SoBRA
The Society of Brownfield Risk Assessment

SOCIETY OF BROWNFIELD RISK ASSESSMENT

TOP TIPS ON CONCEPTUALISING AND CHARACTERISING CONTAMINANT DISTRIBUTION IN SOIL

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This report is published by the Society of Brownfield Risk Assessment (SoBRA). SoBRA has produced a series of accessible and concise practitioners' guides to support informed decision making with respect to risk assessment within the UK. This report is designed to complement these guides. It presents work undertaken by a SoBRA sub-group composed of volunteers listed in the acknowledgments below.

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1 INTRODUCTION

BACKGROUND

The CL:AIRE "Professional Guidance: Comparing Soil Contamination Data with a Critical Concentration" publication (v 1.1 February 2021) emphasised the importance of developing, refining and thoroughly understanding the Conceptual Site Model (CSM) for a site (and limitations in the data set) prior to considering whether statistical analysis would be applicable and reliable for a soil contaminant data set.

To support the risk assessment community, SoBRA has developed this series of Top Tips outlining key considerations and steps an assessor should consider, specifically when considering the contaminant elements of a CSM. These Top Tips are suitable to be used at all stages of evaluating the potential risks associated with ground contamination at a site, from desk study through to remediation verification.

This document was produced by SoBRA's sub-group on CSMs and Statistics. These top tips are summary in nature and it is strongly recommended that the reader refers to the documents referenced for more detailed information on each aspect covered here.

The top tips are separated into:

- Factors that can influence the distribution of contaminants in soil; and
- Interpreting soil data to understand contaminant distribution.

The top tips are then followed by two case studies.

2 SCOPE OF DOCUMENT

This discussion paper focuses on detailed factors of the physical and chemical characteristics, and distribution, of contamination within the soil as an integral part of the Contaminant Conceptual Site Model (CCSM), the features of which are often overlooked with respect to the overall ground model and CSM of the site, and subsequent risk assessment. Examples of factors that are often overlooked include how and why contaminants are found where they are (chemical behaviour, mobility of contaminants, spatial variability, variation over time and distance, etc.) and how their distribution in the soil relates to the geology, hydrogeology and history of a site.

This document is not intended to replicate or replace other publications such as BS EN ISO 21365:2020, the Land Contamination Risk Management (LCRM) framework (Environment Agency, 2023) and the National House-Building Council (NHBC), Environment Agency (EA) and Chartered Institute of Environmental Health (CIEH) R&D66 publication (NHBC, EA & CIEH, 2008). These publications provide wider guidance on the risk assessment process of ground contamination at all stages, including appropriate sources of information, site investigation techniques, quantitative risk assessment and the key element of this process - to derive and refine the CSM.

They tend to focus discussions of the CSM towards the end goal of determining the potential risks to receptors from contaminants/substances that are, or may be, present in the ground on a site, with less emphasis on clearly characterising the secondary sources[1]. Of note, the term 'source' is not defined in the Part 2A Statutory Guidance 2012 (Defra, 2012).

The members of the subgroup see many reports that have developed a CSM that has not considered factors that are often overlooked that may influence how and why contaminants are present and how they are distributed and vary over time and distance. These factors can include historical activities, the form of the contamination, the chemical behaviour (such as mobility of contaminants), geology, hydrogeology and hydrology. For the purposes of this document, this element of the overarching CSM will be referred to as the contaminant CSM (CCSM). The CCSM is wider than a source delineation exercise which determines the current spatial distribution of contamination at a Site. The CCSM should also take into account changes of contaminants in the ground over time, be it driven by the physical and chemical properties of the substances, human driven processes such as earthworks or redevelopment, or changes in the environmental setting such as those driven by climate change.

The following Top Tips are designed to guide risk assessors on the key factors to consider in relation to the physical and chemical characteristics, and distribution of contamination of the CCSM **within the soil**.

This document *does not*:

- Consider contamination within groundwater, ground gases or vapours (except where they may impact on soil contamination).
- Provide guidance on how to interpret or sub-divide a dataset.
- Provide guidance on how to carry out quantitative risk assessment.
- Provide guidance on when and how to apply statistical analysis.

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[1] BS EN ISO 21365:2020 Section 5.3 distinguishes between the original source e.g. a spill as a *primary source* and the environmental medium in which the substance is present (i.e. soil gas, ambient air, soil or groundwater) as a *secondary source.*

3 TIPS ON THE FACTORS THAT CAN INFLUENCE THE DISTRIBUTION OF CONTAMINANTS IN SOIL

Not all substances present in soil will be 'contaminants' which are defined in BS EN ISO 21365:2020 as being '*a substance or agent present in an environmental medium as a result of human activity*'. Some key questions that should be considered when developing or refining an understanding of the distribution of substances in soil (and therefore support the assessor with the identification of key contaminants of concern) are set out below, along with some suggestions on where such information may be found.

3.1 What substances of potential concern are likely to be present?

Any assessment of soil contamination can only be based on substances that are known to be present or could plausibly be present.

1. Desk-based research

The site's current and previous uses should be used at desk study stage to determine the potential contaminants that may be present, e.g. through a review of historical maps and by conducting a site visit.

2. Further information

The list of substances that are identified at desk study stage that are likely to be, or are, present at a site should be refined as further information is obtained throughout the lifetime of a project. For example, from the results of laboratory testing, further historical research, or additional information provided by site owners/operators or regulators. In particular, unforeseen contaminants within the soil can often only be identified during intrusive investigation or other groundworks that may indicate the presence of unexpected soil components, for example through observations of unusual colours, staining or sheens, or the presence of odours.

3. Transformation

Some contaminants may transform into either more or less mobile forms (e.g. through oxidation or reduction, biodegradation, or neutralisation in soil) and may not be present in the ground in their original form. Further information on transformation is provided in Section 3.5.

