, the heterogeneity of the waste can make it difficult to collect sufficiently representative samples if only the solid media are sampled. The delegates recognised that sampling and analysis of groundwater or leachate can be useful to obtain a composite sample of mobile contaminants present, and to provide an indication of the more general source.

An iterative approach to ground investigation was recommended by most workshop participants, with further data being collected as more information became available in the waste heterogeneity, and as critical uncertainties were identified. This may result in later stages targeting material with high gas or leachate generation potential.

2.3.5 Laboratory analysis requirements (difficulties in analysing sample matrix, analysis of emerging contaminants)

The importance of having a broad enough testing scope to capture the plausible contaminants of concern was agreed. However, a standard suite of possible contaminants was not considered desirable and it was preferable for the suite to be tailored to the desk study. The use of screening methods including Gas Chromatography – Mass Spectroscopy Tentatively Identified Compounds (GC-MS TIC) and Time of Flight analysis to pick up unforeseen organic contaminants was also advocated. It is important to have adequate limits of detection when undertaking leachate analysis.

When assessing data it is important for the practitioner to understand the sampling approach and sample preparation method so they can in turn understand how representative the results are of the material as a whole. For example, whether the sampler has collected only material small enough to fit into the sampling container, and whether the analysis has been limited to particles below a certain sieve size.

The importance of using an accredited laboratory and including Quality Assurance (QA)/ Quality Checks (QC) checks was also agreed by all present.

When investigating landfills, the heterogeneity of the waste can make it difficult to collect sufficiently representative samples if only the solid media are sampled. The delegates recognised that sampling and analysis of groundwater or leachate can be useful to obtain a composite sample of mobile contaminants present, and to provide an indication of the more general source.

2.3.6 Additional requirements – increased potential for contamination of underlying aquifers.

The potential conflict between the need for investigation for risk assessment, and the potential to create new migration pathways through the investigation process was discussed. The importance of the comprehensive desk study was reiterated, and the need for precautionary drilling methods where there was high risk or greater uncertainty, for example, when trying to establish if there was a basal liner between the waste and the underlying aquifer. Precautionary drilling methods such as dual skin could be used.

The importance of good liaison with regulators prior to undertaking ground investigation was emphasised.

2.3.7 Innovations in landfill investigation

The workshop delegates were asked for examples of practical and effective innovations in landfill investigation techniques.

- Drones

Drone based technology was being utilised (or offered) for rapid survey of topography (including settlement), of vegetation stress and dieback, for investigation of large unsafe structures on an abandoned landfill (Republic of Ireland not UK). The possible use of infra-red cameras on drones was also discussed (though not yet seen in practice).

- Lidar

Lidar information was also recommended for topographic survey and subsidence assessment.

- Portable Analytical Techniques

The use of portable technology including GC-MS was discussed. It was recognised that the technology has not had the uptake anticipated when it was introduced, and a number of factors were considered responsible. These include the mobilisation cost (including operator training) and need for laboratory validation testing, making it generally not cost effective for most investigations which are of relatively short timescale and lower sampling frequency.

- Real-time Monitoring

Real-time gas monitoring and continuous gas monitoring are being used. Some users reported mixed findings with continuous gas monitoring technology, with inconsistencies in the data raising more questions than were answered, and difficulties validating the results with conventional monitoring.

- Gore Sorber ™

The use of Gore Sorber ™ technology for passive soil gas sampling was recommended by some delegates as an innovative technique that appeared to offer real advantages in a cost effective and practical manner.

- Advanced Geophysics

Advanced Geophysics was considered practical for investigating historic landfill sites as a non-intrusive method providing imagery of both lateral and vertical extents of historic landfill. A multi-technique approach using resistivity imaging, ground penetrating radar and electromagnetic ground conductivity was recommended. Those experienced in geophysics were considered best placed to advise on a site specific basis as technique and survey parameters must be selected to suit site conditions, desired depth penetration and survey objectives.

2.4 Conclusions and Recommendations

It was agreed that a good conceptual model was fundamental to site investigation design, and should be based on a desk study using information from as wide a range of sources as possible.

The workshop felt that one of the biggest challenges facing those investigating and assessing ground investigation data from closed landfills was the inconsistency in approaches to logging heterogeneous made ground in landfills. Whilst British Geological Survey classifications for artificial ground exist[1], it was recommended that guidance including a standardised logging method for made ground in landfills should be developed.

[1] Earthwise issue 20, British Geological Survey (2004). Artificial ground mapping our impact on the surface of the Earth. https://www.bgs.ac.uk/staff/docs/4600/MAPPING_OUR_IMPACT_2004.pdf Last accessed 3rd May 2018.

3 GROUNDWATER RISK ASSESSMENT FOR THE REDEVELOPMENT OF LANDFILLS

3.1 Introduction

The groundwater risk assessment modelling workshop was facilitated by Brian Bone of the Environment Agency (EA) . The rapporteurs were Theresa Cory and Charlotte Wakefield also of the EA. Group attendees included consultants (large and small), academia, laboratories and the EA. Delegates were present from throughout the UK.

The presentation delivered earlier in the day provided the introduction to the session, which covered a brief history of landfill permitting and some of the EA officers' observations on the submitted hydrogeological risk assessment for landfill sites (current permitted and historical landfills).

3.2 Objective

The objective of the workshop was to consider key issues associated with the DQRA for landfill sites. Delegates were asked to consider a wide range of issues and identify the main areas of concern, priorities, barriers and uncertainties with examples of credible risk assessment principles or methodologies that are accepted by the broad risk assessment community. A number of pre-defined points formed the basis of the discussion.

3.3 Key Issues

3.3.1 Objectives setting/ Framing the assessment/ Regulatory context

It was identified that it is important to have a clear understanding of what is driving the models when assessing risks to the water environment from landfill sites such that an appropriate data can be collected and models selected.

It was agreed that the regulatory regime and context should be confirmed as part of the assessment objectives as Scottish Environment Protection Agency (SEPA)/ EA/ Natural Resources Wales (NRW) may have specific guidance/positions for Water Framework Directive (WFD) and Groundwater Daughter Directive (GWDD).

The Definition of Hazardous Substances: Joint Agencies Groundwater Directive Advisory Group (JAGDAG)[2] and UKTAG consultation outcome was also discussed.[3]

3.3.2 Approaches to modelling and risk assessment

The following products are readily available and used:

- LandSim[4];
- Remedial Targets Methodology (RTM)[5];
- ConSim[6]; and
- ESI Risk Assessment Modelling (RAM)[7].

It was felt important to include all justifications of parameters used in the risk assessment particularly when choosing Probability Distribution Functions (especially in LandSim and ConSim). It was also considered important to state and identify key areas of uncertainty in the models used. This is already considered industry normal practice.

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[2] JAGDAG is made up of representatives from the Environment Agency, Natural Resources Wales, Scottish Environment Protection Agency, Northern Ireland Environment Agency and Environmental Protection Agency Ireland (the agencies), together with Defra, Welsh Government, Public Health England and industry representatives.

[3] Post workshop note: The Environment Agency published a new UK wide list of hazardous substances and non-hazardous pollutants on JAGDAG's website in January 2018. This list only confirms that JAGDAG have considered whether specific substances are hazardous or non-hazardous. http://wfduk.org/sites/default/files/Media/JAGDAG/2018%2001%2031%20Confirmed%20hazardous%20substances%20list_0.pdf Last accessed 14th February 2018.

[4] See www.landsim.co.uk Last accessed 15th March 2018.

[5] Environment Agency (2006). Remedial Targets Methodology, Hydrogeological Risk Assessment for Land Contamination. Product Code: GEHO0706BLEQ-E-E

[6] http://www.consim.co.uk/ Last accessed 15th March 2018.

[7] ESI Consulting, Risk Assessment Modelling Software (RAM3), https://esi-consulting.co.uk/wp-content/uploads/2017/08/ESI_Software_RAM3.pdf. Last accessed 15th March 2018.

The discussion turned to dense non-aqueous phase liquids (DNAPLs) and their management in landfill sites. The group felt that ordinarily this would be addressed in the investigation and risk assessment of a contaminated land site as an industrial source which would likely involve targeted removal.

It was highlighted in respect to risk assessment for landfill sites, that there is a need to look at hydraulic conductivity of the waste versus that of the pathway.

3.3.3 Testing and analysis

The discussions turned to source term leachate tests and what the appropriate leachate tests were to use for organics. As a result of this discussion, the group felt that a summary sheet on the key leachate tests to correlate with the RTM guidance would be useful[8].

The group held a discussion over leachate source analysis, and how often this is done when looking at redeveloping historical landfill sites where contaminants have already entered the groundwater. It was agreed that there is a need to understand whether the source term has reached peak concentrations (or not) and if it is continuing to leach.

Key contaminants (amongst others) commonly found in landfills identified in the workshop were (*groundwater indicators):

- Mecoprop*
- Naphthalene
- Metals
- Aniline*
- Semi Volatile Organic Compound (sVOC)*
- Bromate
- VOCs*
- Chloride*
- Ammonium/ AmmN*

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[8] Post workshop note: The Environment Agency has suggested readers refer to: Environment Agency, 08 March 2012, Evidence Commentary, BS ISO 18772:2008. Soil Quality – Guidance on Leaching Procedures for Subsequent Chemical and Ecotoxicological Testing of Soils and Soil Materials provided in Appendix 3.

- Methaldehyde
- Phalates

It was noted that the Minimum Reporting Values (MRV) for a number of contaminants are getting lower and laboratories are not yet able to achieve all of these more stringent standards. This has on occasion led to uncertainty in the risk assessments being completed. At such times consultation with the regulators should be made.

3.3.4 Emerging contaminants

A key emerging contaminant discussed by the Network for Industrially Co-ordinated Sustainable Land Management in Europe (NICOLE) has been Perfluorooctanesulfonic acid (PFOS). The first use of PFOS was in the 1950s and there is therefore, the potential for this 'emerging contaminant' to appear or be detected in historical landfills in present day. These could 'emerge' as a result of advances in detection capabilities and lower detection limits.

The workshop participants felt best practice would be to compile a table in reports that presented the 'contaminants and age of first use'. Such a table would give an indication when looking at a historical site (*e.g.* in the 1950s) what type of contaminant may be present. However, this could be covered in the CSM (*i.e.* is inert, inert?). A clear understanding of the CSM was considered essential to give an understanding of what may have been deposited given the age of site.

3.3.5 Reviewing guidance and tools and what's missing

Everyone present identified that the signposting of guidance was important. It was noted that the Contaminated Land Applications In Real Environments (CL:AIRE) Water and Land Library (WALL) is hosting contaminated land guidance and an audit that all relevant information was contained would be helpful in respect to Landfill Risk Assessment.

