BS 10175:2011+A1:2013

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Investigation of potentially contaminated sites – Code of practice

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Publishing and copyright information

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Foreword

Publishing information

This British Standard was published by BSI Standards Limited, under licence from The British Standards Institution, and came into effect on 31 March 2011. It was prepared by Technical Committee EH/4, *Soil quality*. A list of organizations represented on this committee can be obtained on request to its secretary.

The initial drafting of this British Standard was produced in association with BIS as part of their on-going programme of support for standardization.

Supersession

BS 10175:2011+A1:2013 supersedes BS 10175:2011, which is withdrawn.

Information about this document

This standard is intended to be read in conjunction with BS ISO 10381-1, BS ISO 10381-2, BS ISO 10381-3 and BS ISO 10381-6 which deal with various aspects of investigation and sampling of soil and soil materials to determine quality, not only on land potentially affected by contamination, but also agricultural, natural and near-natural sites. This series of international standards is currently being revised.

This edition is consistent with current methodologies and has been updated to take account of developments in planning, sampling, testing and assessment since the publication of BS 10175:2001.

Text introduced or altered by Amendment No. 1 is indicated in the text by tags [A1⟩ ⟨A1]. Minor editorial changes are not tagged.

One of the changes introduced in this amendment of BS 10175 is the deletion of Annex I. Annex A in BS 8576 summarizes the regulatory regimes dealing with land contamination with reference to the Part 2A Contaminated Land regime, the Building Control regulations and the planning process. These represent the main contexts in which the investigations for land contamination and for ground gas are carried out following the processes set out in BS 10175.

Presentational conventions

The provisions in this standard are presented in roman (i.e. upright) type. Its recommendations are expressed in sentences in which the principal auxiliary verb is “should”.

The word “may” is used in the text to express permissibility, e.g. as an alternative to the primary recommendation of the clause. The word “can” is used to express possibility, e.g. a consequence of an action or an event.

Commentary, explanation and general informative material is presented in smaller italic type, and does not constitute a normative element.

Contractual and legal considerations

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a British Standard cannot confer immunity from legal obligations.

In particular, attention is drawn to the following primary legislation and the statutory regulations.

- The Environmental Protection Act 1990, as amended [1];
- The Contaminated Land (Wales) Regulations 2006 [2];
- The Contaminated land (Scotland) Regulations 2000, as amended [3];
- The Contaminated Land (England) Regulations 2006 [4];
- The Environment Act 1995 [5];
- The Radioactive Contaminated Land (Modifications of Enactments) (England) Regulations 2006 [6];
- The Radioactive Contaminated Land (Modifications of Enactments) (Wales) Regulations 2006 [7];
- The Radioactive Contaminated Land (Scotland) Regulations 2007, as amended [8];
- The Water Resources Act 1991, as amended [9];
- The Water Act 2003 [10];
- The Water Environment and Water Services (Scotland) Act 2003 [11];
- The Water (Northern Ireland) Order 1999 [12];
- The Wildlife and Countryside Act 1981 [13];
- The Conservation (Natural Habitats, etc.) Regulations 1994 [14];
- The Town and Country Planning Act 1990 [15];
- The Town and Country Planning (Scotland) Act 1997 [16];
- The Building Control Act 1990 [17];
- The Construction Design and Management (CDM) Regulations 2007 [18];
- The Control of Substances Hazardous to Health (COSHH) Regulations 2002 [19];
- The Factories Act 1961 [20];
- The Offices, Shops and Railway Premises Act 1963 [21];
- The Health and Safety at Work, etc. Act 1974 [22];
- The Pollution Prevention and Control Act 1999 [23];
- The Control of Pollution Act 1974, as amended [24];
- The Environmental Damage (Prevention and Remediation) Regulations 2009 [25];
- The Environmental Damage (Prevention and Remediation) (Wales) Regulations 2009 [26];
- The Environmental Liability (Scotland) Regulations 2009 [27];
- The Environmental Protection (Duty of Care) Regulations 1991 [28];
- The Environmental Permitting (England and Wales) Regulations 2007 [29];
- The Pollution Prevention and Control (Scotland) Regulations 2000 [30].

Introduction

The recommendations and guidance of this British Standard are applicable to the investigation of all potentially contaminated sites and also to land with naturally elevated concentrations of potentially harmful substances.

The management of land potentially affected by contamination involves identifying risks arising from the presence of contaminants in order that appropriate action can be taken. The risk assessment of a potentially contaminated site requires a variety of information, including:

a) details of the historical uses of the site and surrounding area and the potential for the presence of contaminants (the potential sources);

b) identification of who or what could be affected by the contaminants (i.e. receptors);

c) information on the pathways by which contaminants could migrate or come into contact with receptors (including details of any physical characteristics of the site that will affect contaminant movement).

This information is gathered by a process of site investigation as set out in this standard.

The results of the investigation ought to delineate all known aspects of the site that could impinge upon or affect source-pathway-receptor scenarios defined within the conceptual model.

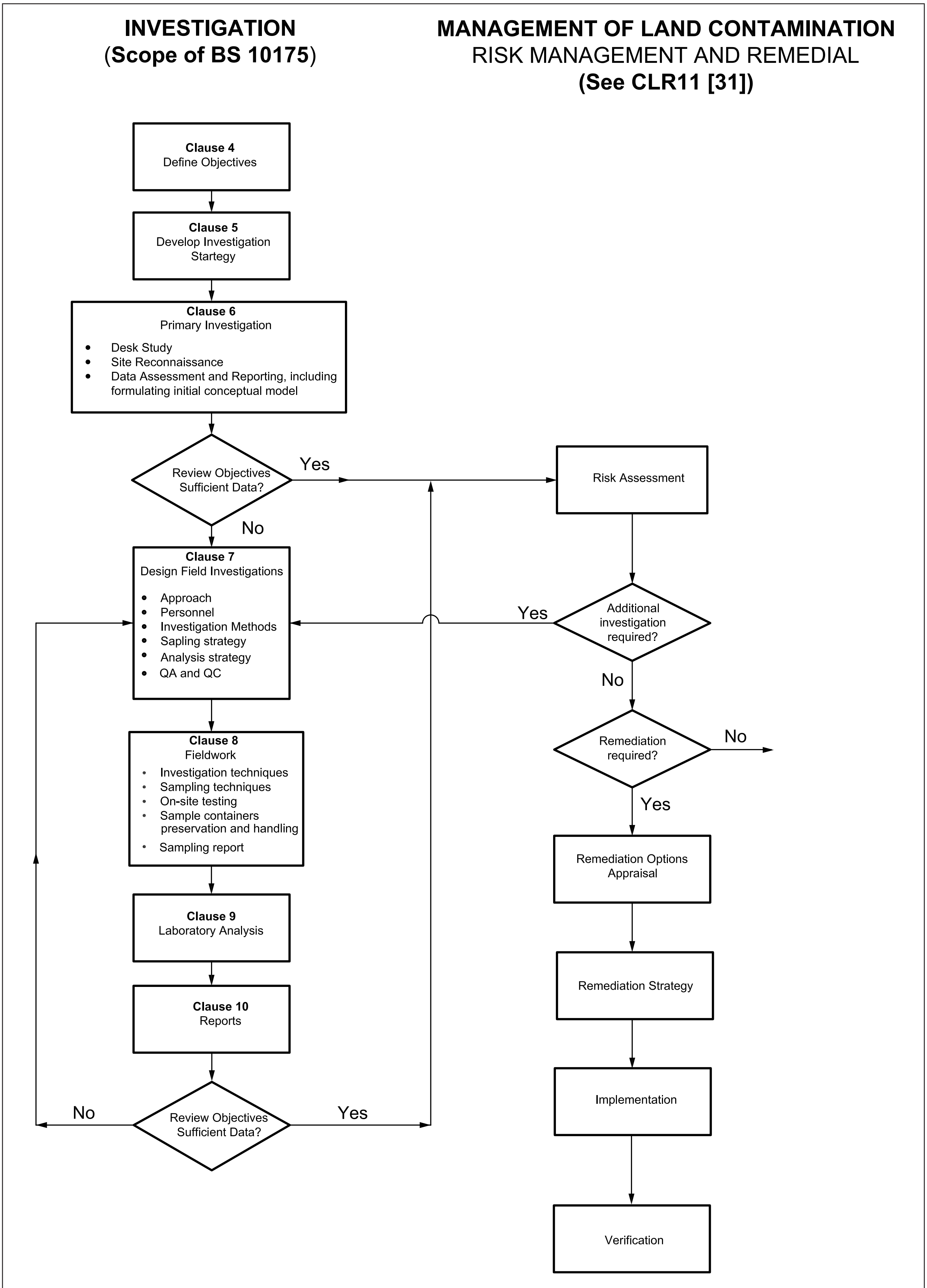
The conceptual model is a description and/or representation of the site, incorporating what is known about the ground and groundwater conditions; the actual and potential contamination; the physical conditions and environmental setting; the receptors; and potential pathway linkages between contamination sources and receptors. Depending upon the objectives of the investigations, it could be relevant to consider new future receptors associated with the construction and completion of a new development, as well as existing receptors. The conceptual model leads to the formulation of contamination-related hypotheses, which the investigation process examines through the collection of relevant data.

The conceptual model is first formulated during the preliminary investigation (desk study) and informs subsequent investigations, if these are necessary, to meet the objectives of the overall investigation. One of the objectives will be reduction of uncertainty in the conceptual model.

The process of investigation involves a number of phases and typically begins with setting the objectives of the investigation. At the end of each phase of investigation, the information obtained is reviewed to determine whether the objectives have been met or there is a need for further investigation, and to address data gaps or uncertainties in the conceptual model. Where further investigation is necessary, the design of the next phase is based on, and utilizes, the information previously obtained.

The process of investigation, and how it relates to the management of land potentially affected by contamination, is illustrated in Figure 1. The recommendations of this standard are presented in the sequence of steps that are to be followed in the investigation process, and Figure 1 indicates which clause refers to each step. Annex A provides examples of how the recommendations of this standard can be applied.

Figure 1 **Site investigation process in the management of land potentially affected by contamination**



The use of the conceptual model to assess the need for remedial action of land affected by contamination is a part of the risk assessment process. Guidance on how to carry out a risk assessment is outside the scope of this standard.

NOTE 1 Guidance on the management of contaminated land has been published by the Department of the Environment, Food and Rural Affairs (Defra) and the Environment Agency [31]. This gives guidance on the assessment of land known to be or potentially affected by contamination and can be used in conjunction with the recommendations of this standard. Particular attention is drawn to chapter 2, Risk Assessment.

NOTE 2 Some requirements for investigation lie beyond the needs of a risk assessment, for example, a sampling scheme for remediation verification or the selection and detailed design of a remediation scheme. In such situations the procedures and methods described in this standard can be used to design the relevant investigation.

[A1) *NOTE 3 Guidance on investigations for Volatile Organic Compounds (VOCs) and permanent gases such as methane and carbon dioxide, is provided in BS 8576, which has been prepared to be used in conjunction with this British Standard.* (A1]

1 Scope

This British Standard gives recommendations for, and guidance on, the investigation of land potentially affected by contamination and land with naturally elevated concentrations of potentially harmful substances, to determine or manage any risks. It covers:

a) setting the objectives of an investigation;

b) developing a strategy for the investigation;

c) designing the different phases of the investigation;

d) sampling and field testing;

e) laboratory analysis;

f) reporting,

in order to obtain scientifically robust data on soil, groundwater, surface water and ground gas contamination.

It is intended for use by those with an understanding of the risk-based approach to the assessment of sites (as described in the Model Procedures for the Management of Land Contamination (CLR 11) [31]).

The relevant recommendations and guidance within this standard are intended to ensure that the objectives of an investigation are achieved and that appropriate data for the risk assessment are obtained. However, it is not feasible to provide detailed guidance for every possible investigation scenario.

This British Standard does not give:

1) guidance on certain constraints or problems that can affect a site, such as geotechnical aspects (which are covered by BS 5930);

2) guidance on legal aspects, including the need for licences and permits, etc.;

3) detailed guidance for the investigation and assessment of radioactively contaminated sites (see Note 1);

4) procedures for the formal assessment of the potential risks posed by land potentially affected by contamination (see Note 2);

5) guidance on sampling from stockpiles (see Note 3);

A1) 6) detailed guidance on investigations for ground gases, i.e. Volatile Organic Compounds (VOCs) and permanent gases such as methane and carbon dioxide. (A1

NOTE 1 Guidance on the investigation and assessment of radioactivity in soils is given in the BS ISO 18589 series. The appropriate methodology for such works will be dependent on the nature of the contamination and the site conditions and ought to be discussed with the regulator in advance.

NOTE 2 See the guidance published by Defra and the Environment Agency in CLR 11 [31].

NOTE 3 Guidance on sampling stockpiles is given in ISO 10381-8 and BS ISO 18283.

When relevant, this standard is to be used in conjunction with other standards and codes of practice, for example, A1) BS 8576 for investigations for ground gas and (A1 BS 5930 for investigations for civil engineering purposes.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

A1) BS 5930, *Code of practice for site investigation* (A1

BS 6068-6.4, *Water quality – Part 6: Sampling – Section 6.4: Guidance on sampling from lakes, natural and man-made*

BS 6068-6.12, *Water quality – Part 6: Sampling – Section 6.12: Guidance on sampling of bottom sediments*

BS 6068-6.14, *Water quality – Part 6: Sampling – Section 6.14: Guidance on quality assurance of environmental water sampling and handling*

BS 6187, *Code of practice for demolition*

BS 8485, *Code of practice for the characterization and remediation from ground gas in affected developments*

A1) BS 8576:2013, *Guidance on investigations for ground gas – Permanent gases and Volatile Organic Compounds (VOCs)* (A1

BS EN 12457 (all parts), *Characterisation of waste – Leaching – Compliance test for leaching of granular waste materials and sludges*

BS EN ISO 5667-1, *Water quality: Sampling – Part 1: Guidance on the design of sampling programmes and sampling techniques*

BS EN ISO 5667-3, *Water quality: Sampling – Part 3: Guidance on the preservation and handling of samples*

BS EN ISO 14688, *Geotechnical investigation and testing*

BS EN ISO 17025, *General requirements for the competence of testing and calibration laboratories*

BS ISO 5667-5, *Water quality – Sampling – Part 5: Guidance on sampling of drinking water from treatment works and piped distribution systems*

BS ISO 5667-6, *Water quality – Sampling – Part 6: Guidance on sampling of rivers and streams*

BS ISO 5667-11, *Water quality – Sampling – Part 11: Guidance on sampling of groundwaters*

BS ISO 10381-1, *Soil quality – Sampling – Part 1: Guidance on the design of sampling programmes*

BS ISO 10381-2, *Soil quality – Sampling – Part 2: Guidance on sampling techniques*

BS ISO 10381-3, *Soil quality – Sampling – Part 3: Guidance on safety*

BS ISO 10381-6, *Soil quality – Sampling – Part 6: Guidance on the collection, handling and storage of soil under aerobic conditions for the assessment of microbiological processes, biomass and diversity in the laboratory*

BS ISO 11074, *Soil quality – Vocabulary*

BS ISO 11464, *Soil quality – Pretreatment of samples for physio-chemical analysis*

BS ISO 14507:2003, *Soil quality – Pretreatment of samples for the determination of organic contaminants*

BS ISO 18512:2007, *Soil quality – Guidance on short and long term storage of soil samples*

3 Terms and definitions

For the purposes of this British Standard the terms and definitions given in BS ISO 11074 apply, together with the following.

3.1 Definitions

3.1.1 accuracy

closeness of agreement between a measurement result and the true value of the measurand

NOTE The term "accuracy", when applied to a set of measurement results, describes a combination of random components and a common systematic error or bias component.