3.2 How did the substance enter the soil?

How the substance originally got into the soil is often one of the most important factors controlling the distribution of contamination in soil. For instance:

1. Made Ground and placed fill

A range of contaminants can be present within Made Ground. Made Ground may be placed in the ground as part of deliberate filling actions or accidentally through general activities and operations on a site. Immobile contaminants will tend to remain with their material of origin. These materials can be redistributed and dispersed by activities that move the soil around, such as later earthworks, construction, demolition, reprofiling, remediation, animal burrowing or erosion. Immobile contaminants will be redistributed and dispersed with these Made Ground materials. Key information in characterising the distribution of contamination that enters soil by these routes includes:

- Historical maps, archaeological plans, topographical surveys, and aerial photos showing where particular structures were present prior to demolition, where historical pits, ponds or depressions were located.
- The presence of disturbed soil, and if subsequent disturbance is known or likely to have occurred.
- Made Ground with particular soil characteristics encountered during site investigations (e.g. colour and composition).
- Whether the area is cultivated, and compost added, or where digging is carried out to turn the soil.

2. Surface deposition

Some contaminants enter the soil surface by deposition such as via atmospheric deposition or surface runoff. If immobile in nature, they may stay where they are deposited, subject to physical redistribution by humans, animals or erosion (See Point 1 above). Key information in characterising the distribution of contamination that enters soil by these routes includes:

- The origin of the material that has or is being deposited (e.g. from a site visit, historical maps and site plans).
- Deposition maps (e.g. from atmospheric deposition maps if available).
- Areas of loose soil, surface water flooding information, topography and the direction of surface water flow over these areas.

3. Leaks, spills and disposal of liquids

Liquids tend to enter the soil accidentally via leaks from: bulk storage tanks and pipework, smaller storage containers and poorly maintained drainage systems; via accidental spills; or through direct deliberate disposal. As a result, the highest concentrations of contaminants introduced to soils by these mechanisms tend to be located in: ground near to and/or below these types of infrastructure; chemical, product and waste storage areas;

and waste disposal areas. Key information in characterising the distribution of contamination that enters soil by these routes includes:

- Substances that are currently or have previously been stored (e.g. from current and previous site plans, observations from a site walkover, chemical and waste inventories, historical maps, Environmental Permits).
- The volumes and timescales of such storage.
- Locations and condition of infrastructure such as tanks, pipes, drains, storage areas (e.g. from site walkover, site plans, historical maps, aerial photos, service plans, inspection, and maintenance records).
- Details of any known leaks or spills (e.g. from site incident records and actions taken).
- The depth of a known or suspected leak or spill and areas where liquids may flow into including details of secondary containment, the presence and condition of hardstanding, and the presence of preferential pathways (e.g. from drains or service routes).

4. Naturally-occurring

Some substances occur naturally in soil, such as heavy metals in zones of mineralisation. Key information in characterising the distribution of naturally-occurring substances that could be present at elevated concentrations in laboratory analytical results that may pose a risk to human health or the environment includes:

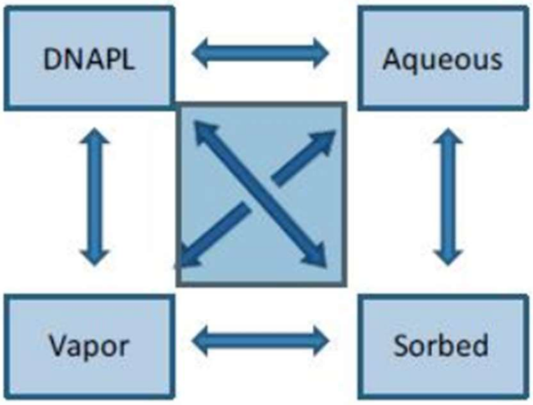
- Natural geology and depth of lodes (e.g. from British Geological Society (BGS) maps, ‘normal’ background soil chemistry data such as UK Soil Observatory maps and data from the BGS project on normal background concentrations of contaminants in UK soils, deposits encountered during site investigation).
- The location of previous mine workings (e.g. from BGS and mining records).

3.3 Is the identified substance present in a likely mobile or immobile form?

The mobility of a substance in the soil is dependent on its physical and chemical properties. Immobile substances remain with the original material that was placed in the soil (although this may be distributed by physical processes as discussed in Section 3.2, Point 1). Mobile substances can move through the soil if the ground conditions permit, noting that ground conditions may fluctuate over time e.g. diurnally, seasonally and over longer time periods driven by climate change. Mobile substances in soil can be derived from both on- and off-site sources and include liquids as well as substances that dissolve (primarily in water, although dissolution in other liquids is possible).

The phase(s) (solid, liquid, vapour/gas, non-aqueous phase liquid (NAPL)) of a substance will have an influence on the distribution in the soil. An example for chlorinated solvents is illustrated in Figure 1.

Figure 1: Chemical phases involved in the subsurface mass distribution of chlorinated solvents. Figure reproduced from ITRC (2020).



The phases of a substance present in the ground will be influenced by a number of factors relating to the properties of the substance itself, including and not limited to:

- its physical and chemical properties;
- its concentration;
- the presence of other substances;
- the time of year/temperature; and
- the water saturation level of the ground.

<u>3.4 How could the site setting be influencing the distribution of substances?</u>

The site setting and interpretation of the ground and groundwater conditions are important in understanding the distribution of contaminants within the soil, particularly for mobile substances. There are a number of key factors to consider in the CSM including:

1. Topography and infrastructure features

The site topography and its infrastructure can influence how and where substances may enter and contaminate soil. Key considerations in characterising the distribution of contamination in the soil include:

- How might topography and surface covering influence how and where a substance derived from above ground or a surface input may enter the soil via surface runoff?
- How might preferential pathways such as soakaways, granular backfill around below-ground service runs or damaged drains influence where liquid or dissolved contaminants enter the soil?

- If the substance is derived from a below ground source such as a leaking drain, pipework or UST, what is the likely depth of the input?
- Could a pressurised release have led to a change in the vertical distribution within the soil?