The Chemicals database (CAS) is acknowledged to have been last updated in 2011. No information was available at the time to confirm when/ if this would be updated. It was identified that it is important to have all chemical standards (WFD/ Drinking Water Standards (DWS)/ MRV) in one place if possible. However, ownership of this responsibility was acknowledged to be onerous.

3.4 Conclusions and Recommendations

There was consensus that the CSM underpinning the risk assessment was crucial and it was important to maintain a high quality in work undertaken. The workshop group agreed that guidance on the key leachate tests would be helpful to practitioners and would ensure consistency[8] .

4 LANDFILL GAS

4.1 Introduction

This workshop was designed to encourage a discussion of the key issues associated with landfill gas; more specifically risk assessment techniques associated with ground gas. The workshop was facilitated by Steve Wilson of EPG Ltd and Simon Burr of Campbell Reith Ltd. The rapporteur was Patrick Norwood of RSK Environment Ltd.

The workshop was an open forum for discussion and involved many views and opinions on a range of ground gas related matters, and included both Regulators and Consultants.

4.2 Objective

The objective of this group was to provide a shortlist of four priority issues which could be used to support decision making within the risk assessment community. The majority of the discussion time was focused on the first two key issues, as the most topical areas for discussion.

4.3 Key Issues

4.3.1 Is there scope for expanding the Total Organic Carbon (TOC) approach to moderate and high risk sites?

Historically ground gas risk assessment has largely been focussed on data collected from ground gas monitoring wells. However, the concentrations of ground gases within the artificial environment of a monitoring well can be influenced by a number of factors (see Section 2.0 of RB17 [9]) and are not necessarily representative of the wider ground conditions. Consequently gas flow rate and concentration data collected from installations doesn't necessarily give an indication of risk.

RB17 [9] proposes an alternative method of risk assessment for low risk sites (defined in RB17) as '*sites where the conceptual model has not identified any significant potential sources of ground gas or gas protection is to be provided on site where small volumes of gas may be generated*') by considering the generation potential of the source of

[9] Card G, Wilson S, Mortimer S. (2012). *A Pragmatic Approach to Ground Gas Risk Assessment.* CL:AIRE Research Bulletin RB17. CL:AIRE, London, UK. ISSN 2047-6450 (Online)

ground gas. More specifically, RB17 presents a method of generic assessment for low risk sites where made ground is no deeper than 5 m and has an average depth of 3 m. The approach allows for the determination of Characteristic Situations (equivalent to those presented within CIRIA C665[10] and BS8485:2015[11]) by comparison of the TOC content of a soil to given limiting values. A revised, or sample-specific, TOC can be derived following forensic description (see Section 5 and Appendix C of RB17[9]) and laboratory testing on the fine (<10 mm) soil fraction which can be used within the risk assessment.

Delegates discussed whether the RB17 approach could be applied to sites which may be of moderate to high risk. It was generally considered by the group that a risk assessment relating to moderate to high risk sites requires more than a review of gas results from monitoring wells, and should include a number of lines of evidence to inform risk assessment. The group considered that the RB17 method offers a scientific approach to ground gas risk assessment and therefore the science should be transferrable to moderate and high risk sites as one of a number of lines of evidence within the gas risk assessment.

However, members of the group did have concerns about the limitations of the approach, particularly with regards to the depth/ thickness of fill material, mainly because a large proportion of soils within the upper 5 m are much more aerobic than soils below this depth and the methane generation potential is likely to be lower. It was agreed that practitioners should have a clear understanding of the limitations of using the RB17 approach for medium or high risks sites, and should use the method cautiously where made ground or landfill is in excess of 5 m and only as a line of evidence alongside other data. The limitations and uncertainties associated with using this approach should be documented within the risk assessment.

Delegates who have experience working with landfill operators mentioned that lignin, hemmicellulose and cellulose are used within detailed modelling of gas emissions from operating landfills and questioned whether lignin, cellulose and hemicellulose proportions had been considered as part of the RB17 approach. It was clarified that the RB17 approach is conservative and assumes that all organic matter (see Section 5 of RB17[9]) is degradable, when in fact there may be inclusions of organic materials

[10] Wilson S., Oliver S., Mallett, H., Hutchings, H., and Card G. (2007). Assessing risks posed by hazardous ground gases to buildings. CIRIA 665. London: CIRIA, 2007

[11] BS 8485:2015 Code of practice for the design of protective measures for methane and carbon dioxide ground gases for new buildings

which are not readily degradable (such as ash and clinker). It was considered that there may be an opportunity to refine the RB17 method by including an assessment of lignin, cellulose and hemicelluloses proportions, as the most readily degradable organic materials contain cellulose.

The group considered there to be a disconnect between contaminated land professionals and environmental scientists who work on operational landfill sites. There is a lot of research from operational landfill sites relating to the generation of landfill gases which is rarely applied to, or considered in, contaminated land risk assessment and there may be opportunities to advance ground gas risk assessment techniques if the two industries were to collaborate. Delegates who had worked on the EU funded ACUMEN (Assessing, Capturing and Utilising Methane from Expired and Non-operational landfills)[12] project highlighted that they had derived a gas generation tool that would allow for a quick estimation of current gas generation from non-operational landfills, which may be applicable to gas risk assessment. The tool is purposefully simple and doesn't require detailed data or modelling. The tool uses pre-modelled gas values based on typical UK waste mix from the 1990's. The only data required from users is the landfill opening and closure dates (i.e. operational duration) and gross tonnage deposited. Whilst not specifically designed for ground gas risk assessment, it was considered by the group that the tool may be useful as another line of evidence.

4.3.2 What elements of the site investigation process are critical to the ground gas risk assessment process?

Delegates discussed the site investigation process and which elements they felt were critical to ground gas risk assessment. A summary of the discussion around these elements is detailed below.

- The design of monitoring well response zones.

Response zones should be designed to target sources or pathways. They should not cross multiple sources/ pathways.

- Desk study information, Preliminary Risk Assessment (PRA) and CSM.

Desk study information should be transformed in to a documented PRA supported by a preliminary CSM. The CSM should be presented schematically as a cross section and

[12] https://www.gov.uk/government/groups/acumen-assessing-capturing-and-utilising-methane-from-expired-and-non-operational-landfills Last accessed 3rd May 2018

ideally should be to scale. The CSM should be updated throughout the risk assessment process.

- Soil descriptions.

Good soil descriptions are fundamental to ground gas risk assessment. A number of delegates raised concerns that the standard of logging across the industry has declined in recent years. It was concluded that those undertaking the site investigation process need to be competent, and soil descriptions should not be left to subcontractors to complete (e.g. drilling operators).

- Soil and rock permeability.

It is important to understand the permeability of the underlying strata to inform the CSM and to allow for an informed risk assessment to be made. Soakaway tests can be undertaken to understand permeability; alternatively gas permeability tests can be undertaken on samples within a laboratory.

- Data frequency.

Careful consideration should be given to data frequency. It may be more useful to focus data collection to boreholes where concentrations of ground gasses are lower or more variable, than those which consistently demonstrate high concentrations.

- Groundwater considerations.

Where response zones are submerged within groundwater, dissolved gasses can come out of solution leading to artificially high concentrations within monitoring wells. In some cases the opposite can happen and ground gasses can dissolve leading to artificially low concentrations within the headspace of monitoring wells.

In the USA they aim to install wells above the anticipated water table. Where shallow water tables are present, other techniques for data collection such as flux box testing may be more appropriate.

- External influences on monitoring.

External factors can impact on the results of ground gas monitoring. For instance, whether a landfill site's gas extraction system is operational or non-operational may heavily impact on measured gas concentrations within monitoring wells.

- The number and location of wells.

The number and location of monitoring wells will be dependent on site specific considerations. It is important that the number and location of the wells takes in to consideration the CSM and are targeted to plausible sources and pathways.

- Anecdotal information.

On-site issues may affect results and should be considered as part of the risk assessment process. For instance, monitoring wells may not be sealed adequately resulting in air being sucked in to the well and misleading monitoring results.

- Flow types.

Understanding the different flow types (pressure driven or diffusive) and the differences between flow types is important when collecting data from a site and assessing the risk.

Following the discussion, delegates were asked to vote on the element they thought were most important. The group concluded that understanding the CSM was the most important element of the ground gas risk assessment process since this informs the design of the site investigation and underpins the risk assessment.

4.3.3 Whether and when should gas monitoring taps be left open or closed?

It is common practice that gas taps are closed between periodic monitoring visits. However, experience from some practitioners has demonstrated that by opening gas taps between monitoring visits, gas concentrations remained comparable (as if they were closed) yet flow rates were less variable, which is considered by some to be more representative of wider ground conditions and the gas regime.

The group considered that a detailed understanding of the CSM should be used to inform whether gas taps are to be left open or closed between monitoring visits. For instance, if a site has a covering of an impermeable layer such as a clay cap on a landfill, closed taps may be more reflective of ground conditions. However, if monitoring is being undertaken on a constant gas generation source such as a landfill without a cap, open gas taps may be more appropriate. Any decision regarding leaving gas taps open or closed should be clearly documented within the risk assessment.

Delegates were concerned that whilst there may be evidence that open gas taps are more representative of the gas regime on certain sites, there is a strong perception within the industry that gas taps should be closed. Consequently there was a general consensus that regulators may be less accepting of data where gas taps were left open and in some cases practitioners had found that where gas taps were left open regulators expressed concerns relating to the monitoring results.

Local Authority representatives within the workshop stated that from their experience it is rare that consultants leave gas taps open and that they would usually require comprehensive justification for the opening of gas taps between monitoring rounds.

The group considered that a research paper on the matter would detail the reasoning for opening gas taps, the implications for gas monitoring result and could alter current perception that gas taps must remain closed between monitoring visits.

4.3.4 Should the ground gas generation potential of fill material be considered as part of general earthwork specifications?

There was a general consensus within the group that fill material used during earthworks has the potential to comprise concentrations of organic material; even manufactured crushed aggregates such as 6F2 may contain some organic material such as wood. Consequently engineered fill materials may have the potential to generate ground gas which could pose a risk to development, and would not have been evaluated as part of the site investigation and gas risk assessment.

Examples where gas generation potential had been considered within earthworks specifications were presented by some practitioners. The sites presented were considered by the group not to be 'general' earthworks projects and typically involved the reprocessing of landfill waste material which was known to be generating ground gasses. The group agreed that on sites where sources with a moderate to high gas generation potential are processed to form engineered fill, then gas generation should be considered as part of the earthworks specification.

Delegates considered that 'general' earthwork specifications are typically designed to ensure fill materials are geotechnically competent. Subsequently very little organic or deleterious material is likely to be included within general earthwork fill materials and consequently the risks from carbon dioxide and methane to future development are likely to be low. Concerns were expressed over the increasing content of plaster board (comprising sulphur) within fill materials, which could present a source of hydrogen sulphide.