[Adapted from BS ISO 3534-1]

3.1.2 conceptual model

characteristics of a site that are relevant to the occurrence and potential effects of ground contamination that describe the nature and sources of contamination; the ground, groundwater, surface water, ground gases and volatile organic compounds (VOCs) that could be present; the environmental setting; potential migration pathways; and potential receptors

NOTE A conceptual model is usually presented in a tabular, textual and/or diagrammatic form.

3.1.3 contamination

presence of a substance or agent, as a result of human activity, in, on or under land, which has the potential to cause harm or to cause pollution

NOTE There is no assumption in this definition that harm results from the presence of the contamination.

3.1.4 controlled waters

inland freshwater, water contained in underground strata and any coastal water between the limit of highest tide or the freshwater line to the three mile limit of territorial waters

NOTE 1 See Section 104 of The Water Resources Act 1991 [9]. "Inland freshwater" includes any lake, pond or watercourse above the freshwater limit.

NOTE 2 In Scotland, references to "controlled waters" in Part IIA of the EPA [1] have been replaced by the statutory definition of "the water environment" pursuant to the Water Environment and Water Services (Scotland) Act 2003 [11]. This definition includes all surface water, groundwater and wetlands.

NOTE 3 In Northern Ireland, controlled waters are defined in Article 2 (2) of the Water (Northern Ireland) Order 1999 [12] as water in waterways and underground strata.

3.1.5 harm

measurable adverse effect on a receptor

NOTE This definition is broader than that given in Section 7(A)(4) of the Environmental Protection Act [1].

3.1.6 hazard

property or situation that in particular circumstances could lead to harm or pollution

(CLR 11 [31])

3.1.7 measurement uncertainty

estimate attached to a test result which characterizes the range of values within which the true value is asserted to lie

3.1.8 pathway

mechanism or route by which a contaminant could come into contact with, or otherwise affect, a receptor

3.1.9 receptor

entity that could be adversely affected by a contaminant(s)

NOTE Examples of receptors include persons, other living organisms, ecological systems, controlled waters, atmosphere, structures and utilities.

3.1.10 risk

combination of the probability, or frequency of occurrence, of a defined hazard and the magnitude of the consequences of the occurrence

(CLR 11 [31])

3.1.11 risk assessment

formal process of identifying, assessing and evaluating the health and environmental risks that could be associated with a hazard

(CLR 11[31])

3.1.12 sampling uncertainty

part of the total measurement uncertainty attributable to sampling

[IUPAC (2005) [32]]

3.1.13 soil

topsoil and subsoils; deposits such as clays, silt, sand, gravel, cobbles, boulders and organic matter and deposits such as peat; material of human origin such as wastes; ground gas and moisture; and living organisms

NOTE This is the meaning ascribed through ground engineering and encompasses fills and deposited wastes.

3.1.14 source
location or feature from which contamination is, or was, derived

3.1.15 uncertainty
lack of knowledge about specific factors

3.2 Abbreviations

bgl	below ground level
BGS	British Geological Survey
BOD	biochemical oxygen demand
CDM	construction design and management
CLO	contaminated land officer (of a local authority)
CLR	Contaminated Land Report
COD	chemical oxygen demand
COSHH	Control of Substances Hazardous to Health Regulations 2002 [19]
Defra	Department for Environment, Food and Rural Affairs
DO	dissolved oxygen
DQRA	detailed quantitative risk assessment
ECD	electron capture detector
EPA (1990)	Environmental Protection Act (1990) [1]
FAAS	flame atomic absorption spectrometry
FID	flame ionization detectors
FP-XRF	field portable X-ray fluorescence
FTIR	Fourier-transform infra-red spectroscopy
GC/MS	gas chromatography/mass spectrometry
HPA	Health Protection Agency
HSE	Health and Safety Executive
HPLC	high performance liquid chromatography
ICP-MS	inductively coupled plasma – mass spectrometry
ICP-OES	inductively coupled plasma – optical emission spectrometry
MCERTS	Environment Agency’s Monitoring Certification Scheme
MTBE	methyl-tert butyl ether
NIEA	Northern Ireland Environment Agency
NISMR	Northern Ireland Sites and Monuments Record
OS	Ordnance Survey
PAH	polycyclic aromatic hyrdocarbon
PCB	polychlorinated biphenyl
PET	polyethylene terephthalate
PID	photo-ionization detector
PPS	Planning Policy Statement

QA	quality assurance
QC	quality control
RCAHMS	Royal Commission on the Ancient and Historical Monuments of Scotland
RCAHMW	Royal Commission on the Ancient and Historical Monuments of Wales
RFMMs	rapid field measurement methods
SEPA	Scottish Environment Protection Agency
SVOC	semi-volatile organic compound
TCE	trichloroethene
TPHs	total petroleum hydrocarbons
UKAS	United Kingdom Accreditation Service
USEPA	United States Environmental Protection Agency
UXO	unexploded ordnance
VOCs	volatile organic compounds
XRF	X-ray fluorescence

4 Setting the objectives of an investigation

4.1 General

The first step in any investigation of land potentially affected by contamination should be to set clear and appropriate objectives (see **4.2**) taking into account:

a) the client's reasons for requesting the investigation to be undertaken (these should be clearly set out by the client);

b) the decisions that need to be made regarding the site;

c) the confidence required for making these decisions;

d) the findings of any investigations already carried out;

e) the findings of any risk assessment(s) completed to date.

NOTE 1 The client might require the investigation and/or risk assessment for their own use or to comply with a regulatory requirement.

The objectives should be set before the strategy of the investigation (Clause **5**) is established and the investigation is designed (Clause **6** to Clause **10**).

The objectives of a site investigation will vary, depending upon the stage in the process that has been reached and the underlying intentions for the land involved, but may, for example, be to:

1) provide information on contamination of the ground and groundwater;

2) provide information on natural concentrations of potentially hazardous substances;

3) gather the information needed to form, or further develop, a conceptual model, including identification of potential pathways and receptors for the purposes of the risk assessment.

4) support a risk assessment;

5) provide data for the design of remedial works;

6) provide data for re-use or disposal of soils as waste.

The formulation or refinement of a conceptual model should always be one of the investigation objectives and the model should be reviewed and revised in response to the additional information.

In some circumstances benefits can be gained from investigations that combine the needs of contamination and geotechnical objectives. However, the use of an integrated investigation should not be allowed to compromise the objectives or requirements of either investigation (see **7.2**).

Before entering into a contract, the prospective investigator should endeavour to make sure that the client or the client's adviser understands the likely regulatory requirements and that it has been set down whether the investigator is or is not to be responsible for meeting these requirements.

NOTE 2 Sometimes the primary purpose of an investigation may be to "benchmark" site conditions (e.g. contamination levels) for future reference.

NOTE 3 An investigation will often be carried out in one of the following contexts.

i) In support of a planning proposal carried out on behalf of the client (who may or may not be the site owner).

ii) In connection with the potential sale and purchase of a site to enable its value to be estimated, taking into account potential contaminated land liabilities and possible remediation requirements.

iii) In connection with the potential determination of a site under the Part 2A regime [1,5] commissioned by the regulator or appropriate person.

NOTE 4 When the investigation is carried out in connection with a planning application or discharge of a Planning Condition, the resulting report will be submitted to the planning authority and be reviewed by the local authority's designated technical specialist, who is typically the "contaminated land officer" (CLO). When the investigation is carried out in connection with a Part 2A determination, the resulting report will be submitted to the relevant regulator (usually the local authority, but the Environment Agency in England and Wales in the case of Special Sites). In both these situations, early consultation with the primary regulator's technical representative is recommended to ensure that the detailed investigation meets the needs of the regulator. [A1⟩ Further information on regulatory regimes dealing with land contamination can be found in Annex A of BS 8576:2013. ⟨A1]

4.2 Setting investigation objectives

Answers to the following questions, amongst others, should be provided when drawing up the investigation objectives.

a) What are the reasons for the investigation?

b) What data gaps or uncertainties need to be addressed?

c) What information is needed?

d) What level of detail and accuracy of measurements are required?

e) What are the spatial and temporal investigation boundaries?

f) In the context of providing information for a risk assessment, what are the specific purposes of the risk assessment?

*NOTE Examples of typical investigation objectives that can be associated with different phases of investigation (see **5.2**) are provided in Table 1. Further examples of typical objectives and applications are given in Annex B.*

As information is developed during an investigation, the impact on the objectives and the objectives themselves should be reviewed to determine whether these require modification or extension.

Table 1 **Typical objectives of different phases of an investigation**

Phase	Typical objectives
Preliminary investigation (desk study and site reconnaissance) (Clause **6**)	To provide information on past and current uses of the site and surrounding area and the nature of any hazards and physical constraints. To identify current and likely future receptors, potential sources of contamination and likely pathways and any features of immediate concern, including those that could be introduced in the future. To identify any aspect of the site requiring immediate attention (e.g. insecure fences, hazardous substances accessible to trespassers or likely to be dispersed by wind or water). To provide information on the geology, geochemistry, soil, hydrogeology and hydrology of the site. To identify potentially different sub-areas (zones) of a site, based on differing ground conditions; potential contamination; and past, present and future uses. To produce an initial conceptual model for the site as a whole and/or for zones within the site. To provide information for the preliminary risk assessment (see **6.3.2**). To identify areas where informed decisions are to be made using specialist assessment techniques or advisors, e.g. if there are ecological, unexploded ordnance (UXO) or archaeological considerations. To provide data to assist in the design of potential subsequent exploratory and main investigations and to give an early indication of possible remedial requirements. To provide information relevant to worker health and safety and to the protection of the environment during field investigations (Annex C). To identify the need to involve regulatory bodies prior to intrusive investigation.
Exploratory investigation (optional) (Clauses **7**, **8**, **9** and **10**)	To test the conceptual model(s) of contamination and site characteristics. To obtain further information in relation to potential sources of contamination, likely pathways and features of immediate concern. To obtain further information on the geology, geochemistry, soil, hydrogeology and hydrology of the site. To provide further information to aid the design of the main investigation, including health and safety aspects. To provide data for a review of the conceptual model and to update the risk assessment.
Main investigation (Clauses **7**, **8**, **9** and **10**)	To obtain data on the nature and extent of contamination, the geology, geochemistry, soil, hydrogeology and hydrology of a site. To provide data to review the conceptual model and to update the risk assessment. To provide data for the selection and design of remedial works.
Supplementary investigation(s) (if required) (Clauses **7**, **8**, **9** and **10**)	To provide clearer delineation of a particular area (zone) of contamination or a contamination plume. To address or clarify specific technical matters (e.g. to confirm the applicability and feasibility of potential remedial options or obtain information for their design).

NOTE 1 For the purposes of this British Standard, geology includes made ground and fill.

NOTE 2 A phase of investigation might be undertaken in a number of stages if necessary to achieve the full objectives of the investigation and in response to the findings of the previous phase(s).

NOTE 3 In BS ISO 11074 the terminology preliminary, exploratory, main and supplementary investigation is equivalent to the terminology Phase 1, Phase 2, Phase 3 and Phase 4 investigation, respectively.

NOTE 4 When an exploratory investigation is not carried out prior to a main investigation, the latter needs to embrace the relevant typical objectives listed here for the exploratory investigation.

5 Developing an investigation strategy

5.1 General

Having set the objectives of the investigation, an overall strategy should be developed. This should address not only what to do, but also:

a) how it is to be done;

b) when it is to be done (including sequencing of works);

c) who is to do it;

d) what needs to be done to enable the work to be done (e.g. consultations, gaining access and preparation of documentation, including, for example, safety plans, method statements and specifications).

These and other relevant issues should be addressed as the strategies are developed for each phase of the work and zone.

NOTE 1 Recommendations for the development of the overall investigation strategy are given in ***5.2****.*

More detailed strategies for each phase of the work should be developed as the work progresses. These may include development of a sampling (and field testing) strategy and an analytical and testing strategy.

NOTE 2 Sub-clauses ***5.2.7.1*** *to* ***5.2.7.4*** *describe the contexts in which the preliminary, exploratory, main and supplementary investigations are likely to be carried out and the important factors to be taken into account when developing the respective strategies. Sub-clause* ***5.3*** *refers specifically to the development of strategies for field investigations.*

Decisions should be taken early in the project about:

1) what additional expertise (if any) is needed to develop the investigation strategy;

2) whether a formal project team is to be formed, for example to help develop the strategy;

3) whether to assign specific tasks to specific individuals or organizations.

5.2 Overall strategy

5.2.1 General

Development of the overall strategy should include deciding which of the investigation types described in **5.2.7.1** to **5.2.7.4** are to be used, the timing and sequencing of the investigation works and who is to carry out various activities, and identifying what enabling works are required. It should also involve consultation and reporting arrangements during execution and on completion, and formal reviews of the data so that previous decisions taken can be reconsidered in the light of the newly obtained data and other information as the investigation proceeds. The process of identifying and quantifying risks should be ongoing and iterative.

The overall strategy should take into account, amongst other things:

a) the objectives of the work;

b) the site constraints;

c) the suitability of available investigation techniques;

d) the availability of suitable analytical and other test methods.

5.2.2 Phases of investigation

Because the identification, quantification and delineation of contamination (or areas of naturally elevated concentrations of harmful substances) and the assessment of human and environmental risks can be complex, a site investigation should usually be carried out in a series of phases, with each phase designed to achieve specific objectives. The phases will typically comprise preliminary, exploratory, main and supplementary investigations. A preliminary investigation will always be required. However, the requirement for subsequent exploratory, main and supplementary field investigations will depend on the objectives. Each phase of subsequent field investigations should be split into a number of stages, when necessary, in order to obtain sufficient relevant data to characterize potential source-pathway-receptor scenarios.

The approach to site investigations on potentially contaminated sites, including the various phases of investigation, should be in accordance with Figure 2. Data and information obtained at each phase should be reviewed in order to determine whether the strategy requires modification or the objectives have been met. This review process also enables the conceptual model to be revised, and the requirements of the risk assessment and the objectives of the site investigation to be reassessed.