2. Unsaturated ground conditions

The ground conditions can influence the vertical and lateral mobility of substances in the soil on site and depth of mixing. Key considerations in characterising the distribution of contamination in the soil include:

- The permeability of the underlying ground which can support or retard the migration of liquid or dissolved contaminants. Granular or fractured deposits will encourage migration whereas cohesive deposits such as clay are less permeable.
- Are there preferential pathways such as fractures, or layers such as clay lenses where liquids may collect and spread laterally?
- Will the clay content and/or organic matter content of the ground encourage the contaminant to sorb to the soil?
- How could this vary between Made Ground and the various layers of underlying natural geological deposits?
- Is there likely to be attenuation potential in the soil (availability of electron receptors/donors or cometabolites/nutrients) and will the substance degrade over time?
- Is the contamination associated with any specific soil particle size that is directly relevant to an exposure pathway that may be considered at risk assessment stage?

3. Hydrogeological conditions

Although groundwater contamination is beyond the scope of this document, it is important to consider the interaction between contaminants and groundwater where this may influence the distribution of contaminants in the soil. Key considerations in characterising the distribution of contamination in the soil include:

- Is the contaminant likely to be prevented from downward migration by capillary effects? Are there barriers to migration such as zones of low hydraulic conductivity or capillary suction?
- Where is, and what happens at, the groundwater table over time? Fluctuations in groundwater levels can lead to a "smear zone" at the capillary fringe where contamination dissolved in the groundwater or present as light non-aqueous phase liquid (LNAPL) floating at the top of the groundwater column can become trapped

in the unsaturated zone when groundwater falls. The substance can then be transported laterally when groundwater levels are high.

3.5 Does the identified substance transform?

Some substances will biodegrade, degrade abiotically or volatilise. This can lead to a decrease in the concentration of the original substance in the soil over time.

For some compounds such as nitrate, chlorinated solvents, and per- and polyfluoroalkyl substances (PFAS), the original substance can be transformed into other substances whose concentrations may increase in the soil over time. The physical and chemical properties of these generated substances may differ from the original contaminants, for example they may be more toxic and/or more mobile, and their distribution will also require characterising and assessing.

The physical and chemical characteristics of the soil where the contamination is present can have a key influence on the rate and degree of transformation. Key considerations include, but are not limited to:

1. *Redox potential*
   - e.g. Reduction of trichloroethene (TCE) to form vinyl chloride, and of nitrate to form ammonia tend to occur anaerobically i.e. when there is little or no oxygen present.
   - e.g. Biodegradation of gasoline is more rapid when oxygen is present i.e. aerobic ground conditions.
2. *Acidity/Alkalinity*
   - The pH of the soil can affect the mobility of metals through oxidation or reduction. For example, lead tends to form soluble salts under acidic conditions and is generally immobile in alkaline conditions. Other metals, such as chromium and zinc, are amphoteric, being soluble in both alkaline and acid conditions.
3. *Soil organic carbon*
   - Higher organic carbon levels within the soil will limit the mobility of substances which tend to sorb to organic matter such as benzo(a)pyrene (a PAH) compared to a chlorinated solvent such as vinyl chloride.
4. *Other contaminants*
   - The presence of other contaminants may inhibit or encourage degradation. For example, the presence of petroleum hydrocarbons may enhance the rate and degree of degradation of chlorinated solvents by acting as an energy source and electron donor to drive reductive dechlorination.

5. *Soil porosity and permeability*

- The granular/cohesive nature of soil has a key influence on availability of oxygen and other electron donors/acceptors that are critical to contaminant degradation processes.

6. *Soil microbial community*

- Contaminant transformation can be contingent on the right microbial populations being present in the soil.

7. *Human activities*

- Consideration should include whether the natural chemical characteristics of the soil on a site may have been influenced by human activities. For example, disposal of acids/alkalis into the ground may have altered the soil pH in localised areas.
- Previous remediation activities may have affected the soil's natural characteristics in a number of ways e.g. the application of chemical oxidation (Chemox) products may have altered the redox potential or activated carbon may have been applied which would sorb contaminants more strongly.

3.6 Will foreseeable future development affect the current understanding of the contaminant distribution in soil?

The purpose of the risk assessment may be to support future development. This may mean that future movement of soil should be considered within the CCSM (and potentially controlled), along with the removal or addition of cover layers and changes to the chemical and physical environment. Key information for characterising future distribution of contaminants in the soil, and hence provide a CCSM that is relevant to the purpose of the assessment, is to understand the development plans and any uncertainties in the available details, including:

- Whether reprofiling is likely to be required which may alter the location of the soils and the associated contamination, and the current topography which may alter the surface runoff and erosion characteristics.
- If site levels may change which could remove or relocate soils containing contaminants, and could introduce oxygen which could alter the current redox conditions.
- If material is to be imported (in which case this will also need to be assessed).
- If contaminant migration pathways may be removed, altered or introduced, such as the introduction of new water infiltration and drainage systems, foundations, runoff or hardstanding that could affect the contaminant distribution in the soil.

- How surface sealing with buildings, roads and hardstanding might affect current ground conditions e.g. it possible a reduction of oxygen diffusion into the soil which in turn may slow the rate of current biodegradation processes.

4 TIPS ON INTERPRETING SOIL DATA TO UNDERSTAND CONTAMINANT DISTRIBUTION

The first stage of a CCSM is to determine the current distribution of contaminants in the ground. This should take into account all lines of evidence including: the contaminants that are likely to be present (based on the desk study); field observations such as staining or unusual colours; odours encountered in the field; PID headspace readings; and laboratory analytical results. Uncertainties and data gaps should also be taken into account when characterising the distribution of contaminants in the ground.

4.1 Site investigation and soil sampling rationale

With respect to soil contamination, the purpose of the site investigation is to provide additional certainty on the understanding of the contaminants that are present and their distribution, so that the CCSM can be refined. The investigation should be designed, and the rationale for soil sampling and laboratory analysis at each location should be understood (and documented) in the context of the whole CCSM, taking into account all the aspects that are discussed in Section 3.

For example, petroleum hydrocarbon analysis should be carried out on soil samples that are collected at, and below, the depth of the base of a fuel UST, to provide further information on whether the tank has leaked from its base or not. It should be noted that such samples that demonstrate no contamination are as useful as those that record high concentrations because these support in delineating of the extent of any impact.