It was agreed that where gas generation potential is to be considered as part of the earthworks specifications, it is important to estimate post-development gas concentrations and compliance testing may be required. Gas monitoring from existing installations was not considered to be an ideal approach as gas monitoring will be undertaken following completion of earthworks, which is generally too late for any identified issues with the imported material to be easily addressed. TOC analysis and drum tests were considered to be two tests potentially useful to estimate the generation potential in advance of importation of any proposed fill, and to determine whether a material is suitable for use.

4.4 Conclusions and Recommendations

- The RB17 approach can be used as part of a gas risk assessment for sites other than low risk sites, but only as an additional line of evidence. Practitioners should be aware of the limitations of this method and clearly document these within any risk assessment.
- Delegates discussed the site investigation process and which elements they felt were critical to ground gas risk assessment. The group concluded that understanding the CSM was the most important element of the ground gas risk assessment process.
- Discussion was undertaken regarding whether gas taps should be left open or closed between monitoring rounds. Practitioners considered that the CSM should be used to inform decision making when deciding whether to leave gaps taps open or closed, and this reasoning should be clearly documented within the risk assessment. It is recommended that a research paper be considered to understand this better.
- Delegates concluded that although earthwork specifications do not generally consider ground gas generation potential of proposed fill materials, such materials typically include very little organic material for geotechnical reasons. It is recommended that practitioners consider ground gas generation of fill materials as part of earthworks specifications for sites which have already been identified as comprising significant sources of ground gas which is to be reprocessed for re-use on the site, where appropriate.

5 LANDFILL MINING

5.1 Introduction

This workshop was designed to encourage a discussion of the key issues associated with landfill mining. The workshop was facilitated by Kathryn Warren of Ricardo Energy & Environment. The rapporteur was David Schofield of Ramboll Environ.

The workshop was an open forum for discussion and involved many views and opinions on a range of points associated with landfill mining and the potential for expanding its practice. The workshop delegates included representatives from a variety of organisations including remediation contractors, environmental consultancy, academia, environmental analytical testing companies and land development warranty providers. Whilst the group mainly comprised individuals with a general level of understanding, a number of members did have more direct experience of landfill mining.

The workshop started with a general overview of landfill mining provided by the rapporteur. It is understood that there are currently an estimated 200,000 to 500,000 landfills across Europe that could potentially support reclamation activities. In its simplest terms landfill mining comprises the process of physically extracting materials previously deposited at a landfill as a waste. The materials are subsequently sorted for potential reuse, recycling or for energy recovery. The benefits associated with landfill mining include freeing up void space within landfills to support redevelopment or deposition of further wastes unsuitable for reuse. Additionally, there are economic incentives from the resale of reclaimed materials and potential further environmental benefits where addressing potential contamination issues associated with landfilling (*e.g.* land gas generation or contaminated leachate migration *etc*).

5.2 Objective

It was acknowledged by the group that landfill mining is not a well-established/ understood activity (to many in the group) and areas of discussion therefore centred on further promotion of the practice and current perceived limitations. Leading on from an overview provided by the facilitator, the general themes covered were:

- Discussion on the application of landfill mining as part of proposed site redevelopment for alternate land use (housing, industrial, commercial etc);
- Options for future promotion for the adoption of landfill mining practice; and

- Current perceived constraints including lack of coordinated guidance / regulation and economic feasibility of landfill mining.

The objective of the discussion was focused on identifying perceived constraints and potential measures that could be implemented to addressing these three issues.

5.3 Key Issues

5.3.1 The potential application of Landfill Mining as part of redevelopment

The concept was, in general, well received but evident from group discussion that the process is not well publicised and knowledge of current examples was limited (a number of examples identified were considered too commercially sensitive for publication). Indeed, the paper referenced for the basis of the discussion[13] identified that no documented landfill mining had taken place in Scotland at the date of feasibility study.

The consensus opinion was there are a number of potential ways for landfill mining to be more widely applied, though principally as an effective aspect of brownfield site redevelopment rather than as the driving rationale. Engagement with key stakeholders including regulators, land developers, investors, the local public insurance companies and development agencies was considered to be of critical importance. However, it was felt that the combined benefits of economic offsetting (for developers/ investors) and promotion of sustainable practice (under appropriate environmental regulation) could make landfill mining an attractive option if areas of uncertainty are addressed.

Landfill mining was also discussed as a potentially beneficial option for addressing contamination issues at historical landfills either via direct source removal or as a means of reducing the overall contamination profile as part of an ongoing remediation programme.

There was also discussion that landfill mining may be more easily applied at industrial mono-fill landfills rather than at facilities that have historically accepted mixed wastes and/ or including domestic wastes.

[13] Ford, S., Warren, K., Lorton, C., Smithers R., Read, A., Hudgins, M., (2013). *Feasibility and Viability of Landfill Mining and Reclamation in Scotland (Scoping Study), Zero Waste Scotland.* http://www.wrap.org.uk/sites/files/wrap/Feasability%20and%20Viability%20of%20LFMR%20Scotland%20190413_0.pdf Last accessed 14th February 2018.

5.3.2 Options for future promotion for the adoption of landfill mining practice?

The group also spent time discussing the potential options for future promotion for the adoption of landfill mining. It was agreed that the practice would benefit from a coordinated approach with respect to identifying the positives and constraints with the techniques involved and when and where they can be applied.

5.3.3 What are the current perceived constraints and areas of uncertainty associated with landfill mining?

The majority of the open group forum time was spent discussing the main areas of concern, barriers and uncertainties that may prevent more widespread application of landfilling mining. A summary of the discussion around these elements is detailed below.

- Complexity associated with licensing and permitting

Complexity associated with licensing and permitting was identified as a potentially notable problem when trying to promote landfill mining. Time was spent debating the various needs and associated liabilities for environmental permitting, mobile treatment license requirements and whether any permitting requirements would result in a material development constraint.

- Potential delays to land redevelopment timescales

Potential delays to land redevelopment timescales could make landfill mining less attractive to developers, particularly where risks associated with obtaining relevant permits persist. It was felt that in the absence of landfill mining practice guidance the potential economic benefits would be outweighed by costs associated with delays.

- Uncertainty of actual wastes present

Uncertainty of actual wastes present and records on the actual type and volume of wastes deposited hinder forecasting of timescales and best techniques for landfill mining and the potential financial incentive. In addition, the size of the landfill will also affect the economic attractiveness of undertaking landfill mining. Questions were raised on the number of landfills present in the UK that would be economically viable for landfill mining and in turn the number of those sites that would then be located in an area attractive to land development.

- Management of works and associated health and safety issues.

Concerns were noted on the increased management needs associated with management of landfill mining activities, particularly with regards to potential health and safety requirements. Whilst it was considered that safe practice for the management of risk to site workers is well established, with the outfall of Corby in mind, control of risk to off-site receptors may be more onerous (*e.g.* potential generation of asbestos fibres, odour and vapour). The needs for air monitoring, dust suppression were discussed and again acknowledged as routinely established options but still a material issue for public perception of the 'dangerousness' of the activities undertaken. The discussion on health and safety/ perceived risk to public, led to discussions on the absence of overarching guidance.

- Lack of coordinated guidance.

Lack of coordinated guidance, particularly with specific regard to the UK was felt to be an issue. It was acknowledged that there is a great deal of established interlinked waste regulation, which provides complexity when considering landfill mining. Time was spent debating the question of 'when is a waste a waste?' and importantly 'when is a waste not a waste?'. It became clear to the group that an absence of guidance/ regulation causes an element of uncertainty and consequently risk and liability and this reduces the attractiveness of landfill mining. The group did identify the European Enhanced Landfill Mining Consortium website (EURELCO)[14] as a source of useful information.

- Public perception.

There were contrasting feelings concerning the balance on whether overall public opinion would be in favour of landfill mining from a sustainability angle and/ or from the perspective that a contamination source ('landfill') was being addressed for community benefit. The group had experience of public 'Not in my Backyard (NIMBY)' attitudes and cynicism where land is to be redeveloped for commercial residential purposes. In turn, developers would be reluctant to engage a newer practice such as landfill mining where they perceive a risk of opening a route for public objection and delays associated with subsequent planning appeals *etc*. The group also considered whether the connotations raised by the name 'Landfill Mining' would benefit from a name change such as Resource Recovery.

5.4 Conclusions and Recommendations

The benefits associated with landfill mining were considered appreciable and aligned with the principles of sustainable living. The incorporation of landfill mining as part of brownfield land redevelopment, principally as an economic incentive to reduce overall

[14] European Enhanced Landfill Mining Consortium website: https://www.eurelco.org/

costs, was considered the most likely driver for more widespread application of landfill mining. However, the current complexity in addressing the needs of various elements of waste regulation and the lack of coherent guidance was considered a material issue.

In summary, the group identified the following main factors for further consideration:

- Communication with the relevant parties and subsequent buy in from key stakeholders is vital. A simple cost benefit is unlikely to drive clean-up of a landfill purely by money generated from landfill mining. The key mechanism seen as redevelopment and costs, could be used to offsite development outlay;
- The group felt that whilst there is plenty of waste legislation there is a lack of coordinated guidance covering the interlink areas of waste management spanned by landfill mining activities. As such it was strongly agreed an overarching guidance note would be very useful;
- Delegates felt permitting requirements could make developers more reluctant (*i.e.* if waste license still in place post development/ likewise if license removal could be incentive);
- Main barriers perceived are lack of awareness, potential timescales, level of current incentives, public relations/ perceptions ('mining' negative connotation and 'landfill' can equate as a hazardous site) and Health and Safety (what is in the waste); and
- A coordinated approach from groups such as CL:AIRE, SoBRA, Sustainable Remediation Forum (SuRF) was considered an ideal way to promote further awareness and guidance (working with the Environment Agency for regulatory engagement/ endorsement).