Where unacceptable levels of uncertainty remain after completion of the preliminary investigation (**5.2.7.1**) and any risk assessment based on it, the investigation strategy should establish how further information (of an appropriate quality and amount) is to be obtained. The strategy for this further investigation should:

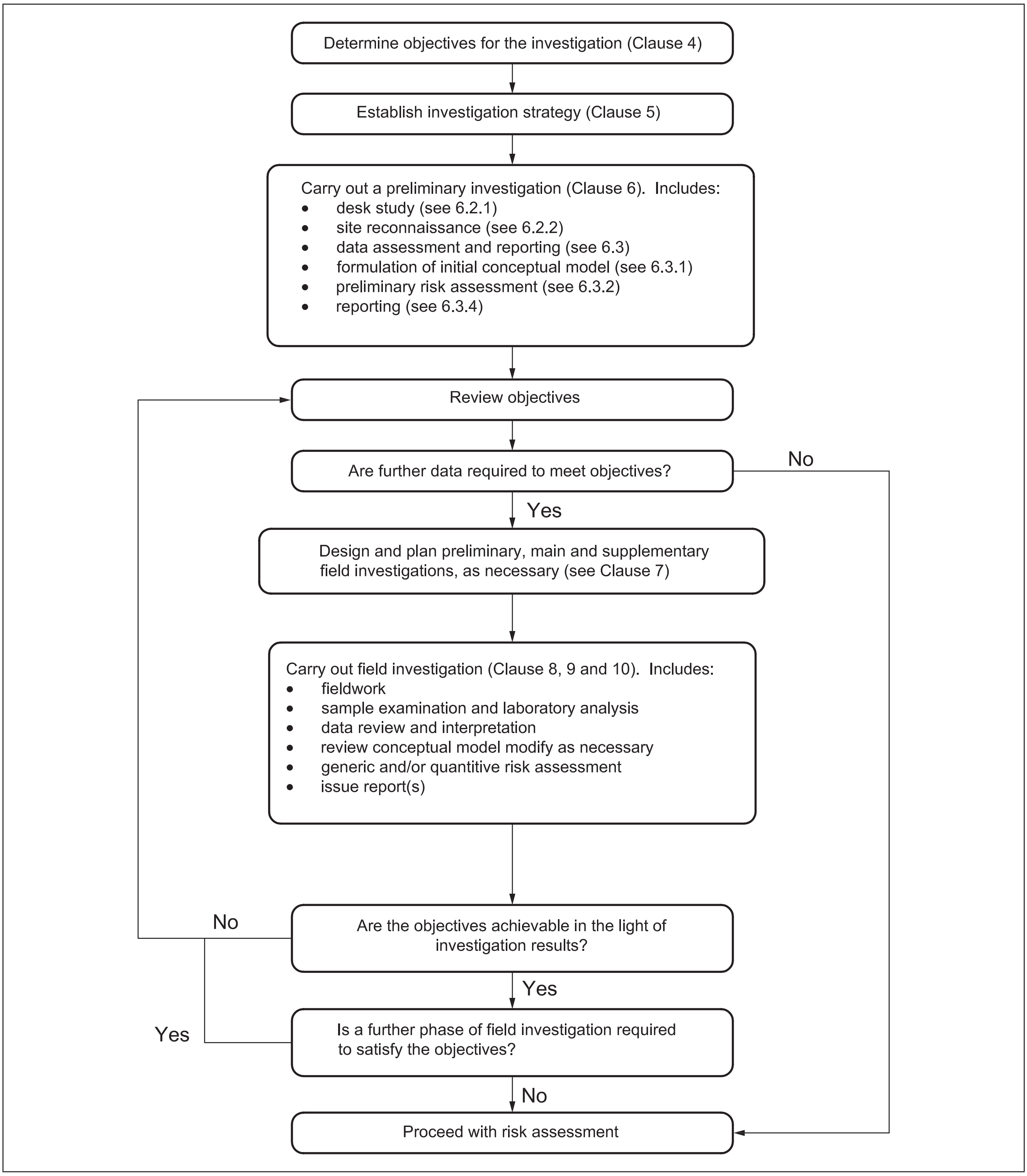
1) be based on the conceptual model, the preliminary risk assessment if one has been prepared, the information available and the information that is not available but deemed essential;

2) take into account the requirements of the risk assessment and the objectives of the overall investigation, and include intrusive (**8.2.3**) and/or non-intrusive (**8.2.2**) investigations as necessary.

The further investigation may comprise an exploratory investigation (**5.2.7.2**) (this could, among other things, provide information that helps to make the strategy for the main investigation (**5.2.7.3**) more cost-effective). However, in some cases, an exploratory investigation may be considered unnecessary, in which case the main investigation should then be implemented directly. A further supplementary investigation (**5.2.7.4**) could later be found to be necessary.

Sufficient time should be allowed between each phase of the overall investigation to enable the information from one phase to be fed into the design of the next.

Figure 2 **Recommended approach to site investigation**



5.2.3 Zoning

Where logical and appropriate, the site should be divided into zones and separate strategies developed for each zone. Zoning may be based, for example, on:

- near-surface geology (e.g. made ground or natural ground);
- deeper geology;
- topography;
- probable absence or presence of contamination;
- previous and current land uses;
- nature of probable contaminants (e.g. VOCs or inorganic compounds);
- intended future use.

Separate conceptual models should be developed for each zone. Zoning should be reviewed after each phase (and stage) of the investigation.

5.2.4 Consultation with regulators

Where there is not already a regulatory requirement to do so, subject to the approval of the client, the relevant regulatory authorities should be consulted and involved in the development of the strategy.

NOTE 1 The benefits of involving the relevant regulatory authorities, particularly the local authority and relevant agencies, in the development of the investigation strategy and consulting these organizations in the early part of the investigation cannot be overstated. Early involvement can assist optimization of intrusive investigations and remediation strategy in line with any regulatory requirements. [A1⟩ Annex A in BS 8576:2013 ⟨A1] provides an account of the regulation of land contamination, those responsible for regulation and the officers to be consulted, especially in the context of the planning process.

NOTE 2 Consultation with the regulatory authorities can be extremely helpful when the investigation is being undertaken to support a planning or permit application, or to satisfy a permit or Planning Condition. Such consultation could be a regulatory requirement.

5.2.5 Preparing to investigate

Consideration should be given to the range of actions that need to be taken to enable the investigation to be carried out, including, for example, team building, assigning roles (**5.2.6**), obtaining permissions and preparation of documentation. These activities are integral components of the investigation but formalizing them into a preparatory stage can help to ensure that everything that needs to be done is done.

NOTE 1 The following lists of activities are not intended to be exhaustive, but as aids to a systematic approach.

The following should be considered in setting the strategy for the investigation.

a) Whether to set up a formal project team.

b) What additional expertise is required, either off- or on-site (e.g. ecological specialists).

c) Whom to consult.

d) What welfare facilities are to be provided.

e) Physical access arrangements.

f) Legal access arrangements, including whether licences or permits are required.

g) Who should undertake which aspects of the investigation.

h) How to carry out and, if necessary, procure the investigation in terms of employment of consultants, contractors, sub-contractors, etc.

i) What interim reports are to be prepared during the investigation (e.g. a sampling report/record, reports of ground gas, monitoring reports as the results are obtained).

j) What information is to be provided to members of the public.

NOTE 2 Any field activities can attract the attention of neighbours and passers-by. Field operatives have therefore to be prepared to answer reasonable enquiries. Such people can be a source of useful anecdotal information; indeed, they might have worked on the site.

The following should be determined.

1) What necessary regulatory permits are required, if any.

2) Whether there are any formal requirements (e.g. conditions attached to planning permissions or environmental permits) for consultation and/or permissions from regulators.

3) Whether an intrusive investigation requires planning permission (this could be required for large investigations considered by the planning authority to be "engineering works").

The following should be prepared, as appropriate.

i) A sampling plan (instructions to field staff as to where to sample, what samples to take and what measurements to make).

ii) Health and safety risk assessments.

iii) Safety-related documentation.

iv) Environmental risk assessments.

v) Specifications for site investigation and analysis and testing, etc.

vi) Contract documentation.

vii) Method statements for particular activities.

NOTE 3 General guidance on the management of projects on contaminated sites is provided in CIRIA SP111 [33] and on the selection of consultants in CLR 12 [34].

NOTE 4 A guidance paper describing the common areas of tension and disagreement and the compromise arrangements that might be adopted when contaminated land consultants are employed has been published jointly by the Association of Geotechnical and Geoenvironmental Specialists (AGS), the Environmental Industries Commission (EIC) and the Association of Consulting Engineers (ACE) [35]. The AGS has also published a number of client guides on aspects of site investigation. While these refer mainly to geotechnical investigations, they could be useful by analogy to clients commissioning investigations of potentially contaminated sites.

5.2.6 Personnel

5.2.6.1 General

There are various roles that need to be performed by one or a number of persons, including project leader, field manager, field investigator and skilled operatives (e.g. drillers). Tasks to be carried out include direction, planning and execution, supervision in the field, sampling and measurement, formation of exploratory holes and logging of excavations and boreholes, etc. Whoever performs these roles should be appropriately knowledgeable, qualified, trained and experienced. The prescription of the qualifications, etc., required by those performing these roles is outside the scope of this standard, except for lead drillers, support operative drillers and the operators of excavating plant for whom the corresponding provisions of BS 5930, **17.8**, apply (see **5.2.6.2**).

NOTE 1 Reference to BS 5930, and related geotechnical standards (e.g. BS 22475-2:2011) can be useful by analogy regarding the roles to be performed and appropriate levels of qualification, etc.

NOTE 2 Those performing these various roles could work for the client, a consultant or a contractor.

[A1⟩ *Clause deleted* ⟨A1]

5.2.7 Scope and application of investigations

5.2.7.1 Preliminary investigation (desk study and site reconnaissance)

The first phase in the overall investigation process should always be a preliminary investigation (see Clause **6**). This should include reference to historical records (**6.2.1.2.1**) and other sources of information (**6.2.1.2.2**), consultation with relevant sources (**6.2.1.3**) and a site reconnaissance (**6.2.2**). However, the objectives might not require all the elements recommended in **6.2**, in which case the strategy should identify what elements of the preliminary investigation are essential and those that do not need to be addressed.

Where elements of a preliminary investigation described in **6.2** are not to be included, these should be documented in the report, and any limitations on the final assessment arising from the omissions should be clearly understood by all parties involved and stated in the report.

The strategy should provide for a review of the information obtained at the conclusion of the preliminary investigation to determine if the objectives have been achieved (and are still appropriate) and whether there is a need to carry out an exploratory investigation and/or main investigation (**6.3.3**).

Consideration should be given to whether the site should be divided into zones (see **5.2.3**) if this has not already been done. Separate conceptual models should be developed for each zone that is identified.

The output from the preliminary investigation should include the initial conceptual model (**6.3.1**) and a preliminary risk assessment (**6.3.2**) based on the information available.

NOTE 1 Preparation of a preliminary risk assessment requires interpretation of the information gathered during the preliminary investigation. Although a preliminary risk assessment will usually be an *essential prerequisite for the design of further phases of investigation, guidance on how to do this is outside of the scope of this standard, so reference needs to be made to CLR 11 [31].*

NOTE 2 It is likely that there will be different requirements for further investigation of each zone.

[A1⟩ *NOTE 3 For sites where it is anticipated ground gases might be present and requires an investigation, additional guidance on preliminary investigations is provided in BS 8576.* ⟨A1]

5.2.7.2 Exploratory investigation

An exploratory investigation is a limited investigation and should be designed to:

a) reduce uncertainty in knowledge of the site, including determining the accuracy or otherwise of contamination-related and other hypotheses developed in the preliminary investigation, thereby enabling the initial conceptual model to be refined;

b) provide information that helps the design of any subsequent main investigation.

Depending on the objectives of the investigation, and such other considerations as site access, land ownership and project programme, a decision may be taken to not carry out an exploratory investigation, but to proceed directly with a main investigation (**5.2.7.3**).

However, where an exploratory investigation is undertaken, it should comprise non-intrusive and/or intrusive elements as appropriate. The intrusive element should include as appropriate collection and analysis of soil (**7.6** and **8.3.2**), surface water (**7.7.3.6**), groundwater (**7.7.3** and **8.3.3**) and ground gas (**7.7.4** and **8.3.4**) samples, and the *in situ* monitoring of ground gas, certain groundwater parameters and groundwater levels. A non-intrusive investigation technique (see **7.6**, **8.2.2** and Table 5) can be used, for example, as an aid to locating below-ground structures or other features of the site.

Whether to apply a particular non-intrusive technique before or after some or all of any intrusive works have been carried out should be decided and justified, with the input of any necessary expert advice as appropriate.

Where the conceptual model output from the preliminary investigation identifies the likelihood of localized sources of contamination, and there is inadequate information to confirm the direction of groundwater flow, an appropriate strategy should be developed to investigate contamination at the suspect locations, the water table at several (triangulated) positions and groundwater quality. In this situation, the use of targeted sampling locations is likely to be most appropriate (see **7.7.2.2**).

The information obtained from the exploratory investigation should be used to refine the conceptual model and in the design of any subsequent investigation(s).

NOTE 1 An exploratory investigation is not intended to provide sufficient data to permit a site-wide detailed quantitative risk assessment (DQRA). It might, however, provide sufficient data for a DQRA on a small part of the site or on a specific element if the investigation is specifically designed with this intent in mind. It might also be sufficient (depending on the objectives and uncertainty reduction required) to fulfil a regulatory requirement.

NOTE 2 The exploratory investigation could indicate that the contamination pattern is more complex or the concentrations and/or the extent of contamination are greater than anticipated. In such situations it is likely that further investigatory work will be necessary in order to refine the conceptual model and provide adequate robust information for the risk assessment.

5.2.7.3 Main investigation

The main investigation should comprise, as far as is practical, collection of:

a) all information necessary to test the accuracy or otherwise of contamination-related and other hypotheses developed in earlier phases of the overall investigation;

b) all information necessary for the assessment of risks to all potential receptors;

c) information relevant to the selection, design and costing of remedial works.

NOTE 1 The detail required will depend upon the objectives of the investigation.

NOTE 2 When an exploratory investigation has not been carried out, it could be necessary to test a number of contamination-related and other hypotheses in the main investigation as would be done during an exploratory investigation.

The main investigation should include the use of non-intrusive investigation methods, as well as intrusive methods, as necessary. Expert advice should be obtained as to whether it is best to apply a particular non-intrusive technique before or after some or all of any intrusive works have been carried out.

The investigation should include, as appropriate, collection and analysis/testing of soil (**7.6.2** and **8.3.2**), surface water (**7.7.3.6**), groundwater (**7.7.3** and **8.3.3**) and ground gas including VOCs (**7.7.4** and **8.3.4**) samples, and the *in situ* monitoring of ground gas, certain groundwater parameters and groundwater levels.

The design of the investigation should take into account all the information and hypotheses developed in the earlier phases of investigation and the objectives for this phase of the work. Particular attention should be paid to the sufficiency and quality of the data, taking full account of the historical and current use(s), likely heterogeneity and underlying stratigraphy.

NOTE 3 The amount and nature of the information required from the main investigation will vary according to the nature of the site and the possible requirements for remedial action. The implications of the decisions on what actions need to be implemented will vary from site to site. The amount and quality of information available will dictate the degree of confidence that can be attributed to the decision making process.

During the subsequent assessment of risks and hazards, all possible migration pathways relevant to the contamination should be considered, and an appreciation in space and time of the contamination established. The possible migration pathways should inform the design of the main investigation, since detailed knowledge of physical and chemical soil properties and the local hydrology is essential for reaching defensible conclusions.

The risk assessment should take into account the risks of making incorrect decisions based on the amount and quality of information available.

All parties involved in the decision making process should be fully informed as information is produced, to confirm that the information is sufficient for the purpose intended.

In a main investigation, the greater proportion of sampling locations should be non-targeted to aid the reliability of interpretation (see **7.7.2.3**) and the use of statistical methods for assessment of the data. However, targeted sampling should also be employed as necessary, for example, to delineate or confirm an area of contamination detected during an exploratory investigation.

The relative density of sampling in each zone should take into account the findings of earlier phases of investigation, including the uncertainty associated with each zone.

5.2.7.4 Supplementary investigations

A review of the outcome of the main investigation could identify aspects and areas where an unacceptable level of uncertainty or deficiency of information remains. Where such uncertainties or deficiencies are identified, a supplementary investigation should be carried out. This should be designed to produce specific information. It should use targeted and/or non-targeted sampling as appropriate.