4.2 Multiple lines of evidence

Laboratory analytical results should not be used in isolation when trying to understand the distribution of soil contaminants on a site. They provide a small quantitative snapshot of the whole qualitative and semi-quantitative array of evidence that is collected during desk study and site investigation.

Although this document focuses on the soil element of the CCSM, data from other contaminant phases (i.e. dissolved, vapours/gases and NAPL) may support the understanding of the CCSM. For example, by providing evidence of site-specific chemical behaviours (see Sections 3.3, 3,4 and 3.5) and active migration pathways (see Sections 3.2, 3.3 and 3.4). Some tips on how multiple lines of evidence are commonly used are summarised below.

1. Zoning on the basis of history

Made Ground from two (or more) areas may need to be assessed separately, even if the material appears to be of a visually similar nature in the field. For example, where aerial photographs show buildings were demolished at different times (so the material in the two areas has a different history) and review of the laboratory data shows that the two areas have different contaminant profiles.

2. Characterising distribution of immobile contaminants

When characterising the distribution of immobile contaminants that are heterogeneously distributed through near-surface deposits or Made Ground that comprise visually similar material, the material should be treated as one body and should not be separated into layers by depth. For example, the commonly seen practice of automatically considering the top 1 metre differently from deeper soils of the same body with no supporting evidence from field records or laboratory results that this is an appropriate decision. Evaluating the material body as a whole provides a more complete and robust characterisation of soil contamination in the context of the CCSM.

3. Cross-checking laboratory data and field records

Laboratory data should be cross-checked with field records to provide a more complete picture of contaminant distribution. Petroleum hydrocarbon analytical data from a sample of black soil with a strong diesel odour collected from depth should be linked to the observations of black soil with a strong diesel odour extending from shallower depths. For example, a spot analytical result from 3 m bgl may actually represent the contaminant concentrations in soil from 0.5 to 3m bgl, and therefore identify a greater volume of impacted soil than the laboratory data alone may suggest.

4. Linking soil contamination back to desk study information

Linking the example data in Point 3 above back to desk study information could be used, for example, to indicate leaking shallow below ground pipework (from 0.5 m bgl) connected to a nearby diesel AST. However, using the laboratory data alone may erroneously suggest the presence of a UST leaking at depth (at 3 m bgl).

5. Cross-checking laboratory data and field records

Where a previously unknown trench containing unusually coloured soil or material such as spent oxide is identified during the intrusive investigation, it will be necessary to reassess the CCSM in light of this new information.

4.3 Targeted or non-targeted soil sampling

Consideration of what each soil sample represents varies with the contaminant (or classes of contaminants) under assessment. It is entirely possible that a sample location targeting solvent at a former tank can also provide data on the distribution of heavy metals in the Made Ground at that location without undue bias, but the CCSM will be different for both contaminants.

4.4 Zoning soil data

Zoning or grouping of laboratory analytical results is a critical requirement when performing quantitative risk assessment (QRA) and can have an important impact on the outcome. As discussed in the Sections above, the data should first be zoned or grouped based on the identified primary source(s) with consideration of the vertical and spatial distribution of the soil contamination. This has the advantage of using all the information that has been collected during the desk study and fieldwork (including logs and physical descriptions or other records such as odours and headspace readings) in making the assessment.

Once the distribution of contamination has been characterised, the soil CCSM can then be developed to take into account the purpose of the assessment and any foreseeable changes in contaminant distribution based on the aspects discussed in Section 3. For example, if a site is to be developed, this can inform the options for material re-use in the context of exposure and potential risks to future receptors following material movements.

An alternative is to group the data by receptor exposure area. For instance, grouping all the near surface soil data from a garden area to assess the exposure of a small child to a given contaminant. This is more likely to be applicable where soil will not be moved following the risk assessment. A key assumption here is that the receptor has an equal probability of being exposed to any of the soil in the area, and any bias towards or away from exposure to particular areas such as a preferred play area versus a planted border is unimportant.

The approaches of zoning, or grouping data by receptor exposure, have different strengths and can lead to different conclusions. The most applicable approach to zoning data is likely to depend on the soil CCSM and the purpose of the assessment. A statement indicating how the various sources have been addressed and the justification for the division of contaminant data should be included in any data assessment, reported with the results of the intrusive investigation. Where there is potential uncertainty, consideration should be given to examining the data in a variety of ways to illustrate this uncertainty.

CASE STUDIES

To support the reader in applying the Top Tips discussed within this document when deriving a soil CCSM, two case studies have been presented below. Both case studies are 'real life' examples and have been extracted from reports, adapted and anonymised, with the permission of the clients. The examples are laid out differently – there is no single formulaic or correct way to present this type of evaluation. The type of contaminant in each case study is different; the nature of each contaminant results in different behaviour, which in turn leads to a different assessment approach.

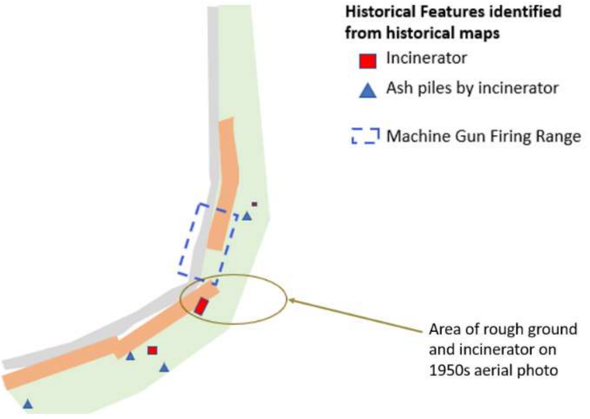
5 CONTAMINANT CONCEPTUAL SITE MODEL CASE STUDY FOR HEAVY METALS IN SHALLOW SOIL

5.1 Chemical behaviour

This case study considers heavy metals which typically have low solubility in soil and hence are relatively immobile. This means that the distribution of heavy metals in soil is generally dictated by the variations in the different soil materials and their anthropogenic components found (e.g., fragments of lead flashing, putty, wiring, bullets etc.). When considering the distribution of heavy metals, it is more important to consider the types of materials present, the potential sources, and the physical reworking of the ground since deposition, rather than properties such as the soil permeability, which are generally less important for immobile contaminants.