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APPENDIX 1

Workshop Participants

WORKSHOP 1: Conceptual Site Models and Site Investigations

Workshop Facilitator

Craig Hampton	Environment Agency

Workshop Rapporteur

Jane Thrasher	Jacobs

Workshop Members

Will Anstey	SLR Consulting
Matt Askin	Environment Agency
Matthew Bond	Hydrock
Sabrina Cipullo	Cranfield University
Huw Edward Davies	Ashfield Solutions
Paul Dennis	Arup
Katie Foster	RSK
Nick Frost	Terraconsult
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Alex Grimmer	BC of King's Lynn and West Norfolk
Ben Jones	ACS Testing Ltd
Richard Lansley	Golder Associates
James Lymer	Wardell Armstrong
Darren Makin	ESG
Nicola MacKenzie	The Highland Council
Mike Plimmer	GEA
Katherine Prosser	WSP/PB
Leon Warrington	Hydrock
Hannah White	National Grid Property Holdings Ltd

WORKSHOP 2: Controlled Waters

Workshop Facilitator

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Workshop Rapporteurs

Theresa Cory	Environment Agency
Charlotte Wakefield	Environment Agency

Workshop Members

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Simon Firth	Firth Consultants
Alexandra Flint	Tweedie Evans Consulting
Catherine Latimer	RSK
Alex Lee	WSP
Matthew Lennard	Vertase FLI
Diogo Martins Gomes	Cranfield University
Trevor Montague	Geosyntec
Rob Reuter	Wardell Armstrong
Mark Rowney	Aecom
Victoria Smith	Terraconsult
Mike Summersgill	SEnSE Associates LLP
Jonathan Welch	Aecom
Liz Willcox	John Grimes Partnership
Geraint Williams	ALS
Julian Williams	Environment Agency

WORKSHOP 3: Landfill Gas

Workshop Facilitators

Steve Wilson	Environmental Protection Group
Sarah Mortimer	Environmental Protection Group
Simon Burr	CampbellReith

Workshop Rapporteur

Patrick Norwood	RSK

Workshop Members

Paul Brennan	EMSS
Roddy Buchanan	Ecologia
Simon Coffey	GRM Development Solutions
Daniel Coles	Hydrock
Selina Daglass	London Borough of Redbridge
David Drury	Golder Associates
Craig Fannin	Terra Consult
Michael Gennaro	Delta Simons
Kristoffer Harries	Ground Gas Solutions
Paul Howlett	Royal HaskoningDHV
David Jacob	Envirolabair
Matthew May	Sweco
John Naylor	Ground Gas Solutions
Jonathan Parry	SLR
Sophie Penney	RSK
Anthony Phin	Campbell Reith
Aldona Rahman	Royal Borough of Windsor and Maidenhead
Ben Rees	Geotechnology
Hallan Sambrooke	Newcastle under Lyme Borough Council
Lucy Thomas	RSK
Charlotte Wheatley	Arcadis Consulting
James Wilson	WPA Consultants Ltd

WORKSHOP 4: Landfill Mining

Workshop Facilitator

Kathryn Warren	Ricardo Energy & Environment

Workshop Rapporteur

David Schofield	Ramboll

Workshop Members

Kate Baker	WSP
Kevin Boyle	Jacobs
Rachael Cains	Ecologia
Fred Coulon	Cranfield University
Andrew Edgar	E3P
Will Fardon	I2 Analytical
Lisa Hathway	NHBC
Brendan Marrinan	Hydrock
Eion O'Sullivan	CGL
Tom Parker	Argentum Fox
Nicole Reid	Mott MacDonald
Peter Sheppard	WSP
Claire Stone	I2 Analytical
Alex Smith	E3P Ltd
Andrew Tranter	RSK
Richard Upton	GRM Development Solutions
Alan Wilson	Jones Environmental Laboratory
Lee Wood	Hydrock

APPENDIX 2

Workshop Preparation Material

Workshop Information Sheet: Conceptual Site Model & Site Investigation

Background: This workshop will look at the key issues associated with the conceptual site model and site investigation for landfill sites. Delegates will be asked to consider a wide range of issues to identify those representing accepted scientific understanding and/ or good practice, and those which require further work to extend, improve or clarify current understanding or practice.

Output: It is anticipated that each of the workshops will provide a shortlist of 4 priority issues that could assist in the investigation of historic landfill sites. The groups will strive to reach a level of agreement on these issues. It is intended that all outcomes from the day will be collated into a published report which can be used to support decision-making within the risk assessment community.

Workshop Structure:

Introduction (approx. 10mins)	Summary of the issues, key literature sources and examples of credible risk assessment principles or methodologies that are accepted by the broad risk assessment community.
Identifying issues and selecting key areas for discussion (approx. 15mins)	Identification of the main areas of concern, priorities, barriers and uncertainties, including any that cut across more than one workshop theme. Please bring ideas for discussion topics along - what do you feel are the key issues and how can they be overcome? The workshops are intended to be driven by the whole group not just the facilitators.
Group Discussion (approx. 50mins)	Some key issues for discussion are likely to include: • Most appropriate drilling techniques for former landfill sites • How to account for the heterogeneous and unpredictable nature of waste in intrusive investigation (number of sample locations/ gas/ leachate/ groundwater wells) • Laboratory analysis requirements (difficulties in analysing sample matrix, analysis of emerging contaminants) • How to estimate post development conditions? • Additional requirements – increased potential for contamination of underlying aquifers.

Summarise discussion (Approx. 15mins)	Summarise agreed points for input into the workshop report and identify a few key points for feedback to other delegates.

Key Papers: The links below identify a few key resources/ papers on the discussion topic. Familiarity with these would aid discussion on the day. Additionally if you are aware of other relevant papers please feel free to bring them along, with a short summary on the day.

- SITE INVESTIGATION STEERING GROUP. Site investigation in construction 4: Guidelines for the safe investigation by drilling of landfills and contaminated land: Thomas Telford, 2008
- BS10175:2011+A1:2013 Investigation of potentially contaminated sites. Code of practice.
- BS8576 Guidance on investigation for ground gas – Permanent gases and Volatile Organic Compounds (VOCs)

Workshop Information Sheet: Controlled Waters DQRA

Background: This workshop will look at the key issues associated with the Controlled Waters DQRA for landfill sites. Delegates will be asked to consider a wide range of issues to identify those representing accepted scientific understanding and/ or good practice, and those which require further work to extend, improve or clarify current understanding or practice.

Output: It is anticipated that each of the workshops will provide a shortlist of 4 priority issues. The groups will strive to reach a level of agreement on these issues. It is intended that all outcomes from the day will be collated into a published report which can be used to support decision-making within the brownfield land risk assessment community.

Workshop Structure:

<table>
<tr><td>Introduction
(approx. 10mins)</td><td>Summary of the issues, key literature sources and examples of credible risk assessment principles or methodologies that are accepted by the broad risk assessment community.</td></tr>
<tr><td>Identifying issues and selecting key areas for discussion
(approx. 15mins)</td><td>Identification of the main areas of concern, priorities, barriers and uncertainties, including any that cut across more than one workshop theme.

Please bring ideas for discussion topics along - what do you feel are the key issues and how can these be solved? The workshops are intended to be driven by the whole group not just the facilitators.</td></tr>
<tr><td>Group Discussion
(approx. 50mins)</td><td>Some key issues for discussion are likely to include:

Objectives setting/ framing the assessment

• How does the regulatory context influence the modelling and risk assessment approach? For example, how might it differ under Part 2A compared to planning? How does ‘prevent and limit’ under the Groundwater Directive apply to land contamination?

Approach to modelling and risk assessment

• What processes and concepts need to be included in the relevant modelling analysis and how can these be translated into a modelling context, for example using conceptual models?</td></tr>
</table>

	• How can we rationalise the complex environmental system into a modelling analysis that is still representative of its behaviour, not data hungry and gives robust predictions? • What are the main (chemical) risk drivers? • Is there evidence of degradation for key contaminants, what are the markers, how far should it be necessary to prove it is occurring on a site specific basis? • How is sustainability considered in our assessments? • How to manage DNAPLs? • Assessment criteria (LoQ, MRVs, DWS, EQS) and is there a need for additional water quality standards? Where should they come from? **Reviewing guidance and tools and what's missing** • Risk assessment methodologies and risk models (P20, ConSim, Landsim) – what are the strengths and weaknesses of current approaches from a practitioners and regulators viewpoint? • Approaches or tools from other fields or other countries that we could learn from • Update on Environment Agency guidance
Summarise discussion (Approx. 15mins)	Summarise agreed points for input into the workshop report and identify a few key points for feedback to other delegates.

Key Papers: The links below identify a few key resources/ papers on the discussion topic. Familiarity with these would aid discussion on the day. Additionally if you are aware of other relevant papers please feel free to bring them along, with a short summary on the day.

- Landsim manual http://www.landsim.co.uk/
- Consim manual http://www.consim.co.uk/
- ENVIRONMENT AGENCY. *Remedial Targets Methodology – Hydrogeological Risk Assessment for Land Contamination*. Bristol: Environment Agency, 2006

  https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/314317/geho0706bleq-e-e.pdf

Workshop Information Sheet: Landfill Gas

Background: This workshop will look at the key issues associated with landfill gas. Delegates will be asked to consider a wide range of issues to identify those representing accepted scientific understanding and/or good practice, and those which require further work to extend, improve or clarify current understanding or practice.

Output: It is anticipated that each of the workshops will provide a shortlist of 4 priority issues. The groups will strive to reach a level of agreement on these issues. It is intended that all outcomes from the day will be collated into a published report which can be used to support decision-making within the risk assessment community.

Workshop Structure

Introduction (approx. 10mins)	Summary of the issues, key literature sources and examples of credible risk assessment principles or methodologies that are accepted by the broad risk assessment community.
Identifying issues and selecting key areas for discussion (approx. 15mins)	Identification of the main areas of concern, priorities, barriers and uncertainties, including any that cut across more than one workshop theme. Please bring ideas for discussion topics along - what do you feel are the key issues? The workshops are intended to be driven by the whole group not just the facilitators.
Group Discussion (approx. 50mins)	Some key issues for discussion are likely to include: • How do we decide when to use the TOC approach, semi-quantitative risk assessment models and detailed quantitative mathematic modelling techniques? Is there scope for expanding the TOC approach to 'medium' risk sites? • The lines of evidence approach – what lines of evidence inform the gas risk assessment process? Are some lines of evidence more important than others? • Compliance testing for the re-use of materials – what techniques are available to us? How can we estimate post development gas conditions? What are the groups experiences of gas generation tests, drum tests and laboratory gas permeability tests? • What elements of the site investigation process are critical to the gas risk assessment process? Including a discussion on, gas taps open / gas taps closed?

Summarise discussion (Approx. 15mins)	Summarise agreed points for input into the workshop report and identify a few key points for feedback to other delegates.

Key Papers: The links below identify a few key resources/ papers on the discussion topic. Familiarity with these would aid discussion on the day. Additionally if you are aware of other relevant papers please feel free to bring them along, with a short summary on the day.