NOTE A supplementary investigation could be required, for example:

- *to provide additional information to design and cost remedial works, for example, to delineate volumes of soil requiring remediation, or to carry out specific tests to evaluate the suitability of specific remedial treatment techniques;*
- *to provide chemical testing information for the classification of wastes;*
- *to monitor groundwater quality and levels, and/or ground gas conditions, after completion of the main investigation to determine any changes in site conditions and to provide additional data to assess risks and aid design of protective measures;*
- *to monitor groundwater and ground gas conditions during and after construction or remediation to determine whether there have been any adverse changes in site conditions.*

5.3 Specific strategies for field investigations

When a field investigation (preliminary, main or supplementary) is to be carried out, decisions should be made regarding:

a) the objectives of the investigation;

b) the form of the investigation [non-intrusive and/or intrusive (see **7.6**, **8.2** and Table **5** and Table **6**)] necessary to obtain appropriate, suitably robust and defensible data in accordance with the objectives;

c) the purposes for which samples are required (e.g. for chemical analysis or other tests);

d) the locations from which samples are to be collected and the number of locations required (see sampling strategy in **7.7**);

e) the number and type of samples to be collected (i.e. soil, water, gas) from each location, the depths at which they are to be collected (see **7.7.2.5**), whether replicate samples are to be taken [for example, to allow assessment and reporting of sampling uncertainty (see Annex D)], and any monitoring requirements (see sampling strategy in **7.7**);

f) the techniques to be used to collect the samples (see Figure 2, Table 7 to Table 9, **8.3.2**, **8.3.3** and **8.3.4**), taking into account: the soil types, groundwater conditions, topography, services and access (e.g. soft landscape, tarmac, presence of buildings, etc), the quality of reinstatement necessary, the depths at which samples are to be collected (**7.7.2.5**), whether a ground gas investigation is included (**7.7.4**), whether water samples are to be collected (**7.7.3**), and the monitoring installations required (**7.7.3** and **7.7.4**);

NOTE 1 The selection of the sampling technique may involve some compromise, for example due to access, headroom, underground services or other constraint. If samples are only required from 2 m to 3 m below ground level (bgl) and the location of buried services is known with sufficient certainty, trial pits might be regarded as the most appropriate technique. However, where there is over-site concrete which is still in use and a good standard of reinstatement is necessary in order, for example, to minimize disruption of the site and allow satisfactory reinstatement, coring through the concrete followed, for example, by use of a dynamic sampling tool could be the more appropriate approach (see Tables 7, 8 and 9).

g) how samples are to be taken to avoid or minimize cross-contamination (**8.2.3.3**);

h) what provisions are to be made for cleaning field equipment between sampling points (**8.2.3.3**);

i) quality assurance procedures to provide an auditable process to enable confirmation that sampling has been carried out in a satisfactory manner (**7.9**);

j) the analyses and tests to be carried out on each sample, and whether these are to be carried out in a laboratory or in the field (see **7.7**, **8.4**, **9.4** and **9.6**), and the analytical and testing strategy.

NOTE 2 Whilst decisions about the type of analyses and testing can usually be made during formulation of the investigation strategy, final decisions about what samples to analyze or test are often deferred until the samples have been obtained. This permits field observations to be taken into account.

k) selection of an accredited laboratory (e.g. UKAS) which can perform tests to an accredited standard (e.g. MCERTS [36]), accommodate the workload (see Clause **9**) and confirm that the analytical methods chosen are appropriate for the planned risk assessment process;

l) how samples are to be handled, stored, preserved and transported to the laboratory so as to minimize alteration prior to analysis or testing (**8.6**);

m) the process for dispatch of samples to the laboratory, issue of instructions to the laboratory and the date by which the results are required;

n) requirements for field instrumentation (**8.4**).

Decisions should also be made about the programme for the fieldworks and the logistics of the site investigation, including the availability of relevant machinery and personnel, permission for site access, liaison with regulatory authorities, completion of health and safety and environmental risk assessments and compliance as appropriate with the CDM [18] and other regulations.

6 Preliminary investigation

6.1 General

A preliminary investigation should always be carried out before any systematic sampling or analysis is specified or undertaken (see **5.3**).

The preliminary investigation should obtain information in order to:

a) assess the likelihood of contamination, its nature and its extent;

b) evaluate the environmental setting of the site and identify sensitive receptors;

c) provide information from which likely source-pathway-receptor relationships can be identified, and which can then be used to formulate a conceptual model to enable the design of a field investigation (if required);

d) determine the requirements for further investigation, if any;

e) identify any special procedures and precautions that will be necessary during subsequent sampling and examination of the site.

A preliminary investigation should be a two-step process involving data collection followed by interpretation and reporting (see Table 2).

The specific scope of each step of the preliminary investigation should vary according to the overall purpose of the investigation and objectives, the availability of existing information, the size and complexity of the site, known or projected future land uses and other relevant site-specific factors.

[A1⟩ *NOTE 1 Additional guidance on preliminary investigations for sites where it is anticipated ground gases might be present is provided in BS 8576.* ⟨A1]

Table 2 **Scope of a preliminary investigation**

Step	Activity
Data collection	Desk study Documentary research (see **6.2.1.2**): • site history; • site setting (location, surroundings, topography); • site usage (including adjacent areas); • site geology, hydrogeology, geochemistry, hydrology; • site ecology and archaeology; • future plans for the site. Consultations (see **6.2.1.3** and Table 3) Site reconnaissance (see **6.2.2**): • detailed inspection; • interviews; • limited ad hoc sampling and field measurements (if appropriate).
Interpretation and reporting	Formulate initial conceptual model (see **6.3.1**). Assess need for, and scope of, further investigation. Preliminary risk assessment (see **6.3.2**) (outside the scope of this British Standard). Prepare preliminary investigation report (see **10.2**).

6.2 Data collection

6.2.1 Desk study

6.2.1.1 General

The desk study should comprise a combination of documentary research (see **6.2.1.2**) and consultations (see **6.2.1.3**).

The desk study should include the following topics, amongst others.

a) The history of the site and adjoining areas, with particular attention to the nature of any industrial processes and other activities that could have been potentially contaminative or could have modified the ground structure to create potential migration pathways.

b) Review of any previous desk study or investigation of the site.

c) The geological, geochemical, hydrogeological, hydrological, topographical, archaeological and ecological setting of the site.

d) Potential receptors of contamination (for example, trespassers, current and intended users, construction workers, surface waters, groundwaters or nearby water abstractions, ecological receptors, property).

e) The proximity of waste disposal sites or other sources of contamination that could have an impact on the site.

f) The existence of naturally occurring harmful materials, such as radon, or naturally elevated concentrations of harmful substances.

g) The presence of any mining activities.

h) Any constraints on an intrusive site investigation (access or height limitations, underground and overhead services or obstructions, noise, working hours, etc.).

i) The potential for the site to contain or have been affected by UXO (see CIRIA C681: *Unexploded ordnance (UXO): A guide for the construction industry* [37]).

j) Review of developers' designs and plans where the site is to have a change of use, with details recorded of the future use/characteristics of the site.

k) Any foreseeable events or changes (e.g. flooding, rising groundwater, change of use of neighbouring sites) that could have an impact on the assessment.

6.2.1.2 Documentary research

6.2.1.2.1 Site location and historical setting

The site location and site boundaries should be accurately established before any investigatory work is commenced.

The site history should be determined using the following and any other appropriate sources of information.

a) Ordnance Survey (OS) maps.

b) Other published maps, for example, insurance, tithe, enclosure or parish maps.

c) Aerial photographs.

d) Documentary records, particularly any previous desk study or investigation reports held by the current (and former) owners of the land, trade directories, the local authority planning records and local libraries.

The level of historical research undertaken should be compatible with the objectives of the investigation. The extent of research into the history of the site will depend upon a number of factors including the complexity of past potentially contaminative uses on and adjacent to the site, the vulnerability of the site geology and local water environment, and the degree of confidence required by the client. The methods and extent of research should be agreed with the client in advance and modified as necessary according to the findings of the preliminary investigation.

*NOTE 1 Table 3 gives a list of the types of information held by national and regulatory bodies. See also **6.2.1.3** for other organizations to be contacted and the type of information to be discussed.*

NOTE 2 Reports can be purchased from a number of private companies which provide a collation of publically available information relevant to characterizing a site's history, geology, hydrogeology and environmental setting and identifying the locations of potentially contaminative land uses, pollution incidents and other features of relevance to a preliminary investigation. These reports do not usually contain geology mapping data at 1:10.560 or 1:10,000 scales, although they are procured and referred to particularly in mining areas.

NOTE 3 Geological maps, datasets and logs of borehole and wells can be purchased from the British Geological Survey and be ordered online at www.bgs.ac.uk/GeoIndex

NOTE 4 Old OS map editions do not represent a complete record of historical land use, but can assist understanding of historical land use.

NOTE 5 Other base maps that can be considered alongside OS maps are UKMap (http://www.geoinformationgroup.co.uk/products/mapping) and Russian Maps, (http://www.russianmaps.co.uk/) which have the benefit of focusing on military establishments.

NOTE 6 Both historical and current aerial photography have to be considered, together with suitable metadata detailing the date when the imagery was taken. English Heritage hold the National Library of Aerial Photographs for England at the National Monuments Record in Swindon. Royal Commission on the Ancient and Historical Monuments of Scotland (RCAHMS) hold the National Collection of Aerial Photography for Scotland in Edinburgh. Royal Commission on the Ancient and Historical Monuments of Wales (RCAHMW) hold the National collection for Wales in Aberystwyth. Aerial photographs for Northern Ireland are held by the Northern Ireland Environment Agency Built Environment.

Table 3 **Types of information available from regulatory authorities**

Agency	Information
Environment Agency (EA), Northern Ireland Environment Agency (NIEA)	Information held on groundwater and surface water quality; aquifer designation and groundwater vulnerability maps; information on pollution incidents; environmental permitting authorizations; current groundwater abstraction licences; operational and closed landfill and waste treatment sites, Special Sites. NIEA also maintains the Northern Ireland Sites and Monuments Record (NISMR), a national record of historical and archaeological sites.
Scottish Environment Protection Agency (SEPA)	Information held on regulatory history (spill/accidents); PPC and IPC authorizations; waste management licenses or exemptions; registrations or licenses issued under the Controlled Activities Regulations [38] (groundwater abstractions and authorized discharges); action taken under the Environmental Liabilities Regulations 2009 [39]; surface water quality and monitoring data; groundwater quality and hydrogeological conditions; protected areas (drinking water protected areas, nitrate sensitive areas, bathing waters, areas designated to protect economically significant species, or for the protection of habitats or species); flood risk information; records of SEPA inspections under Radioactive Contaminated Land (Scotland) Regulations [8].
Local authorities	Contaminated Land Inspection Strategy for their area, identifying potentially contaminated sites (required by Part 2A, EPA [1]). Public register of statutory "contaminated land" in their area. Information on remediation of land affected by contamination. Historical experience of environmental nuisances. Historical planning records describing former land use, including conditions of any relevant planning consents. Closed landfill sites and private water abstractions. (Old) layouts shown in drawings attached to (old) planning applications. Building control records, including former layout of sites and actual or planned locations of underground and above-ground storage tanks. Details of sites with Environmental Permits.
Health and Safety Executive (HSE) and fire authorities	Records of accidents and incidents, fuel storage.

Table 3 **Types of information available from regulatory authorities** *(continued)*

Agency	Information
Petroleum Officer (normally located within the local authority or Fire Service)	Location and status of petroleum storage tanks. *NOTE Information is usually only available with the permission of the site owner.*
Coal Authority	Mining records, coal, brine extraction hazards.
Health Protection Agency (HPA) and Radiation Protection Division	Maps and information on radon in England and Wales.
English Heritage	Historical aerial photographs held at the National Monuments Record. National Monuments Record also maintains a national record of archaeological and historical sites in England.
Royal Commission on the Ancient and Historical Monuments of Scotland (RCAHMS)	Historical aerial photographs for Scotland. Maintains a national record of historical and archaeological sites for Scotland.
Royal Commission on the Ancient and Historical Monuments of Wales (RCAHMW)	Maintains a national record of historical and archaeological sites for Wales.

6.2.1.2.2 Site usage

Details of the past and current usage of the site and its immediate environs, together with information on any incidents (such as spills or detected leakages), should be collated and used in the development of the initial conceptual model. Any available plans of the previous or current layout of different usages on the site should be inspected, as well as any plans of site drainage or underground services.

NOTE 1 Recent aerial views, and sometimes street-level views of the site, can be obtained on internet map sites. These can help establish the context of the site and recent condition. However, the date of the imagery might not be stated and the current condition of the site could be very different to that shown online.

NOTE 2 Examples of some land uses that can give rise to contamination are listed in Annex F.

Research should be conducted to determine whether any of the following common causes of contamination could have occurred:

a) spills or leaks of potentially harmful liquids from tanks, pipes and drains on the surface or underground;

b) deposition or burial of industrial, agricultural or domestic waste or temporary stockpiling of leachable materials (for example, road salt);

c) demolition of industrial structures and dispersal or burial of contaminated rubble and other materials;

d) importation of potentially contaminated fill material onto the land.

In addition, it should be determined whether UXO is likely to be present.

6.2.1.2.3 Geology, geochemistry, hydrology and hydrogeology

All available sources of information on the geological, geochemical, hydrological and hydrogeological conditions of the site should be collected and examined.

COMMENTARY ON ***6.2.1.2.3***
The following sources can be consulted, though this is not an exhaustive list of the available resources.

- *British Geological Survey (BGS) for radon, geological, geochemical and hydrogeological maps for England and Wales, for groundwater vulnerability maps for Scotland, and for borehole and well records*[1]*.*
- *Environment Agency for aquifer designation maps, for earlier groundwater vulnerability maps*[2] *and information on source protection zones for England and Wales and SEPA .*
- *English Heritage (for aerial photographs).*
- *The results of any previous ground investigations carried out on, or in the vicinity of, the site, or information from national surveys covering the vicinity.*

BS 5930 gives a comprehensive list of geological information sources. The supplement published in the Quarterly Journal of Engineering Geology [40] also contains useful information[1]*.*

BGS and Environment Agency mapping and the locations of previous site investigation and well logs deposited with the BGS are sometimes included in reports collating publically available information for preliminary investigations which can be purchased from private companies.

In Scotland, groundwater vulnerability maps are available from the BGS and outline vulnerability information is also available on SEPA's website. There are no formal source protection zones in Scotland.

Information on drinking water protected areas and groundwater resource potential can be obtained on SEPA's website.

6.2.1.2.4 Ecology and archaeology

The preliminary investigation should determine whether the site (or its immediate environs) has been designated as an area of ecological or archaeological significance.

NOTE 1 If it has been so designated, it is likely that there will be constraints on the methods of ground investigation that can be used. It is also likely that ecological and/or archaeological surveys and desk studies will need to be undertaken before any contamination-related field investigations.

The preliminary investigation should also determine whether there are species (e.g. bats, nesting birds and water voles) or habitats of importance subject to legal protection (e.g. Wildlife and Countryside Act [13] or Habitat Regulations [14]).

NOTE 2 The presence of these species or habitats could restrict the timing or method of investigation.

The presence of invasive plant species, such as Japanese Knotweed and Giant Hogweed, should also be determined. Subsequent ground investigations should be designed to avoid any spread of these species.

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[1] More information can be obtained from British Geological Survey, Keyworth, Nottingham NG12 5GG. Tel 0115 936 3143. http://www.bgs.ac.uk

[2] More information can be obtained from the local Environment Agency office. http://www.environment-agency.gov.uk

NOTE 3 The presence of Japanese Knotweed can add to waste disposal and other remediation costs.

NOTE 4 Examples of the organizations to be contacted to determine if there are any ecological or archaeological designations are listed in ***6.2.1.3****.*

6.2.1.3 Consultations

Relevant parties should be consulted, normally in parallel with the documentary research. Client approval should be obtained before entering consultations with third parties and regulators, in case of confidentiality issues, though this could be required by a Planning Condition.

Interviews with persons possessing knowledge of activities on, or adjacent to, the site may be combined with the site reconnaissance visit (**6.2.2**) to obtain further information on, or enhance knowledge of, suspect locations or features, underground services, etc. Anecdotal evidence should be viewed with caution.

Consultations with the local authority's contaminated land officer (CLO) and, when applicable, the Environment Agency (England and Wales) or SEPA (Scotland) should cover methods of ground investigation. It is vital that potential risks to controlled waters, caused by the creation of migration routes during boring or trial pitting, are avoided.

If investigations are likely to be undertaken on (or accessed via) ecologically sensitive sites or agricultural land, organizations such as Natural England, Countryside Council of Wales, Scottish Natural Heritage or the Council for Nature Conservation or the Countryside Office should be consulted about methods of work. Alternatively, the Joint Nature Conservation Committee, which holds information for the whole of the UK, may be contacted for Sites of Special Scientific Interest and European Sites[3)].

The local authority development plan should be consulted to determine whether the site is of national or international importance, as designated by Natural England, Countryside Council of Wales, Council for Nature Conservation and the Countryside and Scottish Natural Heritage, respectively, or of county or local importance.