5.2 Potential sources of heavy metals

Figure 2: Site Map



In the 1920s the site plans showed machine gun ranges and incinerators were present on and adjacent to the site.

In the 1950s aerial photos show disturbed soil in an area of potential concern (APC) where one of the ash stockpiles and the former incinerator was present.

Firing ranges, particularly around the First and Second World Wars, used cupronickel jacketed bullets with a core of lead or lead-antimony alloy. Brass (a copper and zinc alloy) was also used in some bullet jackets as well as in casings. These metals, therefore, may be present within the site soils associated with the firing range. Arsenic may also have been used in lead alloys used in the manufacture for bullets. The desk study indicated that waste from nearby off-site firing ranges, including waste bullets, may also have been incinerated and deposited in the APC near the incinerator, even after the on-site firing range near the APC was no longer in use.

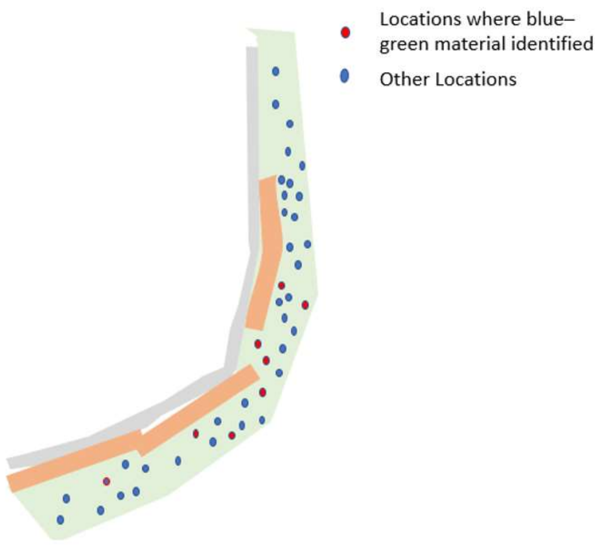
By the 1960s the site had been developed with the ranges being demolished and a number of buildings on the western boundary and open space in the east were constructed. As part of the development, it was anticipated that some levelling and re-distribution of soil had occurred.

5.3 Investigation findings

Initial screening of the soil data identified high concentrations of lead in shallow soil in several samples. These correlated with higher concentrations of antimony and to a lesser extent to elevated copper, nickel and zinc. Lead was therefore used as an appropriate initial marker when considering the distribution of these metals within the soils across the site.

5.4 Spatial distribution of soil types

Figure 3: Spatial Distribution of Lead in Shallow Soil



During the investigation a blue green material was identified, which was generally associated with the highest concentrations of lead.

There was one exception where a green material was identified at one location but concentrations of metals were low. This material was slightly different to the blue green material found elsewhere being a duller serpentine-like green compared to the vibrant colours found elsewhere.

5.5 Lateral distribution

Additional assessment and delineation was carried out using X-Ray Fluorescence (XRF) on-site to further define the heavy metals in soils in-situ. The concentrations were plotted on site plans and showed that, although showing clear local variation, the lead concentrations were highest in areas near the former incinerator ash stockpiles and machine gun ranges, and decreased away from these areas. Blue green material was frequently found to be associated with high concentrations of lead and were absent where heavy metals concentrations were relatively low elsewhere on-site.

5.6 Leaching tests and mobility

Leaching tests carried out as part of waste acceptance criteria testing confirmed the low mobility of the metals in soil, even in the areas where blue green material was identified. The clayey nature of the soil was also considered likely to limit infiltration of water from the surface which would further limit leaching, and therefore contaminant mobility.

5.7 Bioaccessibility

Relative bioaccessibility testing was carried out for a range of metals including lead and arsenic. The relative bioaccessibility of lead using the UBM Barge method was high and ranged from 59 to 97%. The relative bioaccessibility was used to adjust the assessment criteria for the site use.

5.8 Within location variability

The XRF analysis with depth through the soil profile in selected locations confirmed that where the blue green material was present, lead concentrations were high. The XRF also recorded high concentrations in soil near where the blue green material was visually present. This implied that the lead was not just related to one-off flecks of blue green material but appeared to be spread throughout the soil at these areas, although the flecks represented the higher concentrations recorded. This is illustrated in Table 1.

Table 1: Extract from soil logs showing examples of variation in lead in locations where blue green material was present

Location	Depth to top	Depth to base	Description	XRF Depth	XRF lead concentration (mg/kg)
1	0	0.1	Soft, mid brown, slightly sandy, slightly organic, gravelly clay. Gravel comprises fine to medium flint with fragments of organic matter.	0.05	6,390
	0.1	0.2	Light blue green tinged white gravelly friable silt/clay with occasional turquoise fragments. Gravel comprises fine to coarse flint. Crossed string lattice on top.	No data	No data
	0.2	0.3	Black gravelly ash mixed with light blue green tinged white gravelly friable with occasional turquoise fragments. Gravel comprises clinker.	0.25	404,007
				0.2-0.3	122,490
2	0	0.25	Soft mid brown, slightly gravelly, slightly organic, sandy clay. Gravel comprises flint and occasional slag.	0.1	18,868
	0.25	0.45	Soft, light grey slightly gravelly clay with occasional turquoise nodules.	0.4	206,899