- BS 8576:2013 *Guidance on investigations for ground gas – Permanent gases and Volatile Organic Compounds (VOCs)*
- BS 8485:2015 *Code of practice for the design of protective measures for methane and carbon dioxide ground gases for new buildings*
- Contaminated Land: Applications in Real Environments. *A Pragmatic Approach to Ground Gas Risk Assessment.* RB17. CL:AIRE, 2012.
- Wilson S., Oliver S., Mallett, H., Hutchings, H., and Card G. *Assessing risks posed by hazardous ground gases to buildings.* CIRIA 665. London: CIRIA, 2007
- NHBC/EA/CIEH *Guidance for Safe Development of Housing on Land Affected by Contamination* R&D Publication 66:2008
- SEPA/EA, *Guidance on the Management of Landfill Gas*, LFTGN 03, 2004
- British Columbia Ministry of Environment, *Landfill Gas Management Facilities Design Guidelines*, 2010

Workshop Information Sheet: Landfill Mining

Background: This workshop will look at the key issues associated with the landfill mining. Delegates will be asked to consider a wide range of issues to identify those representing accepted scientific understanding and/or good practice, and those which require further work to extend, improve or clarify current understanding or practice.

Output: It is anticipated that each of the workshops will provide a shortlist of 3 priority issues. The groups will strive to reach a level of agreement on these issues. It is intended that all outcomes from the day will be collated into a published report which can be used to support decision-making within the brownfield land risk assessment community.

Workshop Structure:

Introduction (approx. 10mins)	Summary of the issues, key literature sources and examples of credible risk assessment principles or methodologies that are accepted by the broad risk assessment community.
Identifying issues and selecting key areas for discussion (approx. 15mins)	Identification of the main areas of concern, priorities, barriers and uncertainties, including any that cut across more than one workshop theme. Please bring ideas for discussion topics along - what do you feel are the key issues? The workshops are intended to be driven by the whole group not just the facilitators.
Group Discussion (approx. 50mins)	Some key issues for discussion are likely to include: • Best practice – way forward to implement proposed scheme • What a best practice manual would need to cover • International approaches to assessing risk with respect to LFMR
Summarise discussion (Approx. 15mins)	Summarise agreed points for input into the workshop report and identify a few key points for feedback to other delegates.

Key Papers: The links below identify a few key resources/ papers on the discussion topic. Familiarity with these would aid discussion on the day. Additionally if you are aware of other relevant papers please feel free to bring them along, with a short summary on the day.

- Ford, S., Warren, K., Lorton, C., Smithers R., Read, A., Hudgins, M., 2013. *Feasibility and Viability of Landfill Mining and Reclamation in Scotland (Scoping Study),* Zero Waste Scotland.

  http://ee.ricardo.com/cms/assets/Documents-for-Insight-pages/Resource-efficiency/Feasability-and-Viability-of-LFMR-Scotland-1904130.pdf

APPENDIX 3

Environment Agency (2012). Evidence Commentary, BS ISO 18772:2008. Soil Quality – Guidance on Leaching Procedures for Subsequent Chemical and Ecotoxicological Testing of Soils and Soil Materials

Evidence Commentary

08 March 2012

BS ISO 18772:2008. Soil Quality – Guidance on Leaching Procedures for Subsequent Chemical and Ecotoxicological Testing of Soils and Soil Materials

Who should read this note?

Groundwater and contaminated land specialists and technical officers who review or commission risk assessment and risk management strategies for tackling soil and groundwater contamination.

What is BS ISO 18772?

This standard provides guidance on the appropriate use of leaching tests on soils and soil materials in order to determine the leaching behaviour in a risk management context. It specifically includes information on:

- Assessing leaching behaviour;
- The choice of leaching tests, including consideration of organic substances; and
- The interpretation of the test results.

The standard is applicable to natural, contaminated and agricultural soils and soil materials. It builds on the BS EN 12920:2006 methodology for determining the leaching behaviour of wastes under specified conditions.

Two cases are provided that describe:

1. an application of leach tests to determine leaching behaviour and support risk assessment over defined timescales. This case provides clarification on the 7 steps set out in BS EN 12920:2006; and
2. an application for the selection of leaching tests for compliance and comparison purposes.

The standard then gives a description of test methods and provides a basis for test selection to meet the project-specific objectives. For the first time a standard includes consideration of leaching organics, and provides reference to four new leaching test methods for inorganic and organic constituents that are based on the tests developed for waste characterisation.

Why should I use this standard?

Environment Agency (2006) sets out a remedial targets methodology for determining the risk posed by the leaching of contaminants from soil to identified groundwater or surface water receptors. It recommends that, in the absence of direct data, leaching test data are used for determining potential pore water concentrations to assess the risk to controlled waters.

The BS EN 12457:2002 leaching tests are recommended in Environment Agency (2006), although it is acknowledged that the liquid to solid ratio (LS) from these tests are likely to be higher than those observed under field conditions. This may lead to dilution of contaminants in the eluates and an underestimate of potential pore water concentrations. Although the results from the LS 2 test (Part 1) are preferred (Environment Agency 2006), they are still likely to underestimate pore water concentrations.

BS ISO 18772:2008 provides a framework for the user to design, and justify, the selection of leaching tests based on likely short and long term exposure scenarios. Appropriate use of this standard will lead to improved conceptual understanding of the leaching process and reduce uncertainty in the risk assessment for the protection of controlled waters.

When should I use this standard?

We should encourage a consultant, working on our behalf or representing a third party, to use this standard when leaching is identified in the conceptual model as a potential mechanism for transferring contaminants from soil to controlled waters.

How should I use this standard?

The approach for assessing leaching behaviour recommended in BS ISO 18772:2008 can be readily integrated into standard risk management practice outlined in CLR11 (Environment Agency and Defra, 2004). This enables the user to gain a better understanding of leaching behaviour and thereby develop a more robust conceptual model and reduce uncertainty in determining the need for remediation of soil to protect controlled waters. It also introduces an additional range of tests (ISO/TC 21268) to be considered as alternative tests to use when assessing leaching behaviour or compliance. These tests are designed for both inorganic and organic constituents. An overview of leaching mechanisms and key parameters to be considered in selecting test standards is given in the Addendum.

Information requirements for each of the steps of the BS EN 12920 methodology are summarised in Table 1 below. Steps 1 to 5 could be taken into account in the conceptual model developed as part of the risk assessment.

The Addendum gives further information on the leaching tests available to elucidate the factors controlling leaching. Whilst it may not be reasonable to require multiple testing to be carried out for every project, the standard can still be used to ensure the appropriate information is collated and assessed. Where a single test method is proposed, the user must provide justification, linked to the conceptual model, to show that the leaching potential of the soil is not likely to be underestimated.

Recommendation

Currently the potential pore water concentrations of contaminants in soil are estimated from a single leaching test method designed for estimating mass release in comparison to total concentrations (in mg/kg). This does not give an indication of leaching behaviour, and the test is not usually justified through consideration of exposure scenarios. It is difficult to assess the uncertainty associated with this approach.

It is recommended that BS EN 18772:2008 is adopted as good practice in the assessment of risks to controlled waters where leaching from a soil source is identified as a potential pollutant linkage. The standard provides guidance that will enable a robust conceptual model to be developed taking into account the potential leaching behaviour in a site-specific exposure scenario.

It is also suggested that BS ISO 18772:2008 is added to the Information Map in CLR 11 when it is next updated.

Table 1 Information to be collected to integrate BS ISO 18772 with standard risk management practice

Step	Description	Type of information
1	Definition of the problem and solution sought	Contaminants of interest, distribution and phases Targets to meet and compliance point/s Time frame over which targets apply
2	Description of the scenario	Usual and exceptional exposure conditions (boundaries) for main influencing factors (e.g. infiltration, pH of leachant, groundwater level, ambient conditions)
3	Description of the source	History of site and land use Soil characteristics (e.g. particle size, density, fraction of organic carbon) Chemical characterisation (e.g. buffering capacity, contaminant phase) Mineralogy Redox/biological activity
4	Determination of the influence of parameters on leaching behaviour	Identification of key parameters from 2 and 3 within the time frame of interest (for example, influence of LS, organic matter, pH). Determine the influence from parametric (e.g. pH dependence test), multiparametric tests (e.g. upflow percolation test), or simulation tests (large-scale column or lysimeter) Justification must be provided for the selection of tests to address the solutions sought.
5	Modelling of the leaching behaviour	May be required, particularly where the source term is time-dependent. The complexity will depend on the aims of the specific project, but may include geochemical or contaminant transport modelling. The release of DOC and colloidal particles may have a significant bearing on leaching of some metals and organics.
6	Behavioural model validation	This may involve verification of the consistency between leach tests, of predicted behaviour against field testing, or by analysis of monitoring data. LS will usually be used to normalise data from the leaching tests. This can be related to time for specific projects.
7	Conclusion	Analysis of data to determine whether project objectives have been met. Prepare verification report or recommendations for further work.

Definitions

Eluate	solution recovered from a leach test
Leachant	liquid used in a leaching test
Leaching test	test during which a material is put into contact with a leachant and some constituents of the material are extracted
Leaching behaviour	in situ release of substances from the soil, and changes with time, upon contact with a leachant as affected by the field conditions specified in the scenario, within the specified time frame
Liquid to solid ratio	ratio between the total amount of liquid which is in contact with the soil, and the dry mass of the sample, abbreviated L:S and expressed in lkg-1
Lysimeter	large-scale experiment set-up to simulate scenario-specific exposure conditions under more controlled conditions than in full-scale field conditions
Multiparametric test	test aimed at measuring the influence of interrelated specific parameters on the release from a soil in the specified scenario
Parametric test	test aimed at measuring an intrinsic property of a soil or to measure the influence of a specific parameter on the release from a soil in the specified scenario
pH dependence test	test consisting of parallel extractions of the material at an L/S=10 (l/kg) for 48 hours at a series of pre-set pH values. pH is one of the main leaching controlling parameters.
Simulation test	test aimed at simulating the combined effect of various parameters on the release in a specified scenario
Upflow percolation test	test to determine the release of constituents from material packed in a column with a leachant percolating through it. A continuous vertical up-flow is used, so that the column is water saturated.

References

BS EN 12457:2002. Characterisation of waste – Leaching – Compliance test for leaching of granular waste materials and sludges.

BS EN 12920:2006. Characterization of waste – Methodology for the Determination of the Leaching Behaviour of Waste under Specified Conditions. British Standards Institution, London.

BS ISO 18772:2008. Soil quality – Guidance on leaching procedures for subsequent chemical and ecotoxicological testing of soils and soil materials.

CEN ISO 21268:2009 – Soil quality – Leaching procedures for subsequent chemical and ecotoxicological testing of soil and soil materials.

Defra and Environment Agency 2004. Model Procedures for the Management of Land Contamination. Contaminated Land Research Report CLR 11.

Environment Agency 2006. Remedial Targets Methodology. Environment Agency, Bristol, UK.