If investigations are likely to be undertaken on (or accessed via) archaeologically sensitive sites, the archaeological adviser to the local authority should be consulted about the proposed programme and methods of work. In England and Wales it is usually the County Archaeological Adviser who should be contacted, although in London English Heritage advises the local authorities for all boroughs, except Southwark and the City of London.

NOTE A full list of advisers for the United Kingdom is available from the Association of Local Government Archaeological Officers (ALGAO) website (http://www.algao.org.uk/).

[3)] More information can be obtained from Natural England, Website http://www.naturalengland.org.uk ; Scottish Natural Heritage, Website http://www.snh.org.uk or email enquiries@snh.gov.uk; The Countryside Council for Wales, Tel. 0845 1306 229, Website www.ccw.gov.uk; Council for Nature Conservation and the Countryside (Northern Ireland), Website http://www.cnccni.gov.uk/; Joint Nature Conservation Committee, Website http://www.jncc.gov.uk/ Tel: 01733 562 626; Association of Local Government Archaeological Officers UK (ALGOA), Website http://www.algao.org.uk/.

6.2.2 Site reconnaissance

A reconnaissance of the site, neighbouring land and the local area should be made, ideally after carrying out documentary research (see also **6.2.1.2**). Arrangements for the reconnaissance visit, including access, should be agreed with the client and the site owner and/or occupier, as appropriate, before being undertaken. The visit should be made by a suitably qualified, trained and experienced person.

The principal objectives of the visit should be to:

a) verify information on the site collated during the desk study;

b) collect additional information about the site, its environs and any potential contaminants, pathways and receptors;

c) record observations of aspects of the site and its environs not revealed by the desk study, including the presence of invasive plant species;

d) collect information that will assist in the planning of any subsequent phases of field investigation (for example any constraints to access).

The topography of the site should be observed and compared to levels anticipated by the desk study. Raised ground and artificial slopes could be indicative of made ground imported onto the site.

A strategy for the visit should be decided in advance and suitable plans, checklists and reference documentation prepared.

A health and safety risk assessment should also be carried out for the visit. This assessment should be based on the results of the desk study, but may be refined once the preliminary investigation is completed. The assessment should be kept under review as the investigation proceeds, but where there is any doubt as to the presence or degree of contamination then protective equipment should be used. Personnel undertaking the visit should be briefed on any hazards that could be encountered and any precautions to be taken.

If buildings still remain in which potentially contaminating processes could have taken place, the past and present usage should be reviewed and the buildings inspected for evidence of actual and potential contamination.

A request should be made for personnel visiting the site to be accompanied by someone familiar with the site, such as a plant manager or safety officer in the case of an industrial site.

During the site visit photographs of salient features should be taken, where permissible.

If during the site reconnaissance anything is seen that is considered likely to pose an immediate threat to human health and safety or the environment, this should be reported immediately to whoever is in control of the site so that any essential urgent action can be taken.

NOTE 1 Sampling is not normally undertaken during a site reconnaissance. However, it might be appropriate to do so where materials are identified during the visit that could potentially present an immediate hazard to vulnerable receptors. This ought only to be undertaken if it can be done safely using appropriate containers and protective equipment. If not, an urgent exploratory investigation could be planned where the objective is to determine whether an immediate risk is present from the identified site materials.

NOTE 2 There might be a duty under the Health and Safety at Work Act [22] and/or professional Code of Conduct to do this.

NOTE 3 Additional, detailed guidance on carrying out preliminary field inspections of land potentially affected by contamination is given in:

a) CLR 2, published by Defra/Environment Agency [41];

b) SP103, published by CIRIA [42].

NOTE 4 Detailed guidance on the field inspection of buildings prior to decommissioning or demolition is provided in SP102, published by CIRIA [43].

6.3 Data assessment and reporting

6.3.1 Formulating the initial conceptual model

The information from the desk study, site reconnaissance visit and consultations should be collated and evaluated to formulate an initial conceptual model of the site.

The initial conceptual model should identify, as far as possible:

a) potential types, depths and extent of soil, groundwater and ground gas contamination present in different zones of the site;

b) the likely vertical and horizontal stratification of natural and man-made layers beneath the site;

c) strata variability (occurrence and thickness) in different areas of the site and their relative permeability, both vertically and horizontally;

d) potential migration routes (including airborne dispersion);

e) the presence of physical features such as service trenches, drainage runs, soakaways, underground storage tanks, power lines and former foundations that could influence the occurrence or migration of contamination or provide a constraint to investigation;

f) the occurrence of any biological, chemical or physical processes that could affect contaminant concentrations and migration (including natural attenuation);

g) the characteristics of groundwater bodies beneath the site, including groundwater levels and flow directions;

h) the presence of surface water bodies on, or adjacent to, the site;

i) presence and planned (or potential) presence of human receptors;

j) presence of other actual or potential receptors;

k) presence of controlled waters;

l) any foreseeable event, for example rising groundwater, variable sea water levels or nearby construction, that might affect a) to k).

The initial conceptual model may also include hypotheses about the presence of made ground, underground obstructions, buried river channels, the expected directions of groundwater flow, number of aquifers and details of groundwater recharge, permeability of the ground, the physical and chemical properties of the expected contaminants, their possible degradation products, the location and form of the contaminant source, duration, etc.

When further investigations are carried out the additional information should then be used to refine the conceptual model.

Where there are data gaps or uncertainty in the initial conceptual model, these should be highlighted.

*COMMENTARY ON **6.3.1***
Guidance on formulating an initial conceptual model is outside the scope of this standard. ASTM E1689-95 [44] and National Groundwater and Contaminated Land Centre report NC/99/38/2 [45] give guidance on formulating a conceptual model.

6.3.2 Preliminary risk assessment

A preliminary risk assessment should be undertaken once the initial conceptual model has been formulated and the source-pathway-receptor linkages identified. Where adequate site investigation information has been obtained during the preliminary investigation, a qualitative, or generic-quantitative, risk assessment can be undertaken. Information from previous investigative works should be either verified or used with caution.

However, where little or no previous investigation has been undertaken, only a qualitative assessment can be made. The effects of uncertainties in the information available on the outcome of a risk assessment should be identified and recorded.

*COMMENTARY ON **6.3.2***
Guidance on carrying out a formal risk assessment is outside the scope of this standard. Risk assessment covers: a) identification of contaminants, pathways and receptors; b) estimation of the likelihood, nature and extent of exposure to a hazard, and the risk of adverse effects; c) assessment of the likely pollutant linkages and the degree of risk; and d) evaluation of the need for controlling the identified risk. Site investigation provides baseline information for stage a) of the process. CLR 11 [31] provides guidance on risk assessment.

6.3.3 Further investigations

The findings of the preliminary investigation should form the basis upon which the requirement for, scopes of and phasing of subsequent exploratory or main investigations are decided.

The risk assessment and the objectives of the investigation should be reviewed and the need for further investigation considered (see Figure 1), based upon the quantity and quality of previous site investigation information available, the level of confidence required from the actual characterization of ground conditions and hazards and the results of the risk assessment.

6.3.4 Reporting

The preliminary investigation should be completed by the issue of a report. Subject to the specific brief for the investigation, the report should include the factual results of the desk study, site reconnaissance and consultations, together with the conclusions drawn (including presentation of the conceptual model), and recommendations for further research and/or ground investigation.

*NOTE For further guidance on reporting, see Clause **10**.*

7 Design and planning of field investigations

7.1 General

One, two or three phases of field investigation (exploratory, main and supplementary) could be necessary to meet the investigation objectives (see Clause **4** and Table 1) and implement the strategy (see Clause **5**). Generally the field investigations should be designed to provide further information for revisions and updates of the conceptual model and risk assessment and/or the design of remedial works.

Field investigation should be designed to:

a) achieve the stated objectives, including the reduction of uncertainty (see **7.7.1**);

b) determine the presence or absence of contamination and, if present, determine the concentrations and distribution of contaminants, in accordance with the objectives of the investigation and based on the conceptual model;

c) examine ground and groundwater conditions, including hydraulic gradient, soil permeability, porosity, density, moisture, particle size, etc. (see **G.6**), which can influence movement of contaminants;

d) characterize any actual and potential pathways in terms of migration and possible attenuation;

e) where contamination is known to be present, collect additional data for the delineation of the contamination and the design of remediation plans;

f) where necessary, gather specialized information on receptors' characteristics and behaviour;

g) confirm the extent of contamination in areas where it is suspected and to confirm the presence or absence of contamination in the remainder of the site.

The analytical suite of contaminants identified for analysis (see **9.4**) should be based on the conceptual model and include contaminants linked to the historical activities on the site.

Migration of contamination originating on-site to off-site receptors and migration of contamination from off-site sources onto the site being investigated are important considerations. In situations where the preliminary investigation has identified potentially sensitive receptors or sources of contamination located outside the site, the fieldwork should include investigation at, or beyond, the site boundary. In practice, however, off-site access can be restricted due to land ownership issues. Permission for access to such adjacent areas should be obtained.

The permission of the site owner should be obtained, preferably in writing, prior to the commencement of the field investigation.

NOTE 1 Permits to dig could be required at a site before works can commence. These might be required from the landowner, the tenant, the manager and/or archaeologists.

Where relevant to the objective of the investigation and findings of the risk assessment, field investigation proposals should be discussed with the Environment Agency and the relevant local authority in order to incorporate any specific measures they require and ensure that the outcome of the investigation will satisfy regulatory requirements (see **6.2.1.3**). In Scotland discussions with SEPA might be appropriate where pollution of the water environment is being considered or where the site is a potential Special Site under Part IIA.

NOTE 2 Since the development of the conceptual model is an iterative process, each investigation phase will reflect different stages of the process, with different associated uncertainties in the quality of information. For example, in the exploratory investigation information confirming the presence of a potential contaminant might be sufficient, whilst in the main investigation quantitative data will always be required together with more accurate delineation of the area affected and confirmation of migration pathways. In the supplementary investigation additional information is gathered, for example, to enable further detailed delineation of contamination, to provide further information to aid development of a remediation strategy, or to aid application of a remediation method.

7.2 Integrated field investigations

The degree of integration of contaminated land field investigations with other studies (such as geotechnical or archaeological investigations) should be based upon the findings of the preliminary investigation. Any integrated field investigation should be designed so that it does not compromise the requirements of either investigation. For example, sampling locations for contamination should not be moved from a selected grid pattern (see **7.7.2**) in order to accommodate geotechnical requirements.

*COMMENTARY ON **7.2***
Integrated contamination and geotechnical investigations have the following advantages (which result in lower costs compared to undertaking separate field investigations):

a) simplified project management;

b) common use of equipment and procedures;

c) exploratory holes can be used for more than one purpose;

d) joint health and safety procedures can be established;

e) joint environmental protection procedures can be established;

f) integrated consideration of resultant data.

*Linking the field investigation with other types of studies can also be appropriate in some circumstances. In particular, the ecological survey of a site and surrounding area could indicate contamination on the basis of observed impacts on flora. Archaeological and contamination investigations can share information from geophysical survey work (see **8.2.2**).*

7.3 Site safety and environmental protection

Guidance on site safety issues to be addressed in any field investigation should be obtained from BS ISO 10381-3 (see also Annex C).

Any services should be located and identified by reference to utility companies or to service plans for private land, using services detection equipment, lifting manhole covers (using suitable lifting equipment) where present, and using hand-dug starter pits to prevent accidental damage. Coring through hard surfacing followed by probing or sampling should only be undertaken if service locations are known and are avoided or if hand excavation through the cored hole can be undertaken.

Operations undertaken as part of a field investigation should not cause a nuisance to neighbouring residents or occupants, or create a hazard to the environment.

[A1) Particular care in the selection of appropriate sampling techniques and design of sampling procedures should be taken if it is known or suspected that asbestos fibres or asbestos-containing materials (e.g. fragments of asbestos cement sheeting) are present in the ground. Contingency plans should always be in place so that investigation personnel know how to proceed if asbestos is unexpectedly encountered [107].

NOTE 1 The following publications give additional guidance on site safety:

— *CIRIA R132 [46];*

— *BS ISO 10381-3;*

— *BDA "Guidance for Safe Intrusive Activities on Contaminated or Potentially Contaminated Land" [47];*

— *Construction Design and Management (CDM) Regulations 2007 [18];*

— *HSG47, Avoiding Danger from Underground Services [48];*

— *AGS – Site Investigation Asbestos Risk Assessment [106];*

— *AGS – Safe excavation of trial pits [107].*

NOTE 2 Specific guidance relating to investigations for ground gas is provided in BS 8576. This includes reference to the precautions to be taken when drilling in the vicinity of mined areas and when drilling might cause gas migration. Injudicious choice of drilling method can cause risks to drillers due to gas coming out of boreholes. It can also cause risks to the public (e.g. the occupants and users of neighbouring buildings) due to displacement of gas from the location where drilling is taking place – see HSE Position Statement, Carbon [108] and Guidance on managing the risk of hazardous gases when drilling near coal [109]. Drilling in productive Coal Measures requires a permit from the Coal Authority (see Application for permission to enter or disturb coal authority mining interests [110]). (A1]

7.4 Sampling personnel

The experience of sampling personnel should reflect the requirements of the sampling programme and investigation requirements. Sampling personnel should always be aware of what the samples are intended for and have experience and knowledge of:

a) the types and behaviour of contaminants generally associated with the site's previous use(s);

b) safety and environmental precautions;

c) commonly applied techniques and tools (including their advantages and disadvantages);

d) field testing (if relevant).

NOTE Sampling personnel are responsible for the proper use of tools (including cleaning between sampling locations) and recording relevant observations made during sampling (e.g. odours or discolouration).

For further information on personnel see ***5.2.6****.*

7.5 Pre-investigation considerations

7.5.1 Demolition and clearance

Great care should be taken to prevent site personnel being exposed to risks posed by buildings, e.g. asbestos fibres or falling masonry.

Any demolition should be undertaken in accordance with BS 6187.

Special procedures should be followed for some buildings before the site is cleared, for example, if hazards from asbestos, clinical waste, radioactive substances or microbiological organisms are present. Where the site history shows that such hazards are likely to be present, the assistance of specialist decontamination or demolition contractors should be obtained.

Care should be taken to avoid spreading contamination during site clearance work as indiscriminate demolition can lead to greatly increased remediation costs.

*COMMENTARY ON **7.5.1***
Where buildings exist, but are to be removed as part of a redevelopment, it is sometimes necessary to carry out the field investigation in two stages. Accessible sample locations can be investigated initially and the remainder can be accessed after demolition has occurred.

When demolition is carried out, attention is drawn to statutory requirements for CDM designer risk assessments and health and safety plans [18].

Further guidance on clearance work is given in SP 102 published by CIRIA [43].

It is the responsibility of the asbestos duty holder or their representative to inform any persons undertaking works on a site of its presence, amount and extent. Attention is drawn to statutory requirements for asbestos [49].

7.5.2 Presence of tanks and services

If any residues or raw materials are present in or near tanks and services, especially in liquid form, consideration should be given to the nature of the material and the need for removal before site clearance or sampling begins. This can necessitate a separate initial sampling exercise prior to removal.

Before undertaking any site investigation works in the vicinity of disused underground tanks or associated infrastructure it should be established whether the installation has been appropriately decommissioned and made safe.

*COMMENTARY ON **7.5.2***
There is usually a defined zone around operational underground storage tanks and associated equipments (e.g. fuel lines) within which intrusive work is not permitted.

Tanks and pipes (both above and below ground) and cavities can contain significant amounts of hazardous substances long after a site has closed. Damage to tanks, pipes and drains or the relocation of materials within the site can result in the spread of contamination. Further guidance on decommissioning and removal of underground storage tanks is contained in PPG27, published by the Environment Agency, SEPA and the Environment and Heritage Service in Northern Ireland [50]. Subject to any planning conditions the removal of tanks, pipes and other services may need to be agreed with the Regulator.