Location	Depth to top	Depth to base	Description	XRF Depth	XRF lead concentration (mg/kg)
	0.45	0.6	Soft, slightly organic, sandy gravels of fine to medium sub rounded to rounded flint and occasional slag and clinker and frequent ash.	0.45-0.6	3,665
3	0	0.3	Soft mid brown, slightly sandy, slightly organic, gravelly clay. Gravel comprises fine to coarse, sub rounded to rounded flint and occasional fine to medium brick and ceramic.	0.15	10,579
	0.3	0.45	Soft, light green blue slightly gravelly friable silt/clay. Gravel comprises suspected asbestos containing material (cement bond flat tile).	0.35	151,708
	0.45	0.5	Black gravelly ash. Gravel comprises brick and ceramic.	0.45-0.5	5,561
4	0	0.35	Soft mid brown, slightly organic, slightly gravelly sandy clay with occasional gravels of brick and clinker and fragments of terracotta.	0.15	3,582
	0.35	0.45	Soft mid brown, slightly organic, slightly gravelly, slightly ashy, sandy clay with occasional gravels of brick and clinker and fragments of terracotta.	0.35-0.45	13,390
	0.45	0.55	Pale grey/green friable silt/clay speckled with ash.	0.5	66,705
	0.55	0.6	Dark blue ash with occasional gravel of concrete.	0.55-0.6	157,878
5	0	0.05	Dark brown to black leafy organic matter and twigs.	0.05	7,058
	0.05	0.45	Soft, light green/blue speckled brown clay with nodules of bright turquoise sandy matter.	0.2	298,785
				0.4	320,386
	0.45	0.6	Soft to firm, red brown mottled dark grey clay.	0.5	1,145

5.9 Enrichment

Metal concentrations can be higher in the fine soil component compared to the sample as a whole due to the higher surface area to volume ratio of the fine fraction. People are also more likely to have contact with the fine material within the soil. The process leading to preferential transfer of fine material with higher concentrations of a substance is known as enrichment. This can be a very important consideration particularly where the samples are very gravelly. The testing laboratory used for this study crush and grind the samples prior to analysis and therefore crush the gravel. In order to assess whether enrichment is occurring (or indeed whether the converse is the case, and that the metals detected derive from the large pieces of slag that were encountered), five samples were collected in the southern part of the site to cover material with difference soil components (e.g., blue green material) and a range of lead concentrations. The samples were sieved using a

212 µm sieve and reanalysed for metals. This can also can be used to determine if soil washing to remove the fines may be used as a suitable remediation strategy.

Assessment of the enrichment is summarised in **Error! Reference source not found.**. The results indicated that the finer fraction consistently had a slightly higher lead concentration and hence some enrichment was possible, but the difference was very minor indicating that there was little difference in the fine and coarse fractions and well within sample variability.

Table 2: Assessment of Enrichment of Lead Concentrations

Sample name	**Percentage Composition (%)**		**Lead Concentrations (mg/kg)**			**Enrichment Factor (%) (2,3)**
	Fines (<212µm)	**Coarser Fraction (>212 µm)**	**Whole Sample (1) (mg/kg)**	**Fines (<212 µm)**	**Coarse fraction (>212 µm)**	
Bulk 1	65	35	44,150	48,000	37,000	9%
Bulk 3	79	21	270	300	140	13%
Bulk 4 (OS-4)	39	61	27,120	32,000	24,000	18%
Bulk 5 (OS-5)	53	47	81,710	85,000	78,000	4%
Bulk 6 (OS-25)	59	41	25,310	29,000	20,000	15%

Note: All units mg/kg

(1) Calculated using the following formula:
Conc.[total]=Conc.[t>212µm] x % Composition [>212 µm] + (Conc. [<212 µm] x % Composition [<212 µm]

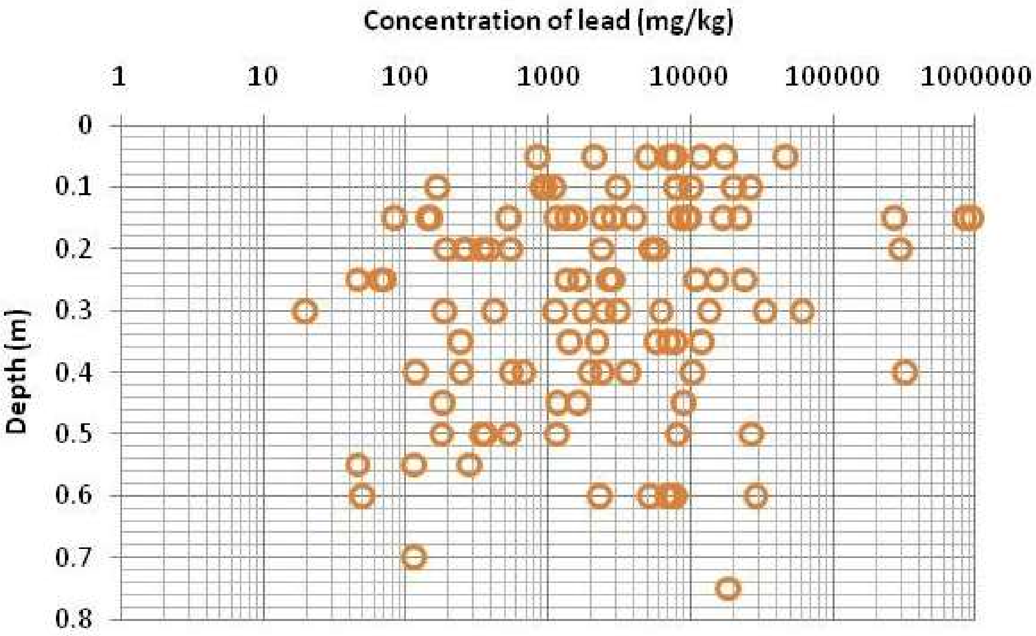
(2) Calculated using the following formula:
(Conc.[<212µm]/(Conc.[total]) - 1) x 100

(3) The enrichment factor may also reflect within sample variability.

5.10 Variation with depth

The variation of lead concentrations with depth within the Made Ground was also considered and are presented in Figure 4. While there was a slight tailing off of concentrations with depth and the highest concentrations were often at 0.2 to 0.4 m bgl where the blue/green material was more commonly found, there was no clear trend, and the high concentrations could occur anywhere throughout the whole of the shallow soil profile.

Figure 4: Concentration of Lead with Depth



5.11 Summary of the contaminant conceptual site model for the heavy metal contamination

The heavy metals were likely to be present due to the former firing ranges in the area which used bullets with elevated concentrations of the heavy metals. These may also have been burned in the incinerators on the site and spread in the tipping area APC. Blue green material was identified in the soil near the incinerators and former ash pile.