ADDENDUM

BACKGROUND INFORMATION ON THE USE AND NATURE OF LEACHING TESTS FOR SOILS

1 Leaching Tests In A Risk Management Framework

Leaching tests may be used to provide valuable data on the release of contaminants from a soil into the aqueous phase and to set compliance targets to ensure that receiving controlled waters are not impacted by the estimated release from the soil source zone. This is set out in Figure 1.

SOURCE TERM		PATHWAY		RECEPTOR
Leaching tests may be used to determine the release of contaminants by leaching under specified conditions. Results must be interpreted in context with reference to the conceptual model.	►	Calculation and modelling of transport of contaminants to groundwater or surface water receptor. Leaching test data are used as input criteria to assess risks to receptors.	►	Leaching target set for compliance point, usually measured by batch test (such as one of the BS EN 12457 standards). A low liquid to solid ratio is advised (L:S 2). Partial column or tank test may also be considered.

Figure 1 Leaching tests in a risk management context

Environment Agency (2006) sets out a remedial targets methodology for determining the risk posed by the leaching of contaminants from soil to identified groundwater or surface water receptors. It recommends that, in the absence of direct data, leaching test data are used for determining potential pore water concentrations to assess the risk to controlled waters. However caution is urged when considering hydrophobic organic contaminants (see section 2.1 below).

Traditionally, the contaminant concentrations in eluates from single batch leaching tests have been taken to be similar to pore water concentrations and constant with time. This assumption can lead to both over- and under- estimates of pore water concentrations being made. This is clearly not desirable in terms of estimating the risks to the water environment from the leaching of contaminants; the need for remediation; and for ensuring that sustainable solutions are applied.

> **Where leaching tests are used it is strongly recommended that BS ISO 18772:2008 is followed as a logical process to aid the selection and justification of appropriate tests.**

2 The Leaching Process

Consider a sample of soil. It can be divided into three phases – solid, liquid (may include non-aqueous phase - NAPL) and gaseous. The partitioning of substances among the phases will be dependent on both intrinsic and external factors (see Table 1).

Table 1 Factors that may influence constituent partitioning in soil

Intrinsic	**Environmental**
Substance: Aqueous solubility Volatility Immiscibility with water Speciation Phase	Infiltrating water or groundwater: Ionic strength DOC/organic solvents Temperature
Soil matrix: Porosity Hydraulic conductivity Organic matter Biological activity Particle size/shape Tortuosity Clay mineralogy Fe-Al oxy-hydroxides pH – buffer capacity	Surrounding strata: Groundwater level Drainage structures Contrast in hydraulic conductivity between contaminant source and adjacent strata
Pore water: pH Ionic strength DOC Colloids Redox potential	Hydrology/hydrogeology: Infiltration rate Groundwater level Water pH Ionic strength
Contact time	Contact time

Laboratory leaching tests are designed to simulate the fundamental mechanisms controlling leaching from a solid to a liquid. It is clear from Table 1 that even the more complex laboratory tests would have difficulty in replicating field conditions. It is therefore important to realise that the results from a leaching test will not give a direct measurement of pore water concentration at the time the sample was collected or at any time in the future. A number of leaching tests can be used to assess the sensitivity of leaching to a number of defined parameters, build knowledge of leaching mechanisms, and enable modelling of release with time. Knowledge of the soil properties and exposure conditions should also be used to justify any statement that a leaching test yields conservative estimates of pore water concentrations.

For waste streams arising from industrial processes the intrinsic factors may be reasonably consistent, and leaching behaviour can be characterised within measurable limits. This may not be the case with contaminated soils as a number of factors, such as particle size, organic matter fraction, or contaminant distribution and ageing, may be highly variable both between and within sites. The selection of leaching tests for soils must therefore be justified and linked to a thorough understanding of both site and soil conditions, using the conceptual model. Site zoning, for example, may be used to subdivide soil types for testing and reduce variability in test results – consistent with standard risk management practice.

2.1 Leaching of non-volatile organic constituents (NVO)

With regard to leaching behaviour, organic contaminants can be divided into three groups:

1. Substances that adsorb strongly to the soil, are only partially soluble in water and are non-volatile (e.g. higher PAHs, PCBs);

2. Volatile substances with a relatively high solubility in water (e.g. BTEX, TCE); and

3. Substances that are highly soluble in water (e.g. phenols, MTBE).

The relevance of leaching tests to each of the groups will be variable. For the first group, the separation of the contaminant from the solid phase (including materials used in the test) will be critical during testing. Loss of contaminant to air will be a key consideration in both sample preparation and the design of a leaching test for the second group, and a leaching test will be of limited use for contaminants that strongly partition to the aqueous phase (i.e. the third group), particularly for already weathered soils, since they are rarely adsorbed to soil in the first place.

Because of the issues above, Environment Agency (2006) recommends that the partition coefficient approach ($K_d = K_{oc}$ x foc) is used to estimate the leaching of NVOs from contaminated soil. This linear equilibrium approach includes a number of simplifying assumptions. These are summarised in Table 2 along with implications and uncertainties associated with estimating leaching behaviour.

Table 2 Assumptions made when using partition coefficients

Assumption	Uncertainty
Kd is proportional to the fraction of organic carbon and distribution between organic carbon and water	The type of natural organic carbon is not taken into account – assumed uniform distribution and properties. The nature and distribution of natural organic matter can have a significant bearing on sorption/desorption rates. (Karapanagioti et al. 2000)
Sorption and desorption are reversible and described by the same Kd	In some cases research has shown lower transfer rates for desorption than for sorption. In addition, in weathered soils, NVOs may become embedded in the matrix and their release controlled by diffusion. (Allen-King et al., 2002, Enell et al., 2004, Grathwohl, 1998)
Sorption (and desorption) are instantaneous	Research has shown this can be a slow, continuing process rather than instantaneous. (Enell et al., 2004, Gamst et al., 2004, Pignatello and Xing, 1996, Wu & Gshwend, 1986)

Estimates of leaching using the Kd approach may therefore be highly conservative, particularly for weathered soils, where the proportion of immobile, highly sorbing natural organic matter is high in comparison to mobile forms. In some cases there may be advantages in carrying out leaching tests, taking into account the potential problems, to develop a better understanding of leaching behaviour and therefore improve confidence in risk management decisions. A significant amount of research has been carried out on developing leaching tests for organics, particularly in the Netherlands and Denmark (e.g. Comans, 2001, Hansen et al, 2004, 2005).

Until recently most leaching tests available in the UK and Europe have been developed for inorganic constituents, but have often been applied to organic contaminants without due regard to the suitability of the methods. BS ISO 18772:2008 now provides a framework for evaluation of leaching behaviour of both inorganic and NVO constituents. Four standard tests are referenced, building on those standards developed for waste characterisation, which take the properties of organic constituents into account. These tests are currently not validated and are listed below.

ISO/TS 21268-1, Soil quality — Leaching procedures for subsequent chemical and ecotoxicological testing of soil and soil materials — Part 1: Batch test using a liquid to solid ratio of 2 l/kg dry matter.

ISO/TS 21268-2, Soil quality — Leaching procedures for subsequent chemical and ecotoxicological testing of soil and soil materials — Part 2: Batch test using a liquid to solid ratio of 10 l/kg dry matter.

ISO/TS 21268-3:2007, Soil quality — Leaching procedures for subsequent chemical and ecotoxicological testing of soil and soil materials — Part 3: Up-flow percolation test.

ISO/TS 21268-4, Soil quality — Leaching procedures for subsequent chemical and ecotoxicological testing of soil and soil materials — Part 4: Influence of pH on leaching with initial acid/base addition.

Any test data presented for organic constituents should be viewed with caution, and the methods used subject to close scrutiny because:

- The sampling and preparation methods required by a standard test may not be conducive to preservation of volatile and semi-volatile organics;
- Desorption of low solubility organics from the solid matrix may take significantly longer than a standard equilibrium test permits;
- Degradation may influence the concentration of contaminants desorbed during testing;
- The liquid:solid ratio used may result in excessive dilution;
- The influence of headspace on volatile organics;
- Organics may sorb onto container walls; and
- Resorption onto equipment may take place during solid-liquid separation.

The selection and use of leaching tests and interpretation of the results are discussed further in the following section.

3 Leaching Tests For Inorganic And Organic Constituents

Three levels of detail and justification should be provided to the regulator when leaching tests are used for inorganic, organic or a mixture of constituents:

1. The selection of leaching test or tests;
2. The selection of test parameters; and
3. The use and interpretation of results.

In order to assess leaching behaviour of a material in a particular exposure scenario it is strongly recommended that a number of tests are conducted, in particular to assess the dependence on pH and liquid/solid ratio (LS). Leaching tests do not simulate field conditions, but help to establish boundaries on leaching behaviour.

3.1 The selection of leaching test or tests

A number of leaching tests have been developed for inorganic constituents, and some of those have been adapted for NVO. Additional tests have been developed principally to address critical conditions associated with leaching such organics (e.g. the equilibrium column test, Hansen et al., 2004).

The choice of leaching tests applicable to meet specific objectives will depend on the information gathered from steps 1 to 3 of BS EN 12920:2006 (as followed in BS ISO 18772:2008). These steps are:

Step 1: Definition of the problem and the solution sought;
Step 2: Description of the scenario; and
Step 3: Description of the source

and should be followed when developing the conceptual model for the site.

Generally, the extent of the leaching test programme will depend not only on the specific objectives, but also on other management issues such as the quantity of contaminated soil, the available budget and the feasibility of alternative solutions. The types of test available are briefly described below and their advantages and limitations summarised in Table 3.

Batch test: A relatively simple test, conducted in a glass (or similar inert) container at a fixed liquid to solid ratio (often 2 l/kg or 10 l/kg). The leachant is either distilled water (BS EN 12457) or 0.001M CaCl2 solution (ISO TS 21268 - to reflect the ionic strength of groundwater). The container is agitated for a set time to obtain equilibrium between constituents in the solution and soil. The eluate is separated from the solid by centrifugation or filtration.

Serial batch test: A series of batch tests where, after agitation for a defined time and solid-eluate separation, the solid is added to a new leachant at a progressively higher LS. A leaching profile can be established from the data, which could be used to model temporal release of leachable constituents. Part 3 of BS EN 12457:2002 represents the simplest form of a serial batch test, where two agitations at LS 2 and LS 8 are carried out.

Percolation test: The test is performed in columns with a leachant of distilled water (prEN 14405) or 0.001M CaCl2 solution (ISO TS 21268 part 3). The flow rate is set such that the linear velocity is about 15 cm/day through an empty column. The flow is upward to ensure water saturation and local equilibrium conditions. Eluates are collected for several fractions to build an extraction profile for cumulative LS of 0.1 to 10. The column test is therefore run to test calibration against simple batch tests at either LS 2 or LS 10.