7.5.3 Unexploded ordnance (UXO)

The potential for the site to contain or have been affected by UXO should be highlighted within the preliminary investigation (see **6.2.1.1**). Measures should be undertaken to mitigate risks during the field investigation if determined necessary by a UXO risk assessment (see Note).

NOTE Guidelines on UXO risk assessment and mitigation are provided in CIRIA C681 [37].

7.5.4 Disposal of rubble and waste materials

During intrusive investigations waste material, including spoil and groundwater, can be generated. Suitable disposal routes should be identified and arrangements made for the classification and safe disposal of the waste if it is considered necessary to remove the material from the site. While a suitable disposal route is being considered, the material should be stored securely in a way that avoids contamination of the underlying ground, the water environment, the atmosphere or the surrounding land.

For guidance on what constitutes a waste and waste classification, reference should be made to the latest guidance on the Environment Agency, Scotland Environment Protection Agency or Northern Ireland Environment Agency websites (see http://www.environment-agency.gov.uk/business/topics/waste/default.aspx, http://www.sepa.org.uk/waste/waste_regulation/guidance__position_statements.aspx or http://www.doeni.gov.uk/niea/).

NOTE Guidance on the requirement for a licence or permit to store waste can also be found on these websites.

Material classified as a waste should only be removed from site by a licensed waste contractor.

7.6 Method of field investigation

7.6.1 General

The strategy for the field investigation (see Clause **5**) should be formulated to take into account the investigation objectives and site-specific features. Field investigation of a site may be carried out by non-intrusive and/or intrusive methods (see **8.2**).

7.6.2 Non-intrusive investigations

The feasibility of using non-intrusive techniques depends on ground conditions and the features of interest, so the techniques should be selected accordingly for each particular site. Specialist advice should be sought, as necessary, on the applicability of the proposed techniques, where this expertise does not already exist within the project team.

*COMMENTARY ON **7.6.2***
*Non-intrusive investigations can be carried out using a range of technologies, the advantages and disadvantages of which are discussed in **8.2.2** and Table 5.*

These methods can be useful within an exploratory investigation, if carried out, or as part of a main investigation where the presence of features associated with contamination is suspected, but the specific locations are not known.

7.6.3 Intrusive investigations

The objectives of most field investigations necessitate the collection of samples of soil, water and/or gas and there are many different techniques available for such sampling. The techniques should be chosen having regard to the samples to be collected, the locations and depths of sampling, the analytical requirements and the constraints of the site (e.g. limited access, hard landscape).

Where groundwater or ground gas contamination is suspected, monitoring wells should be installed to enable specific groundwater and ground gas sampling requirements to be met.

When selecting an intrusive technique (see **8.2.3.1** and Table 6), the need to prevent contamination migration (caused by the creation of temporary or permanent connection between aquifers or between contaminated ground and underlying aquifers) should be considered.

In order to select appropriate sampling techniques for investigation:

a) the safety of investigators and the public should be considered;

b) the requirements for sampling should be established;

c) the sampling locations, types and depths of samples to be collected and the monitoring facilities installed should be determined in accordance with **7.7.2.5**;

d) potential environmental impacts should be considered and taken into account.

*COMMENTARY ON **7.6.3***
*The methods of carrying out intrusive investigations, including the installation of permanent and semi-permanent monitoring wells, are discussed in **8.2.3**, Table 6 and Table 7, where the advantages and disadvantages of selected methods are described.*

7.7 Sampling strategies

NOTE The sampling strategies discussed in this sub-clause are not applicable to the sampling of stockpiles. Guidance on sampling stockpiles is given in ISO 10381-8 and BS ISO 18283.

7.7.1 General

The sampling strategy for any phase of intrusive investigation that follows the preliminary investigation should take into account:

a) the objectives of the investigation and findings of the risk assessment to date;

b) the data requirements (quantity, type and quality) for the planned risk assessment and/or to permit statistical analysis of the data;

c) the possibility of dividing the site into zones or areas (see **5.2.3**);

d) the location, pattern and number of sampling points (see **7.7.2** to **7.7.4**);

e) the depths from which samples are to be collected and any monitoring requirements (see **7.7.2.5**);

f) the analyses required and whether any *in situ* or field testing is appropriate and necessary (see **8.4** and Annex F);

g) the methodology by which samples are to be collected (**8.3**), stored and preserved (**8.6**), taking into account any off-site analysis to be undertaken (see Clause **9**);

h) any measures needed to protect personnel and the environment (see **7.3** and Annex C), including avoiding creation of additional migration pathways.

Additional site-specific factors that might affect the location of sampling points (for example, site size, topography, depth and direction of groundwater, and physical obstructions) should be identified.

Practical considerations, such as access restrictions and ecological features, can also constrain the positioning of sampling locations. Information gaps resulting from access restrictions should be noted and taken into consideration during subsequent risk assessment as a source of uncertainty. Where possible, field investigation in formerly restricted areas should be undertaken during subsequent phases of investigation.

The sampling strategy should be sufficiently flexible to permit representative samples of all strata and materials encountered to be collected, including any anomalous material.

NOTE 1 For simplicity, reference is made here only to chemical analysis. However, as indicated earlier, a range of other tests might be considered. For example, to determine the physical properties or biological characteristics of the soil.

The reason(s) for choosing a sampling strategy (including the choice of locations and frequency of sampling) should be included in the final report (see **10.3**).

Possible heterogeneity of distribution of contaminants should be taken into account when designing the sampling strategy, since this will influence the selection of sample locations and the number of samples collected (see **7.7.2**). Greater confidence in the field investigation can be achieved by increasing the number of samples taken and analysed, as significant differences in the sample composition over small areas within a site can occur.

Once the samples have been obtained, decisions should be made about which samples to analyse and for which contaminants, based on the conceptual model and historical activities on the site (see **7.8**).

Any sample submitted to the laboratory should be representative of the location and depth from which it was taken.

NOTE 2 The uncertainty associated with sampling in site investigations is generally greater than that associated with the analysis. Confidence in the representativeness of sampling is discussed in ***7.9.2****.*

Water bodies tend to be more homogeneous in composition than soil. However, stratification can still occur in groundwater and surface waters. This should be taken into account in the design of the sampling strategy. Allowance should also be made for contamination migrating against the direction of water flow, for example, where the direction of movement of dense non-aqueous phase liquids permeating into the ground is affected by impermeable material, such as obstructions or clay (see also **7.7.3.4**).

NOTE 3 Ground gas samples are similar to water samples in that they can be representative of a large area. Nevertheless, the sampling strategy differs from that used for waters because of the greater ability of ground gases to migrate in all directions within the ground.

NOTE 4 Where monitoring locations for groundwater and ground gases are coincident, it is not always possible to install a joint monitoring well, for example, when it is necessary to seal the groundwater monitoring standpipe within the saturated zone and gas monitoring is required in overlying unsaturated soils.

Equipment should be cleaned between use at different sampling locations and within locations when forming boreholes to prevent cross-contamination of samples (see **8.2.3.3**).

Sampling locations should be determined accurately, in both plan and elevation, and preferably be related to the OS Grid and Datum.

7.7.2 Sampling of soils

7.7.2.1 Sampling locations

Locations for soil sampling should be selected based on one or both of the following approaches:

a) targeted (judgmental) sampling, which focuses on known, suspected or point source areas of contamination (see **7.7.2.2**);

b) non-targeted sampling, which characterizes the contamination status of a defined area or volume of a site or zone (see **7.7.2.3**).

Where a conceptual model divides the site into zones with potentially different contamination characteristics, the balance between the two approaches may vary between the zones.

The number and pattern of sampling locations should be informed by the risk assessment and the required degree of confidence that hazards have been identified. The more sensitive the receptors or the greater the hazard, the greater the degree of confidence needed in the outcome of the risk assessment and the subsequent risk management (see R&D Technical Report P5-066/TR [51] for more information). In such cases, a greater number of sampling locations and samples should be selected. Other factors, such as accurate delineation of an area of contamination, also necessitate more intensive sampling.

NOTE 1 See R&D Technical Report P5-066/TR [51] and BS ISO 10381-1 for more information on the design of soil sampling programmes.

NOTE 2 Annex A provides examples of exploratory and main investigation strategies involving targeted (judgemental) and non-targeted sampling locations.

*COMMENTARY ON **7.7.2.1***
The distribution of contaminants on a site can vary because the contaminants can originate from different sources and possess different properties. Even if originating from the same source, different contaminants can behave differently in the ground.

*It is normally relatively cheap to collect samples during the course of a site investigation, even if it is not intended to immediately analyse them all. If samples are properly preserved and stored (see **8.6**), the additional costs of a further sampling exercise can be avoided. Degradation or volatilization of certain compounds (for example, VOCs, pesticides, petroleum hydrocarbons) can occur during storage of samples, so it might not be appropriate to schedule certain analyses (particularly organic parameters) if samples have been stored for an unsuitable period of time (see BS ISO 18512:2007, Tables A.1 and A.2, for more details on recommended holding times for samples designated for different types of analysis).*

7.7.2.2 Targeted (judgmental) sampling

Targeted (judgmental) sampling involves sampling at locations selected on the basis of the conceptual model that are known or suspected to be sources or areas of contamination. Locations may also be targeted along potential migration routes of mobile contaminants.

The number of sampling locations should be based upon the potential source of contamination and its nature.

*COMMENTARY ON **7.7.2.2***
Potential point sources of contamination include past and present storage tanks (above and below ground), below-ground fuel supply pipework, drains, backfilled pits and waste disposal areas, handling areas where spills of hazardous materials could have occurred, etc.

The application of statistical tests (for example, calculating upper or lower confidence limits using the approach outlined in the CIEH/ CL:AIRE document, Guidance on Comparing Soil Contamination Data with a Critical Concentration *[52]) are valid only in relation to unbiased sample data. Consequently, data collected from targeted sampling cannot be used in the application of statistical tests.*

7.7.2.3 Non-targeted sampling

7.7.2.3.1 General

Non-targeted sampling should usually be carried out using a regular pattern of sample locations.

If there are any regular topographical or site use patterns on the site (ditches at regular intervals, systematic undulations of the terrain, tank farms, etc.), the sampling pattern should not coincide with the topography in a way that could introduce a bias or systematic error in the samples. This can be avoided by careful selection of the base or starting point of the sampling grid and, where necessary, by careful selection of the grid spacing.

*COMMENTARY ON **7.7.2.3.1***
The reasons for selecting a regular sampling pattern in site investigations are:

*a) the reliability of interpolation between sampling locations declines sharply as distance increases; additional samples can be taken during a further investigation within the pattern to reduce the distance between locations (see **7.7.2.4**);*

b) data from further investigation can be readily correlated;

c) sampling locations are simpler to establish in the field;

d) location of areas of contamination is simplified;

e) design of further investigations is easier.

Reliability of interpolation between sample locations depends on variations in soil characteristics. Made ground soils are typically highly heterogeneous. Therefore, the concentration of hazardous substances in soil can vary greatly, both laterally and vertically over short distances. In well-stratified sediments, vertical variations in concentration are normally much greater than horizontal variations so that interpolation horizontally is much more reliable than vertical interpolation. Vertical interpolation through different strata is not possible.

7.7.2.3.2 Non-targeted sampling patterns

When choosing the sampling pattern, it should be borne in mind that contamination with sharply defined boundaries rarely exists. Increasing concentrations may be used as broad indicators of a greater degree of contamination, even though the areas of highest concentration might not have been sampled.

*COMMENTARY ON **7.7.2.3.2***
A simple, regular sampling pattern allows selection of locations for different stages of investigation. This standard does not give detailed guidance on sampling patterns, but various patterns of sampling have been identified (see BS ISO 10381-1, R&D Technical Report P5-066/TR [51] and CLR 4 [53] for further information).

a) *The most common pattern used for establishing sample locations is the square grid with samples taken at the intersections. A square grid sampling pattern has the advantage that a wide spacing can be used, for example in an exploratory investigation. Additional sample locations can be readily located within that pattern in subsequent investigations by reducing the grid spacing. This is particularly useful when interpreting results and designing any further investigations.*

b) *Regular triangular grids can sometimes provide greater effectiveness than regular square grids (BS 10381-1).*

c) *The herringbone pattern, which uses a form of offset regular grid, is statistically more likely to identify linear contamination in two dimensions than the square grid pattern [item a)], see CLR 4 [53].*

Studies (for example, CLR 4 [53]) that have been undertaken to evaluate the relative efficiencies of various non-targeted sampling patterns for different shaped areas of high levels of contamination have indicated that both square and herringbone grid patterns give adequate results.

7.7.2.3.3 Non-targeted sampling density

The spacing between sampling locations should be determined according to the conceptual model, the phase of the investigation, acceptable levels of uncertainty and the requirements of the risk assessment. An exploratory investigation usually requires a lower density sample spacing than a main investigation (see R&D Technical Report P5-066/TR [51] for more information).

Typical densities of sampling grids can vary from 25 m to 50 m centres for exploratory investigations, and 10 m to 25 m centres for main investigations. A greater density of sampling grid (for example 10 m centres or less) should be considered where:

a) heterogeneous contamination is indicated, for example, on a former gasworks site;

b) contaminant concentrations identified during an earlier investigation are close to the critical levels of interest, recognizing the uncertainties of measurement in the concentration values;

c) a high level of confidence is required for the outcome of a risk assessment (for example, for a housing development);

d) delineation is required along the edges of known areas of contamination;

e) the "averaging area" is small [see item 1) in Commentary].

*COMMENTARY ON **7.7.2.3.3***
It is possible to assess the sampling grid required for a given area based on a specified degree of statistical confidence that the area has been characterized. Two such methods are provided in the following references.

1) *R&D Technical Report P5-066/TR [51] provides a methodology for determining the sampling density for main investigations. The methodology requires an averaging area for the site (or smallest area of concern) to be defined and the required probability of detection for that area to be determined.*

2) *CLR 4 [53] provides methodologies for estimating the number of sampling points necessary to ensure a required probability of finding a contaminated area is achieved. Two methodologies are described, based on whether the site is judged to require uniform or variable sampling densities (i.e. whether different areas of the site are assessed to have an equal or unequal probability of containing contamination). The number of sampling locations required to achieve a given level of confidence of finding a "hot spot" can be reduced by using variable rather than uniform sampling densities (involving the application of Bayesian statistics, i.e. making a priori assumptions about the probability of finding a contaminated area in sub areas of the site) and by undertaking sampling in two or more stages (staged investigation) [53].*

7.7.2.4 Composite sampling

Spatial composite sampling, in which a number of incremental samples are taken over a wide area (e.g. a field), should not normally be used for the investigation of land potentially affected by contamination due to the:

a) difficulty of comparing resultant data with guideline concentrations that relate to spot samples;

b) possibility of disguising isolated locations of high concentration by mixing with samples of lower concentration;

c) possibility of loss of volatile compounds during the compositing processes;

d) difficulty of achieving an adequately mixed and representative sample;

e) difficulty in undertaking statistical analysis of composited data.

Cluster sampling, in which incremental samples are taken over a small area (e.g. 1 m^2), can be used when taking surface samples and, in certain circumstances, from excavations. In the latter case, they should be taken from a single stratum (see also Table 9).

*COMMENTARY ON **7.7.2.4***
Spatial composite sampling involves collecting a number of equally spaced samples of the same size, following a prescribed pattern, over a sampling area. These samples are bulked together to form the composite sample. This sample represents the mean quality of the area sampled. Composite sampling is often used where a sample is required to evaluate soil quality for agricultural purposes or for waste characterization of a stockpile.

Some jurisdictions specify the use of a form of composite sampling for the assessment of surface and near-surface soils using generic guideline values.

*For advice on the collection of soil samples see **8.3.2**.*

7.7.2.5 Sampling depths

When developing the sampling strategy, the sampling depths should be considered after establishing the sampling locations.