Although the blue green material was noted to potentially be indicative of particularly high concentrations of these metals, using lead as a marker for all heavy metals detected, the concentrations appeared to be distributed throughout the shallow soil near those sources. This indicates that the redevelopment of the site in the 1960s is likely to have moved some this material, for example levelling and turning over of the soil has mixed fragments of blue green material into the shallow ground, some of which may be too small to be visible.

The significant local variation observed in the lead concentrations may reflect the clumpy distributions of lead particles from this type of incomplete mixing. Because of this, multiple measurements of heavy metals may be required to define the boundary of the contamination away from the source areas where the blue green material was observed. In-situ XRF measurements may be used to support such an assessment of the lateral extent and boundary of the contamination.

6 CONTAMINANT CONCEPTUAL SITE MODEL CASE STUDY FOR A SEMI-VOLATILE ORGANIC COMPOUND

6.1 Background

A site located on the northern edge of a derelict heavy industrial area was earmarked for redevelopment as residential apartment blocks as part of the regeneration of the wider area. A desk study and shallow intrusive investigation were carried out to support the proposed redevelopment.

6.2 Site setting

The site is currently a disused lorry park and during a walkover, most of the ground surface was noted to be black top that was in poor condition and that localised areas of loose hardcore were also present.

Ordnance Survey historical mapping and aerial photography showed the former use of the site to have been offices and a car park that were part of a coal tar distillation works that was operational from around the turn of the 20th Century until the 1970s. The main operational area of the works was located off-site, adjacent to the east of the site. No development was shown on the historical mapping and aerial photography on the subject site until the 1950s, at which time the offices and car park were constructed. The office buildings on the site were subsequently demolished in the 1990s and the car park taken over by a haulage firm for lorry parking. The client reported that the site has been disused for the past two years. During the site walkover, remnant structures of the tar distillation works, including above ground bulk storage tanks, were noted to remain on the adjacent site to the east. No further details of the presence of any underground structures or pipework on the derelict operational area could be ascertained through desk study research.

The current immediate surrounding land uses are:

- North – Road with terraced housing beyond.
- South – Recent redevelopment for warehousing.
- East – Derelict tar distillation works, awaiting clearance and regeneration.
- West - Recent redevelopment for retail.

BGS mapping indicated that the site was likely to be underlain by River Terrace Deposits and/or Alluvium with London Clay Formation bedrock beneath.

6.3 Key findings from site investigation

The investigation locations were typically non-targeted and were considered to provide adequate site coverage for a preliminary investigation. It was intended that the full thickness of superficial deposits should be ascertained where possible, depending on the limitations of the drilling technique employed. However, due to the presence of a layer of gravels, this was not possible.

The geological sequence encountered is laid out in Table 3.

Table 3: Geological sequence encountered

Stratum	**General Description**	**Depth Range (m bgl)**		**Thickness Range (m)**
		Top	**Base**	
Made Ground	Typically black top, with granular hardcore present at some locations.	0	0.1-0.25	0.1-0.25
Made Ground	Silty sands and gravels of varying size fractions containing anthropogenic materials including brick, ceramic, wood and fragments of black top.	0.1-0.25	0.75-1.2	0.5-1.1
Alluvium	Typically encountered as bands of sandy or gravelly CLAY and very clayey SAND with some more distinct layers of fine to medium gravels.	0.75-1.2	>5	>3.8-4.25

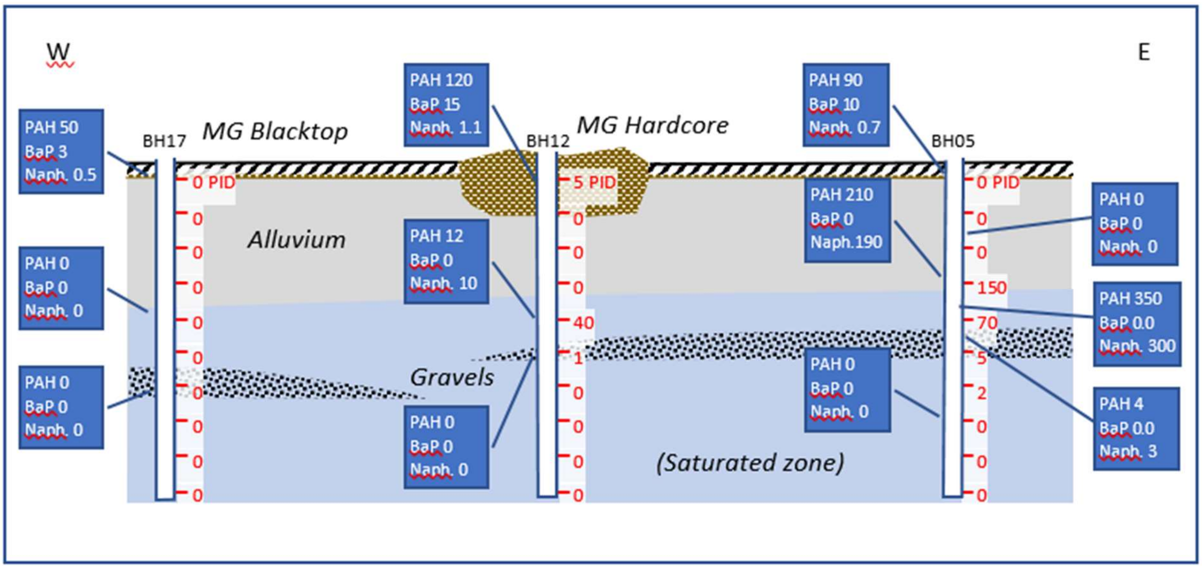
Headspace measurements of total volatile organic compounds (TVOCs) in the field were recorded using a photoionisation detector (PID). A creosote-like odour was noted within the unsaturated alluvial deposits just above groundwater strikes and at the same depth as the most elevated PID readings. Resting groundwater levels were recorded on subsequent monitoring visits at similar depths to the groundwater strikes between 3-4 m bgl, indicating that the groundwater was unconfined.

Soil samples were analysed in the laboratory for a range of contaminants and naphthalene was identified as a contaminant of concern (CoC) within both the Made Ground and the Alluvium.