Equilibrium column test: This test is developed for NVO constituents. It is performed in glass columns at a fixed LS depending on the properties of the test material (between 1 and 2 l/kg). A continuous vertical up-flow is applied, so that the column is continuously water saturated. The leachant is 0.005M CaCl2 containing 0.5 g/l NaN3 (to prevent degradation) and is re-circulated in the test system for 7 days to obtain equilibrium. The flow velocity is approximately 0.7cm/h (Darcy velocity). The eluate is collected directly as one single fraction after 7 days of recirculation without further separation (Hansen et al, 2004).

Availability test: This test is intended to estimate the maximum leachable amount of constituents under aggressive leaching conditions. The test differs for inorganic (EA NEN 7371) and organic (Comans, 2001) constituents. For inorganics availability is determined on a ground sample (max particle size 125 µm)from two consecutive extractions at pH 7 (LS 50) and pH 4 (accumulated LS 100), buffered using nitric acid. For organics a single batch extraction is carried out with 1000 mg/l humic acid at pH 12. The high pH is maintained to keep dissolved organic carbon (DOC) in solution.

pH dependence test: This is a series of parallel batch leaching tests conducted at LS 10 on size reduced (<1 mm) samples. As other tests above, the leachant is either distilled water (prEN 14997) or 0.001M CaCl2 solution (ISO TS 21268 part 4) buffered to a defined range of pH using nitric acid and sodium hydroxide.

Sequential extraction test: Such tests are rarely used other than for research purposes. A number of methods have been published (e.g. Environment Canada, 1990, ASTM D4793-88). They involve agitation of solid with a sequence of, often increasingly aggressive, leachants. The resulting fractions from this type of test are not well defined in terms of chemical speciation and do not provide quantitative data. Sequential extraction tests will not be discussed further.

Monolithic tank test: This test may be used to assess the release of constituents from soils that have been solidified (Environment Agency, 2004). The test is static (no agitation) and is conducted on solid, stable samples of defined dimensions at natural pH (unbuffered distilled water). Results are generally interpreted on a surface area basis (mg/m2). The cumulative leaching over the first four days can be used as a compliance test. This test is not suitable for granular soil materials. A standard is available for use in the UK for wastes that have been solidified for reuse or disposal (EA NEN 7375:2004).

Table 3 Advantages and limitations of leaching test methods (adapted from Hansen et al., 2005)

Test method standard	Objective	Advantages	Limitations
Batch test BS EN 12457 Parts 1, 2 & 4 ISO TS 21268 Parts 1 & 2	Compliance with regulatory target Estimate of pore water concentration	These are relatively simple, and most readily available test methods	Do not provide information on leaching mechanism or permit modelling of time-dependent release. LS is considerably greater than field conditions Number of steps (e.g. separation) may increase sorption to equipment.
Serial batch test BS EN 12457 Part 3 ASTM D4793-93	Release of constituents against LS ratio	These are relatively simple test methods. Stepped leaching will give some indication of leaching mechanism (time-dependence)	L:S is still considerably greater than field conditions. Number of steps (e.g. separation) may increase sorption to equipment.
Percolation test prEN 14405 ISO TS 21268 Part 3	Release of constituents against LS ratio Estimate of pore water conc. at low LS	This test provides useful information on leaching as a function of time (L:S), down to reasonably low L:S. Eluate sample directly from column – minimal separation steps. Useful information for modelling release.	Less familiarity with column testing. More expensive than batch due to set-up, run time and volume of leachant. Flow rate is critical as local equilibrium must be established.
Equilibrium column test Hansen et al. 2004	Compliance with regulatory target Estimate of pore water concentration,	The test is derived specifically for NVO – combining the advantages of batch and column testing	The test does not provide information on long-term leaching mechanisms. This method is not adopted and needs to be validated further
Availability test EA NEN 7371 Comans 2001	Estimate potentially leachable constituents	Relatively simple, well-established set-up for inorganics. May place leaching from other tests into context.	Availability is not clearly defined for organics. Number of steps (e.g. separation) may increase sorption to equipment.

Table 3 Cont.

Test method standard	Objective	Advantages	Limitations
pH dependence test prEN 14997 ISO TS 21268-4	Estimate changes in release due to pH changes	Relatively simple set-up. Provides useful information on sensitivity of leaching mechanism to pH changes.	Number of steps (e.g. separation) may increase sorption to equipment.
Monolithic tank test EA NEN 7375	Estimate rate of diffusion from monolithic material	Diffusion may be identified as the main mechanism of release from monolithic materials (e.g. cement-stabilised soils) Useful information for modelling release.	Use limited to monolithic materials1. More expensive than batch due to set-up and run time.

Waste characterisation and the ISO TS 21268 tests

Some of the leaching tests developed for waste characterisation (Lewin et al., 2002, 2004, van der Sloot and Dijkstra, 2004) have been further refined for subsequent chemical and ecotoxicological testing of soils (BS ISO 18772: 2008). The key differences between the suites of tests relate to contact time, nature of leachant and separation technique. These are summarised in Table 4 for the L:S 2 batch tests, with justification given for the changes.

The selection of particular tests must be justified and there are good technical reasons for supporting the use of the ISO TS 21268 tests for soils.

Table 4 Key differences between BS EN 12457 and ISO TS 21268 L:S 2 batch tests

Test condition	BS EN 12457:2002 part 3	ISO TS 21268 part 1	Justification for change
Contact time	24 hr +/- 0.5 hr	24 hr +/- 0.5 hr, 6 hr only if it can be shown that equilibrium is reached	To reduce turn-round time. To minimise abrasion caused by solid-solid contact. This option is not likely to be relevant to NVO, where equilibrium may not be reached in 24 hr.
Leachant	Distilled, deionised or demineralised water, 5 <	As BS EN 12457, but made to 0.001M	To simulate a “natural” ionic strength of pore water.

1 A variation based on the NEN 7347 tank test is under development for compacted coarse granular material

	pH < 7.5 and conductivity < 0.5mS/m	CaCl2	To promote agglomeration and reduce colloid formation and filter clogging.
Container	Glass or HDPE/PP with inert cap e.g. PTFE	Borosilicate glass with inert cap e.g. PTFE	To minimise sorption of NVO constituents to equipment
Separation	0.45μm membrane filter	Centrifugation followed by specific solid-liquid separation (e.g. membrane filter, vacuum extraction)	To minimise overestimation of constituents because of "artificial colloids". Critical parameter for hydrophobic organics – centrifugation must be used where organics are identified constituents.
Status	Validated	Not validated	

3.2 Conditions That May Influence Leaching Test Results For Inorganic And Organic Constituents

Sample preparation: such as particle size reduction or screening and removal, can change the leaching behaviour of the soil. Most leaching tests have defined maximum particle size limits, and oversized particles should be described, weighed, and measures taken (either removal or size reduction by crushing or disaggregation) should be fully documented. Size reduction will expose fresh surfaces and may have a profound effect on leaching behaviour (either way). The method used may also have a significant bearing on results obtained. It is recommended that size reduction is minimised to retain the physical properties of the soil.

Conventional laboratory sample preparation methods may also have a significant impact on the concentration of volatile organic compounds retained in the soil, exacerbating losses that occurred during sampling. For this reason the TS 21268 tests are not valid for organic compounds that are volatile under ambient conditions.

Containers and equipment: The choice of container and equipment should be made to minimise the interaction with constituents in the eluate, in particular through adsorption of NVO constituents. As a result, more stringent requirements are placed in the ISO TS 21268 series of tests. Irrespective of the test methods used, where NVOs are under study the most stringent requirements of the ISO TS 21268 should be used.

Leachant: For most soil materials, the final composition of the eluate is controlled predominantly by the composition of the soil. It makes little difference whether the leachant consists of de-mineralised water or (real or artificial) rainwater. The leachant used in most leaching tests has therefore been standardised over the years to "Distilled water, demineralised water, de-ionised water or water of equivalent purity (5 < pH < 7,5) with a conductivity < 0,5 mS/m according to grade 3 specified in EN ISO 3696".

The ISO TS 21268 tests depart from this and require the leachant to be made up to 0.001M $CaCl_2$ in order to:

- provide a leachant with an ionic strength similar to that of typical soil pore water; and

- enhance the agglomeration of soil particles, thereby limiting the presence of ‘artificial’ colloids and organic matter that would not occur under field conditions (increased abrasion under agitated batch test conditions can lead to the formation of ‘artificial’ colloids).

Other leachants may be required for particular tests, for example EA NEN 7371, prEN 14997, Comans 2001. Any departure from prescribed conditions should only be considered in exceptional circumstances, and the use of an alternative leachant should be fully justified and reported – for example to meet specific project objectives. It is expected that more rigorous QA/QC testing would apply to any departure from a standard.

The ISO TS 21268 series of tests suggests that a biocide (e.g. NaN_3) may be added to the leachant for NVO to eliminate the possibility of biodegradation during testing. This may be particularly relevant where column tests are proposed due to the extended duration of testing. Further work needs to be carried out to determine the impact of using a biocide as the ionic strength of the leachant will be changed. It would therefore be prudent to run parallel batch tests with and without biocide to assess significance on a case-by-case basis.

L:S ratio: Batch leach tests are usually conducted at L:S 10, primarily for practical reasons – to facilitate solid-water separation and derive sufficient sample for subsequent chemical testing. But the choice of an LS mass ratio for leaching should depend on the objectives of the study.

High LS ratio batch tests (e.g. LS = 10): can be used for a wide range of soils; maximise the transfer of constituents (mg/kg); and produce enough volumes for performing the chemical analyses.

Low LS ratio batch tests (e.g. LS = 2): can be used where the objective is to achieve concentrations in the eluate (mg/l) as close to pore water concentrations as possible; or to make it less likely that concentrations are below the limit of detection for the analytical methods used. This test may not be appropriate for clay soils due to separation difficulties. If highly soluble constituents are present the eluate may become saturated and lead to an underestimate of their leaching potential. There may also be insufficient sample available to conduct all chemical testing.

The use of column testing for the collection of eluate fractions at a range of L:S ratios is more suited to describe the amount of constituents leached at a given LS. But the actual eluate concentration at a given LS is not established as the results represent averages over increasing ranges of LS (for example LS 0-0.1 through to LS 5-10). If actual concentrations are required then small eluate samples could be collected at those precise LS values. Initial pore water concentrations, and concentrations at any LS, can be estimated using a kappa value derived from the column test results (see Section 3.3).

Knowing infiltration and dimensions of the source zone, LS can be used to correlate concentrations to exposure time. To place the LS ratio in perspective: for a 2 m thick layer of soil with a density of 1 t/m^3 through which water (e.g. infiltrating rainwater) is percolating at a rate of 200 mm/a, an LS of 2 l/kg and 10 l/kg will be attained in 20 years and 100 years, respectively. For a 20 m thick layer of soil with a similar density and percolation rate, LS ratios of 2 l/kg and 10 l/kg will be attained after 200 years and 1,000 years, respectively (BS ISO 18772:2008).