The samples should be collected to represent a specific depth or narrow band of strata.

A soil sampling strategy should include taking the following samples, unless only specific layers are being targeted, e.g. in some supplementary investigations.

a) Samples from the immediate surface layer. This layer should be defined on a site-specific basis related to the conceptual model and the risk assessment. The surface layer sampled may vary between the surface and a depth of 0.5 m and could require sampling at more than one depth. Material that could either be disturbed by rainwater runoff and carried to adjacent water bodies or present an immediate exposure hazard might require sampling in the uppermost 0.1 m. Where there are health hazard concerns, e.g. in domestic gardens, samples should be taken of materials which people could come into contact with (which generally comprise shallow and surface strata).

b) Samples from within made ground at fixed depth intervals (often 0.5 m).

c) Additional samples within made ground to reflect any identifiable changes in appearance, in made ground or other material of interest.

d) Samples of natural ground beneath made ground. The first sample of natural ground should be taken close to the boundary with the made ground (approximately 0.25 m to 0.5 m into natural ground).

If the conceptual model or field investigations indicate the need to continue sampling into the natural ground underlying the site, e.g. in more permeable ground, sampling should be carried out as deep as is necessary to characterize and identify contamination migration. Samples should typically be collected at 1.0 m depth intervals in natural ground, but this will depend upon the conceptual model, the findings of the risk assessment and field observations.

The depths of sampling should take into account the nature of the proposed development. For example, services and strip foundations are typically installed to a depth of 1.5 m, but main sewers and foundation piles can be installed at much greater depths.

Where ground is likely to be removed for engineering purposes, this should be taken into account when determining the sampling depth. This allows adequate information to be obtained on the contamination status at the anticipated reduced level.

NOTE 1 Samples of natural strata, if uncontaminated, can indicate the local, natural (background) chemical conditions and can be of assistance when determining the extent of contamination migration. Soils taken from beneath made ground can be subsoils and can differ in composition from the topsoils that would be naturally associated with them.

*NOTE 2 The use of field testing (see **8.4** and Annex F) or detectors, such as photo ionization detectors (PIDs), can aid the determination of sampling depths.*

Sampling of ground in the capillary zone immediately above the water table should be considered, as slightly soluble compounds and light non-aqueous phase liquids tend to concentrate in this region. Sampling of the smear zone should also be considered if the groundwater level fluctuates significantly, for example as a result of tidal influences.

Dense non-aqueous phase liquids can accumulate on the surface of impermeable materials, obstructing vertical migration, so sampling at the boundary between permeable and impermeable material should be considered.

7.7.2.6 Field sampling decisions

The overall strategy should normally be specified before site work is started. Where field observations, such as visual or olfactory evidence of contamination or evidence of plant damage, are noted, additional samples to those scheduled should be taken in response to these observations. Where samples are taken in response to site observations or client/engineer requests and are not typical of the strata from which they were taken, an accurate record of this should be kept so as to inform subsequent data users that this was the case.

7.7.3 Sampling of waters

7.7.3.1 Designing a groundwater sampling strategy

7.7.3.1.1 General

The design of a sampling strategy for groundwater should take into account the recommendations of **7.7.1**. Monitoring well locations should be determined on the basis of the conceptual model, the investigation objectives and accessibility, both during the installation and for subsequent monitoring. A phased approach to groundwater investigation is often appropriate and should be undertaken, where applicable.

NOTE Table 4 describes the scope of groundwater investigations that could be appropriate for different phases of field investigation.

Although most groundwater sampling is undertaken using new, purpose-designed monitoring wells (see **8.3.3.2**), existing wells or boreholes may be used, provided they are suitable for the purpose of the sampling programme (see **7.7.3.1.2** and **7.7.3.1.3**). Where a borehole intersects the water table, a sample should be obtained from a monitoring well installed after the completion of drilling and well development (see **8.3.3.2**).

Wells should not be screened across more than one hydrogeological unit (for example, well response zones should not span across perched water in the made ground and a deeper aquifer below).

Monitoring wells should be provided with sufficient protection to prevent vandalism. Suitable measures can include the installation of a lockable cover (e.g. stop-cock cover set in concrete).

Collection of groundwater samples should be carried out in accordance with BS ISO 5667-11.

Water samples obtained during trial pitting can be used for screening for the presence of groundwater contamination and to establish whether it is necessary to install monitoring wells. However, caution should be applied when considering the analytical data from such samples, since the ground disturbance caused by digging can affect the composition of the water sample. It is not good practice to obtain water samples for chemical testing during the drilling of boreholes for the same reason.

Table 4 **Phasing groundwater investigations**

Phase of investigation	Sampling/monitoring activities
Exploratory investigation	Construction of limited number of installations within and around the site based on preliminary investigation data and initial conceptual model A). Measurement of water levels. Preliminary water quality analysis.
Main investigation	Construction of additional monitoring installations to give broad cover across area of interest. *In situ* testing (for example, pump testing or permeability measurements to determine aquifer properties). Further monitoring of water levels. Water quality analysis.
Supplementary investigations	Further adjustment of monitoring network, where appropriate, based on findings B). *In situ* testing (for example, pump testing or permeability measurements to determine aquifer properties). Further monitoring of water levels. Water quality analysis.

A) Installations used may be piezometers (to determine water levels/pressures) or standpipes (for preliminary water quality sampling/determination), depending upon the objectives.

B) Earlier findings should be used to determine location, depths and types of installations required.

When all monitoring work has been completed and there is no further need for the monitoring wells, these should be sealed by grouting with suitable material, ensuring that the grouting is effective above and below the water table.

NOTE Further guidance on the decommissioning of boreholes can be found in the Environment Agency guidance document Decommissioning Redundant Boreholes and Wells *[54].*

COMMENTARY ON ***7.7.3.1.1***
Information on groundwater flow helps to identify the most suitable locations and depths for monitoring wells. A phased approach can be required in which flow patterns are first established, and then further monitoring wells installed where they are considered most likely to produce useful information (see Table 4). For example, the information from the initial conceptual model, particularly with respect to assumptions about the aquifer being sampled, could be limited. The exploratory investigation could then be needed to provide information on basic parameters such as hydraulic gradient, direction of flow, presence or absence of low permeability strata and the vertical profile of aquifers beneath a site. Subsequent investigations could then be needed to refine and expand on the information obtained.

There are two generic source types of groundwater contamination: diffuse-source and point-source. Each type requires a different approach when determining the appropriate sampling pattern and frequency.

Further guidance on the design of water sampling programmes and health and safety considerations during water sampling can be found in BS EN ISO 5667-1.

Other techniques, such as non-intrusive methods and probe holes, can provide information on which to base the locations of groundwater monitoring wells.

7.7.3.1.2 Sampling strategy for diffuse-source contamination of groundwater

Diffuse source contamination of groundwater can be the result of a number of diffuse inputs from within a site, but can also result from off-site sources. When there is no clearly defined source, groundwater monitoring wells should be installed on a non-targeted basis (see **7.7.2.3**).

The monitoring wells should be used to determine the direction of groundwater flow and the water quality upon entering and leaving the site. Wells installed in the same aquifer to determine the direction of groundwater flow should be located in a triangulated pattern (wells in a line do not provide adequate information to establish the direction of groundwater flow).

NOTE Further guidance is provided in the following documents.

- *BS ISO 5667-11;*
- *Environment Agency:* Remedial Targets Methodology, Hydrogeological Risk Assessment for Land Contamination *[55];*
- *Environment Agency: TGN02* Monitoring of landfill leachate, groundwater and surface water *[56].*

7.7.3.1.3 Sampling strategy for point-source contamination of groundwater

Monitoring wells should be located on a targeted basis based on the conceptual model and the investigation objectives.

Wherever practicable, a groundwater monitoring well should be installed directly below an identified potential source. However, such installations can allow contaminants to migrate vertically. Alternatively, the monitoring well may be installed at the outer down-gradient edge of the potential source.

NOTE 1 This alternative position reduces the possibility of vertical migration, but does not identify the maximum concentration of contamination. Guidance on the design and installation of monitoring wells to reduce cross-contamination and creation of contaminant pathways can be found in EA Science Report SC020093 [57].

Groundwater monitoring wells should be installed up-gradient and down-gradient of a potential source. These monitoring wells may also be used to determine the direction of groundwater flow (depending on the number and layout of the wells) and the quality of the groundwater flowing onto the site.

Further monitoring wells should be considered (depending upon the objectives and phase of the investigation), for example, at progressive distances down the hydraulic gradient from the source of contamination. Provision should also be made for sampling from a range of depths (see BS ISO 5667-11 for further guidance.)

NOTE 2 Local groundwater levels can be raised ("mounded") within an above-ground landfill so that flow occurs outwards in all directions including against the regional groundwater flow direction. In such circumstances it is helpful to also place monitoring wells to the side as well as up-gradient.

NOTE 3 Contaminants can move against the direction of groundwater flow by diffusion especially when the rate of groundwater flow is low. This means that contamination might be detectable upgradient of a source. Care is needed therefore when interpreting data from up-gradient wells.

7.7.3.2 Tools for assisting sampling strategy design

A number of tools may be used in the design of the groundwater sampling strategy, including:

a) flow net modelling: if data from several groundwater monitoring locations are already available, it is possible to move beyond a groundwater contour plan and establish the most likely flow paths of groundwater from various areas under a site, by constructing a groundwater equipotential plan;

b) mathematical modelling: appropriate computer modelling packages may be used during most stages of groundwater investigations to analyse and present data, from which hypotheses on the rate and direction of contaminant movement can be derived, though care is necessary to ensure that the output does not overstate the validity of, for example, a limited data set.

7.7.3.3 Nature of contaminant (including non-aqueous phase liquids)

In designing a groundwater monitoring programme, consideration should be given to the nature of the likely contaminants. If contaminants are encountered which were not anticipated, this could necessitate additional investigation involving the installation of specific monitoring wells to address the contamination encountered.

Groundwater monitoring should address the contaminants identified during the preliminary investigation, which may include both dissolved contaminants such as metals and organic compounds and hydrophobic materials [for example, non-aqueous phase liquids (NAPLs)] which could be present as free product.

If NAPLs are present, consideration should be given to the effect of, for example, the following factors on their distribution in the groundwater.

a) The solubility of NAPLs in water and other solvents.

b) Their sorption properties.

c) Degradation compounds of specific NAPLs.

d) The potential for NAPLs to migrate.

Where liquids are present that are less dense than water, i.e. light non-aqueous phase liquids (LNAPLs), boreholes should be screened over a depth range that spans the level of the water table so that the LNAPL can be more easily detected and the thickness of the liquid phase determined.

Dense non-aqueous phase liquids (DNAPLs) will migrate to the base of the hydrological unit and can collect on, or be deflected by, lenses of low permeability material. Investigations for DNAPLs are difficult and should include monitoring wells that fully penetrate the aquifer, where possible, and are screened at the base and at points where low permeability material is present.

NOTE 1 Separate wells may be formed to different depths. However, it can be difficult to ensure adequate seals in nested wells (in the same borehole), so it is preferable to form wells to different depths in separate boreholes, to ensure the targeted water body is sampled without cross-contamination.

NOTE 2 Further guidance can be obtained from the Environment Agency's Remedial Targets Methodology *[55] and Science Report SC020093 [57].*

*NOTE 3 Where volatile NAPLs are likely to be present, information on the potential location of the contaminant plume may be obtained by carrying out ground gas monitoring (see **7.7.4.3**). This information can also be used for determining the location of monitoring wells.*

7.7.3.4 Low permeability strata

Where a monitoring well installation passes through low permeability strata, routes allowing dispersal of contamination into underlying groundwater can be created. In such situations, a larger diameter hole should be formed down to the low permeability strata and an impermeable plug of suitable material and sufficient thickness, for example, bentonite/cement grout with a thickness of at least 1 m, placed in the borehole. This could necessitate some preliminary trials to confirm that the selected material is effective. The plug should be allowed to set before continuing the borehole by forming a smaller diameter hole. In this way a seal (to prevent the downward migration of contamination) is created. The borehole should be grouted as the casing is withdrawn in order to complete the seal.

NOTE A phased approach to investigation (i.e. using the results from an exploratory investigation to design a main investigation), together with appropriate installation techniques (particularly where severe contamination is suspected), can reduce the potential for contamination.

7.7.3.5 Timing and frequency of monitoring

Where practicable, groundwater should be characterized using data from a series of sampling operations. For example, a number of samples should be taken over a relatively short period of time, and then less frequently over a longer period. The periods of time between sampling should be dependent on the findings of the earlier sampling operations.

In addition, the sampling frequency should be based on the temporal and spatial variations in the quality of the groundwater and its flow.

*COMMENTARY ON **7.7.3.5***
Changes in the quality of groundwater are usually much more gradual in time and space than those in surface waters. In some aquifers, factors producing seasonal variations in quality could exist.

Groundwater levels vary during the year in response to a variety of factors, including changing weather conditions and plant transpiration rates. Obtaining a full picture of annual variations requires monitoring over 12 months and could require several years. Groundwater levels can also fluctuate during the day due to tidal influences.

The timing of sampling can be adapted to take into consideration known or expected fluctuations in groundwater levels (for example, due to tidal influence), flow directions, etc.

Continuous assessing of pH, temperature and electrical conductivity can provide a useful means of monitoring the need to increase or decrease the sampling frequency. In cases where there has been a considerable change in any of the parameters, it is advisable to consider extending the range of parameters being monitored.

Further guidance on sampling frequency is given in BS ISO 5667-11.

7.7.3.6 Sampling of surface waters

The collection of surface water samples and sediments from surface water should be carried out in accordance with BS 6068-6.4, BS 6068-6.12 or BS ISO 5667-6.

7.7.4 Monitoring and sampling of ground gas

7.7.4.1 General

Where hazardous ground gases (including permanent gases and vapours) could be present (for example, on or adjacent to areas of landfill, made ground, alluvial ground, solvent or fuel storage, mining, buried dock sediment and/or peat), the composition and migration potential of the ground gas should be determined.

[A1) *Text deleted* (A1]

Special considerations should be given to the potentially significant risks of toxic effects, asphyxiation or explosion while investigating and monitoring suspected or known sources of gas emission. If a site poses a potential gas hazard, a “permit to work” system should be instigated.

[A1) *Text deleted* (A1]

*COMMENTARY ON **7.7.4.1***
Degradation of organic matter can give rise to both methane and carbon dioxide, and to a variety of other gases, depending on the ground conditions and the nature of the material. Gases can also be transported in solution by migrating landfill leachate and groundwater. Gases, such as carbon dioxide and methane, can also arise from natural geological strata such as coal and chalk. Further information on the ground gas generation potential of various sources and the properties of gases and vapours is provided in Section 2 of C665, Assessing Risks Posed by Hazardous Ground Gases to Buildings *[59]* [A1) *and BS 8576* (A1].

Volatile organic compounds (VOCs) can have associated vapours, the concentrations of which can vary in the ground gas above different parts of a plume, but which can be used to indicate the location of the plume. See CIRIA C682 [60] [A1) *and BS 8576* (A1].

7.7.4.2 Methods for determination of ground gas composition

7.7.4.2.1 Sampling strategy

Monitoring well locations should be determined on the basis of the conceptual model, the investigation objectives and accessibility. Monitoring well locations may be targeted in locations such as the following.

a) A particular area of a site or stratum which is suspected of generating ground gases.

b) There are zones of permeable geology that could provide a migration pathway from a potential ground gas source.

c) At the closest point to an existing, adjacent or proposed potential receptor such as housing.

d) In areas of low risk, to enable collection of background concentration data.

[A1) The sampling strategy should be developed in accordance with BS 8576. (A1]

Monitoring well locations may also be non-targeted, for example, where potential ground gas generating soils are present across the whole site (such as a site underlain by alluvium). Subsequent monitoring wells may be positioned on the basis of the information obtained from the initial installations.