6.4 Contaminant conceptual site model for naphthalene

The field information and laboratory data were scrutinised to determine the vertical and lateral distribution of naphthalene within the soils underlying the site, as illustrated by the cross-section in Figure 5. The key contaminants detected in the soil samples were polycyclic aromatic hydrocarbons (PAHs).

Figure 5: Correlation of PAH (mg/kg) and PID readings (ppm) with depth across the site



Within near surface Made Ground, concentrations of total USEPA 16 PAHs were recorded up to 120 mg/kg, with naphthalene comprising <1% of the total. Within the capillary fringe, where present, the concentration of total USEPA 16 PAHs was typically higher (up to 350 mg/kg) and with a greater proportion of naphthalene detected (c.80-90%).

Initial observations from the field information and laboratory results suggested that, for a number of reasons, there were two sources of naphthalene on the site, one in shallow Made Ground (CCSM1) and one within the capillary fringe (CCSM2). The following provides the evidence for two separate CCSMs being required for naphthalene:

Naphthalene CCSM 1

- Present within Made Ground.
- Concentrations were moderate concentrations (maximum 120 mg/kg).
- Concentrations within the Made Ground samples were highly variable with 50% of samples being non-detect, and concentrations in the remaining 50% ranging from 0.5 to 120 mg/kg). However, the concentrations tended to be higher in samples that were collected nearer to the surface, coincident with the presence of black top hardstanding and fragments of black top recorded within the Made Ground on the borehole logs.
- Naphthalene is the most soluble and volatile of the USEPA 16 PAHs and, due to the manufacturing process of black top, would not be expected to be present in high proportions within this material as a potential source.
- The distribution of elevated concentrations of PAHs within the soil samples analysed, the field observations of the presence of black top, the low proportion of

naphthalene within the PAH analysis in the near-surface Made Ground (due to the physicochemical properties of naphthalene), and the indicators of coal tar provided multiple lines of evidence that black top was the likely source of naphthalene in the near-surface Made Ground.

- The site history and field observations provided additional lines of evidence. The site history showed that it had been used as a car park since the 1950s, at a time when coal tar was used as a binder in black top. Aerial photographs from the 1950s and 1970s showed that it was covered with hardstanding during this period. The condition of the black top was observed to be poor, suggesting that it had been laid a long time ago, potentially several decades.
- The probable source of the naphthalene in CCSM1 was established to be the black top present on the site from a combination of, weathering of the hardstanding over a prolonged period of time and a small degree of vertical leaching when the material was laid and fragments entrained within the Made Ground which were then sub-sampled and analysed by the laboratory.
- PAHs in black top binder are considered to be within relatively immobile. This supports the initial observations that the source of naphthalene deeper within the Alluvium (see Figure 5) is not the near-surface contamination and that two CCSMs were required for naphthalene at this site.

Naphthalene CCSM 2

- Concentrations of PAHs within soil samples collected throughout the unsaturated profile of Alluvium were typically low or non-detect down to the capillary fringe.
- Concentrations of PAHs then spiked in soil samples collected from immediately above the groundwater table.
- The distribution of naphthalene soil concentrations correlated with spikes in headspace measurements and notes of a creosote-like odour recorded on the borehole logs.
- If black top was the source of naphthalene in the capillary fringe, concentrations would be expected to increase or remain stable in the direction of flow due the processes of accretion and degradation which does not match site observations.
- The laboratory analytical results were plotted onto a cross-section (Figure 5) and it was identified that the higher concentrations tended to be:

  a) towards the eastern site boundary; and

  b) within layers of Alluvium with the greatest silt content.

- The groundwater strikes within the Alluvium during drilling and the resting groundwater levels were similar, indicating that groundwater was not confined.
- A groundwater contour plot was produced using the data collected on resting groundwater levels during the monitoring, and groundwater flow was inferred to be towards the west.
- The groundwater flow direction was plotted alongside the naphthalene soil concentrations within the smear zone. This indicated that the source of naphthalene was most probably off-site to the east.
- The proportion of naphthalene in the PAH soil analysis within the capillary fringe was high (80-90%). Naphthalene is more soluble than the other USEPA 16 PAHs, by up to several orders of magnitude. This suggests that this contaminant has migrated onto the site dissolved within groundwater. (Although beyond the scope of the soil CCSM, this was supported by groundwater naphthalene concentrations in the Alluvium which were below the solubility limit.)
- Given the history of the adjacent site as the active area of a former tar distillation works, and that infrastructure such as above ground storage tanks remained on that site which could still hold residual product, the source of the naphthalene within the deeper unsaturated alluvium was determined to be the adjacent site to the east.
- In summary, the mechanism for naphthalene to be present within the Alluvium on the site was considered to be a three-stage process comprising:

  1) Leaks from sources such as tanks and pipework on the adjacent site to the east (exact mechanism, location, duration and whether on-going or historical unknown) and vertical migration of product into the Alluvium.

  2) Dissolution of naphthalene into groundwater present within the Alluvium and migration in the dissolved phase onto the site.

  3) Naphthalene has been preferentially trapped within the finer silts of the alluvial deposits at the capillary fringe due to the properties of the silts i.e. greater absorption to a higher organic carbon content and lower rates of flushing in comparison to the more permeable gravel deposits.

- Further assessment would be required to reduce uncertainty regarding the source of naphthalene, its impact to the proposed development and impact to the groundwater.

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8 GLOSSARY

Acronyms	Description
bgl / mbgl	below ground level / metres below ground level
BGS	British Geological Society
CCSM	Contaminant Conceptual Site Model
CL:AIRE	Contaminated Land in Real Environments
CCSM	Contaminant Conceptual Site Model
CoC	Contaminant of concern
CSM	Conceptual Site Model
EA	Environment Agency
LNAPL	Light non-aqueous phase liquids
NAPL	Non-aqueous phase liquid
PAHs	Polycyclic aromatic hydrocarbons
PID	Photoionisation detector
PFAS	per- and polyfluoroalkyl substances
SoBRA	Society of Brownfield Risk Assessment
TVOCs	Total volatile organic compounds
USEPA	United States Environmental Protection Agency
XRF	X-Ray Fluorescence

LIMITATIONS

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