Eluate concentrations are likely to be significantly higher in tests that sample at lower LS, as illustrated in Figure 2.

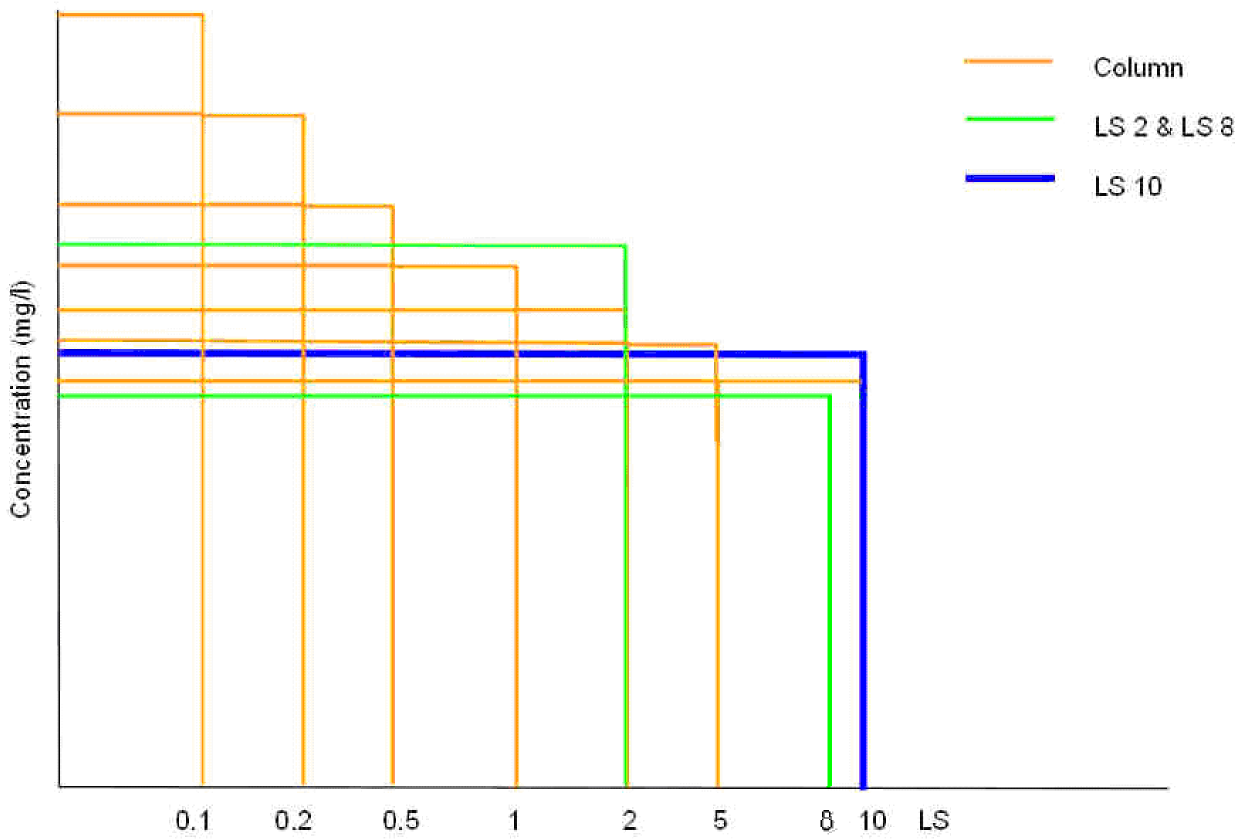

Figure 2: A comparison of constituent concentration in the eluate from single step batch test, two step batch test and column test.

The study objectives should set out clearly whether an estimate of pore water concentration is required, over a defined timescale, or whether contaminant release (in mg/kg) is estimated to set an input parameter for fate and transport modelling. In either case the more useful data will be generated from:

column test > 2-stage batch test > single batch test.

Contact time and duration: For batch tests it is assumed that equilibrium or semi-equilibrium is reached under test conditions. The contact time required depends on the combination of a soil type, particle size and the properties of constituents of interest. Properties of the soil that influence when equilibrium is achieved include particle size and finer-grained fractions (clay mineralogy, organic matter and Fe-Al oxyhydroxides).

In general, 24 hr is considered to be sufficient for equilibrium conditions to be approached for many inorganic constituents and a variety of materials. The contact time can be reduced (ISO TS 21268-1 & 2 permits a reduction to 6 hr) so long as it can be demonstrated that equilibrium or near-equilibrium conditions are established for constituents of interest.

The assumption of equilibrium cannot be made when NVO constituents are being measured. In contaminated soils such constituents may become embedded in the soil with time and their release is controlled by slow diffusion (Hansen et al., 2005). Comans (2001) has shown that a contact time of 48 hr is sufficient to approach equilibrium for ΣEPA-16 PAHs in contaminated soils using the EN12457-3 two-stage batch test.

The actual flow rate of the leachant in a column test is calculated from an apparent linear velocity through an empty column. This velocity is expressed in the same way as, and is comparable to, the rate of infiltration into a soil. The flow rate used will be a balance between replicating field flow conditions and realistic test duration, having regard to soil particle size.

Method of agitation: The aim of agitation is to ensure sufficient contact between the sample and the leachant, to homogenise the solution but not to create new surfaces or disturb surface layers.

Validation of the BS EN 12457:2002 batch tests (van der Sloot et al., 2001) shows that the method of agitation can have a significant influence on eluate concentrations. Based on the results it was recommended that only end-over-end tumbling and roller tables should be used for agitation.

Temperature: Chemical and biological reaction rates are temperature-dependent and care should be taken to ensure temperature during laboratory testing is maintained as constant as possible. A temperature of 20 ± 5 °C is prescribed in the BS EN 12457 and ISO TS 21268 tests. It should be acknowledged that this is higher than the natural groundwater temperature range in the UK, but within safe working conditions for laboratory technicians. Temperature may be particularly important when considering organic contaminants as higher temperature will increase volatility and enhance biodegradation.

pH and redox potential: Changes in pH and redox potential can have a significant effect on the mobility of certain constituents such as amphoteric metals, metalloids, and dissolved organic carbon which, in turn can influence the partitioning of inorganic and organic constituents. In the standard compliance tests (such as BS EN 12457, ISO TS 21268 parts 1 to 3) the final conditions of the test are influenced by the soil properties. The difference between laboratory and field conditions should therefore be taken into account when estimating the effect on constituent release . Exposure to air during sample collection, storage and preparation may also affect the test results as they can lead to pH or redox changes in the eluate.

Separation of soil and eluate: Eluates can be separated from solids by settlement and decantation; filtration; and high-speed centrifugation. This step can have a profound impact on the concentration of contaminant in the eluates and is subject to control in each standard test. Where NVO are to be analysed, high-speed centrifugation must be used. Advantages and disadvantages of separation methods are given in Table 5 (after BS ISO 18772:2008).

In practice, ‘artificial’ colloids may be generated in batch tests that would not be mobilised under field conditions. This can make the effective separation of the solid and eluate more difficult and result in an overestimate of inorganic or organic constituents that are complexed to the colloids. Column tests may be used to overcome both abrasion and separation issues.

Table 5 Advantages and limitations of solid – eluate separation methods

Method	Advantages	Limitations
Decantation	Simple Can be used to simulate run off (reduced or no settlement time)	Difficult to standardise Dependent on soil type (granular) May lead to overestimation (colloids, clay particles)
Filtration	Simple Can be standardised	May lead to overestimation (colloids, clay particles) May lead to underestimation (sorption to filter or cake)
Centrifugation	Potential to control particles present Prevents sorption to filters Can be standardised	Cost and availability

3.3 Use and interpretation of results

Estimation of pore water concentration: The purpose of using leaching tests for land contamination applications is usually to estimate pore water concentrations for groundwater risk assessment. Environment Agency (2006) states that soil pore water concentrations can be determined from leaching tests, but does not expand on the method of derivation.

In the UK the traditional approach to leaching test data has been to use the output from an agitated batch test, usually at LS 10, as the pore water concentration. Reference to figure 2 above indicates that this will lead to erroneous assumptions about potential contaminant concentrations at low LS, and therefore to estimation of pore water concentrations.

A simplified estimation of the release of contaminants as a function of L:S can be described as a declining source as a function of LS, using a matrix and constituent-specific constant, kappa (κ). This approach has been used to derive Waste Acceptance Criteria for each class of landfill by the EU Technical Adaptation Committee for the Landfill Directive (Hjelmar et al., 2001).

The following text is adapted from the Landsim Help files.

The change in concentration of each non-volatile species through time is based on the following equation:

$$C(t) = C(0) * \exp(-\kappa * LS)$$

Where:

- C(t) is the concentration of the species in leachate at any time t (mg/l);
- C(0) is the initial concentration of the species in leachate (mg/l), usually determined when liquid:solid ratio LS = 0.05 l/kg;
- K (kappa) is a species and material-specific constant (kg/l).

Kappa is related to the rate of release of a species from the solid to the aqueous (leachate) phase. The concentration of a species with a high value of kappa (e.g. chloride) will decline more rapidly with time than that of a species with a low value of kappa (e.g. arsenic). Kappa values are experimentally derived from column leaching tests and therefore take into account all the physical and chemical processes occurring during the leaching process.

Kappa is determined by plotting natural logarithm of the concentration against the value of liquid solid ratio (in l/kg) representing the middle of the range for each increment (e.g. LS 0-0.1, mid-point = 0.05). The data should fall on a straight line and the gradient of this straight line is the value of kappa in kg/l. It is assumed that kappa is constant but this is not the case. It is therefore recommended to determine kappa values from the earlier increments of the column test, up to no more than LS 2. This not only provides a more accurate assessment of C(0), but reduces the time and therefore cost of the column test.

4 Recommendations

Where leaching tests are used it is strongly recommended that BS ISO 18772:2008 is followed as a logical process to aid the selection and justification of appropriate tests based on a conceptual understanding of soil and contaminant properties, likely and worst-case exposure conditions, leaching mechanisms, and study objectives. During risk assessment one should characterise the leaching behaviour of contaminated soils using an appropriate suite of tests. As a minimum these tests should be:

- upflow percolation column test, run to LS 2 – to derive kappa values;
- pH dependence test if pH shifts are realistically predicted with regard to soil properties and exposure scenario; and
- LS 2 batch test – to benchmark results of a simple compliance test against the final step of the column test.

These Evidence Commentaries were written by Dr Brian Bone. For further information please contact Bob Barnes.

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