The location of gas monitoring wells should take into consideration the location and number of potential sources, the sensitivity of the (proposed) end use, the direction of possible migration, both vertically and laterally (including, where relevant, man-made features such as service ducts and foundations) and the permeability of the ground (which affects the zone of influence of the wells). Consideration should be given to the locations of proposed buildings and the need to assess off-site migration.

[A1] *NOTE 1 Examples and illustrations of construction of typical gas monitoring wells are provided in BS 8576.* [A1]

Installation of ground gas monitoring wells should be carried out in boreholes or driven boreholes (see Clause **8**). Installation should not be carried out in a trial pit with subsequent backfilling due to the disturbance and aeration of the ground and the uncertainty of the period necessary for original ground conditions to re-establish before monitoring can begin.

Monitoring wells should be provided with sufficient protection to prevent vandalism. Suitable measures can include the installation of a lockable cover (e.g. stop-cock cover set in concrete).

When designing a gas monitoring and sampling programme the following documents should be consulted for further guidance on the application of specific measurement techniques and the frequency and spatial distribution of monitoring and sampling:

1) CIRIA R150 [61];
2) CIRIA C665 (2007) [59];
3) CIRIA C682 (2009) [60];
4) NHBC/RSK Report No. 04 (2007) [62];
5) Wilson et al (2009) [63];
6) BS 8485.

NOTE Local authorities also refer to the Local Authority Guide to Ground Gas *(2008) [64], which is not commercially available, but is essentially the same as The Ground Gas Handbook [63].*

*COMMENTARY ON **7.7.4.2.1***
*Investigations for ground gases generally use monitoring wells to enable field monitoring with portable instruments and the collection of samples for laboratory analysis (see **8.3.4**). Investigations which involve monitoring for soil vapours might require specific installations (see C682 [60]).*

Monitoring of radon is normally undertaken at the location of the identified receptor (for example, within a residential building) using radon detectors (further information can be found at http://www.ukradon.org/).

7.7.4.2.2 Methods of ground gas examination

[A1] Measurements to determine the composition of ground gas and other relevant properties can be found in BS 8576, *Guidance on investigations for ground gas – Permanent gases and Volatile Organic Compounds (VOCs)*.

The sampling strategy should be developed in accordance with BS 8576.

BS 8576 contains illustrations of a number of installations for monitoring permanent gases and VOCs. [A1]

[A1] *Clauses deleted* [A1]

7.7.4.3 Measurement of concentrations of VOCs in ground gas

7.7.4.3.1 [A1) General

Investigations for VOCs should be carried out in accordance with BS 8576. (A1]

[A1) *Subclauses deleted* (A1]

7.7.4.3.2 Timing and frequency of gas and VOC monitoring

The timing, frequency and method of monitoring should be determined initially on the basis of the objectives and the conceptual model in terms of the potential risk to a receptor in combination with the risk posed by the potential source. Timing and frequency should also take account of the level of confidence required as well as natural variations in climatic and anthropogenic cycles.

*COMMENTARY ON **7.7.4.3.2***
Timing and frequency could be related to natural climatic cycles or anthropogenic cycles (such as differing use of a building). For some sites, a single monitoring visit might be adequate, provided that the data are used as part of a multiple lines of evidence approach. However, for some scenarios multiple sampling events might be needed.

7.8 Developing a testing programme

7.8.1 General

The tests (e.g. chemical, physical or biological) to be carried out should be selected on the basis of the investigation objectives and the conceptual model. Consideration should also be given to:

a) the critical levels of interest for each parameter;

b) the precision and accuracy of the methods;

c) whether the analysis is for a specific parameter or for a range of compounds;

d) whether the sample is soil, water or gas;

e) the type of sample containers and the preservation techniques required;

f) the timescales involved (see Clause **9**).

NOTE Information on the circumstances in which the samples are to be taken sometimes needs to be given to laboratory staff so that they can offer pertinent advice.

7.8.2 Soil testing design

The testing regime should be determined with reference to the contaminants identified in the conceptual model and with due regard to the pathways of concern and the potential effects on the appropriate receptor. This information should be used to decide the specific parameters to be analysed. The laboratory analysis should be MCERTS-accredited where possible. The requirements for accredited analysis should be discussed with the regulator in advance.

If groundwater quality is at risk from soil contamination, the following may be appropriate:

a) leachate testing and/or pore water analysis;

b) the determination of soil pH and organic carbon content.

Observations made during sampling should be taken into account when specifying the final testing regime, for example, odour observations could indicate that additional testing, speciation or lower detection levels are required.

NOTE Further guidance on testing requirements for the characterization of soil is given in ISO DIS 11504, BS ISO 15175, BS ISO 15176 and ISO 15800.

7.8.3 Water testing design

The methods of analysis should be appropriate so that the implications for receptors, such as potable water aquifers, can be properly assessed.

Consideration should be given to the collection of data that could subsequently be needed for contaminant transport modelling, for example, pH, dissolved oxygen, redox, major cations and anions.

7.8.4 Gas testing design

[A1) Measurement of gas concentrations and gas and vapour samples for off-site analysis, should be carried out in accordance with BS 8576. (A1]

7.9 Quality assurance (QA) and quality control (QC)

7.9.1 General

QA/QC procedures should be applied at all stages of the investigation. The procedures applied should be capable of confirming the reliability and robustness of the investigation and the data produced, and should take into account:

a) the qualifications and experience of personnel carrying out the work (see **5.2.6** and **7.4**);

b) the qualifications, accreditation and experience of sub-contractors, such as drillers (see **5.2.6.2**), and laboratories (e.g. MCERTS [36] accreditation and UKAS accreditation in line with BS EN ISO 17025);

c) sampling and analysis QA/QC issues, e.g. calibration and accreditation certificates for field testing equipment, blank samples, duplicate samples and duplicate analyses (see Annex D and **9.3**);

d) recording of the work carried out and suitable means of data storage and transfer;

e) chain of custody procedures and sample handling, transport and storage;

f) reviewing and auditing of the work being carried out at all stages of the investigation, including reporting and interpretation.

NOTE 1 Guidance on the quality assurance of water sampling is contained in BS 6068-6.14.

NOTE 2 Two Environment Agency documents give advice on QA/QC for soil and water analysis [36,65].

NOTE 3 The list of MCERTS-accredited laboratories is given on the UKAS website (http://www.ukas.org).

7.9.2 The assessment and control of sampling uncertainty

Sampling uncertainty should be considered as part of every investigation, with thought given as to whether sampling uncertainty is to be quantitatively assessed.

NOTE Further information on quantitative assessment of sampling uncertainty is given in Annex D.

8 Fieldwork

8.1 General

Prior to carrying out a field investigation, the risks to the health and safety of the investigators and to other persons, property and the environment should be considered, and appropriate precautions taken (see **7.3** and Annex C). [A1] Investigations for permanent gases and VOCs should be carried out in accordance with BS 8576. [/A1]

NOTE Attention is drawn to the requirements of the Health and Safety at Work Act [22], the COSHH Regulations [19] and the CDM Regulations [18]. Specific guidance on health and safety during investigations on land potentially affected by contamination is provided in BS ISO 10381-3.

8.2 Techniques

8.2.1 General

The following techniques should be considered when designing a schedule of fieldwork:

a) non-intrusive techniques;

b) intrusive techniques.

NOTE Information on the advantages and limitations of the techniques is given in Table 5 and Table 6.

8.2.2 Non-intrusive techniques

The guidance of a suitably qualified and experienced person should be sought when designing a non-intrusive investigation to ensure that the most suitable methods are used and that the work is carried out at the most appropriate time in the overall investigation.

*NOTE See also BS 5930:1999+A2:2010, Clause **35**.*

*COMMENTARY ON **8.2.2***
Non-intrusive techniques include geophysical techniques, which are indirect methods of investigation that use the properties of subsurface materials, such as density and electrical resistivity, to indicate changes in ground conditions. These techniques may be used when layers or zones of ground have a contrasting property to the surrounding or overlying ground. The techniques can be used cost-effectively to locate features or anomalies in an area prior to further intrusive investigation by drilling or excavation, and can be used to produce three-dimensional models.

A geophysical investigation can help in the identification of irregularities and hidden features in the subsurface. These include:

a) edges of landfills;

b) changes in ground or groundwater conditions;

c) presence and extent of made ground;

d) buried objects or services;

e) location of foundations.

This can reduce the extent of intrusive ground investigation required. Geophysical measurements do not, however, remove the need for intrusive ground investigation.

Certain site conditions, such as a high water table, the presence of sub-stations and overhead power lines, buried obstructions and metal fencing, can limit the applicability of some geophysical techniques. The use of geophysical techniques requires preliminary research to establish the most appropriate technique for the specific investigation. Table 5 provides guidance on the major advantages and disadvantages of the different non-intrusive investigation techniques. Performance of the work and interpretation of the results has to be undertaken by suitably qualified and experienced specialists.

Table 5 **Methods of non-intrusive investigation**

Methods	Applications and advantages	Disadvantages
Conductivity surveys		
Use of a time varying electromagnetic (EM) field to induce a current, which creates a secondary field. Its strength is proportional to the ground conductivity.	Rapid reconnaissance method that can be used to interpret variations in groundwater quality and the presence of buried metallic objects. Qualitative processing for indication of disturbed ground. Can be used as a metal detector to about 3 m below ground level. Gives accurate estimates of terrain conductivity up to 100 mS/m.	For terrain conductivities above 100 mS/m, only a relative measure is possible. Can be affected by cultural "noise", e.g. buried and overhead cables, pipes or fences. Requires repeat measurements with different acquisition geometry for quantitative modelling.
Electrical resistivity surveys		
Measurement of apparent resistivities along a linear array of electrodes to produce an image-contoured two-dimensional cross-section.	Easy to use. Good resolution of resistive layers. Can be used to differentiate between saturated and unsaturated soils. Interpretation can provide profiles and depths of fill.	Contact resistance problems can be encountered in high-resistivity ground. Difficult or impossible to use on hard-standing ground cover. Coarsening of resolution with increasing depth.
Ground penetrating radar (GPR)		
Measurement of reflected microwave frequency EM radiation pulsed into the subsurface using an antenna. Equipment is drawn over the ground surface on a grid pattern.	Rapid acquisition of data, highly portable equipment. High resolution of near surface targets, including plastics pipes, metallic objects, voids and mines. Useful for detecting buried tanks. Can detect gross hydrocarbon contamination.	Poor signal penetration in conductive ground. Only suitable for relatively even ground. Can suffer signal interference through reinforced concrete and from adjacent foundations.

Table 5 **Methods of non-intrusive investigation** *(continued)*

Methods	Applications and advantages	Disadvantages
Magnetic profiling		
Measurement of the earth's total magnetic field intensity using one or more sensors. Gradient data are acquired by using two or more sensors simultaneously.	Rapid reconnaissance method for ferrous targets. Good lateral resolution facilitated by high sampling rates. Good resolution of shallow ferrous targets using gradient array.	Can be affected by cultural "noise", for example, buried and overhead cables, pipes, fences. Can be affected by temporal variations in the magnetic field and by non-ionizing radiation. Poor resolution of clustered deeper ferrous targets, e.g. drums at >3 m. Interpretation expertise required to model depths/volumes.
Microgravity		
Measurement of the changes in the gravity values arising from vertical and lateral density variations in the subsurface.	Survey can be undertaken in areas where cultural "noise" prevents use of EM and seismic surveying.	Slow production of data. Significant terrain corrections could be required for local anomalies in built-up areas.
Seismic refraction		
Measurement of compression (P) and/or shear (S) waves which have been critically refracted along an acoustic boundary and radiated back to surface. Seismic signal is detected using an array of geophones. Shock wave can be produced by hammer on steel plate.	Can be used for estimation of the thickness and depth of lithological units with different densities. Can be suitable for establishing the depth of groundwater table or vertical boundaries such as edges of old backfilled quarries. Can be used for shallow geological surveys.	Requires that seismic velocities increase with depth. Slow production of data. Requires careful use in a culturally noisy environment, e.g. with moving traffic or operating drill rigs. Poor lateral resolution.
Infra-red photography		
Detection of differences in reflected energy.	Can highlight distressed vegetation resulting from contaminated ground or landfill gases. Can be carried out using remote controlled model aircraft.	Results can be caused by natural effects, e.g. waterlogging or drought, and are subject to seasonal effects that influence plant growth. Results need to be interpreted with great care as camera angle can be affected by pitch and roll of the aircraft and the appearance of shadows. Height of the aircraft can be difficult to judge and can influence the results. Local air traffic controllers have to be consulted to check for any flying restrictions.

Table 5 **Methods of non-intrusive investigation** *(continued)*

Methods	Applications and advantages	Disadvantages
Infra-red thermography		
Detection of temperature differences in the ground that could be due to exothermic reactions in landfill sites or below-ground heating in coal-rich spoil tips.	Can be undertaken by helicopter, locally by crane-mounted hoists or by satellite for very large survey areas. Helicopter surveys are useful for examining several sites along proposed road developments.	Ideally carried out at daybreak in calm weather conditions when ground is not covered by snow or heavy frost. Local air traffic controllers have to be consulted to check for any flying restrictions.

8.2.3 Intrusive techniques

8.2.3.1 General

A suitable intrusive method of investigation should be selected based on considerations such as:

a) health and safety (Annex C);

b) environmental protection (**8.2.3.2**);

c) ground type (Table 6 and Table 9);

d) any requirement for permanent installations (Table 6 and Table 8);

e) depth of sampling required (Table 6 and Table 9);

f) contaminant type and form;

g) sample size required;

h) access/disruption constraints (Table 6 and Table 9);

i) cost.

*NOTE See BS 5930:1999+A2:2010, Clauses **13, 14, 19** and **20**, for further guidance.*

When there is uncertainty about the location of services, a "starter pit" should be hand-dug to about 1.2 m bgl before using a drilling technique. Checks should be made periodically for the presence of cables, etc., using an appropriate instrument. This can be a sensible precaution on sites even when services information is provided.

*COMMENTARY ON **8.2.3.1***
Intrusive investigations involve the collection of samples of soil, groundwater and ground gas and the monitoring of groundwater and ground gas, and can be carried out using a variety of techniques.

Environmental cones can be used for the detection and assessment of the distribution of suspected contaminants and for screening exercises and where ground disturbance needs to be minimized. Environmental cones could be suitable for investigation at shallow depth and in exploratory investigations.

Trial pits, augers, boreholes and driven samplers can be used to obtain samples for visual inspection and analysis. Where a monitoring installation is required this may be placed within a borehole.

All intrusive techniques involve some degree of site disturbance, the greatest with trial pits and the least with driven samplers and probing. Table 6 lists a variety of techniques that can be used to collect samples from required depths within the ground, with different degrees of accuracy and levels of representativeness. The advantages and disadvantages of these techniques are also given.

Table 6 **Methods of intrusive investigation**

Methods	Advantages	Disadvantages
Trial pits and trenches		
Can be formed by hand digging (to 1.2 m) or using wheeled or tracked excavators, depending on the requirements of the investigation. For health and safety reasons, trial pits cannot normally be entered unless shored. A suitably wide bucket is chosen according to the depth to be excavated, which allows a good view of the excavation but minimizes the amount of material excavated.	Allows detailed examination of ground conditions (in three dimensions). Easy to obtain discrete samples (where entry is appropriate) and bulk samples. Rapid and inexpensive. Applicable to a wide range of ground conditions. Can be used for integrated contamination and geotechnical investigations. Excavations and excavated material can be photographed. It is good practice to use an identifier board giving the trial pit reference and also a scale, e.g. surveyor's staff.	The investigation depth is limited by the size of the machine (generally, approximately 4.5 m) (see Table 8). Media are exposed to air and there is a risk of changes to contaminants and loss of volatile components. Not suitable for sampling below water. Greater potential for disruption of/damage to the site than boreholes/probe holes. Care is required to ensure that surrounding area is not affected by excavated spoil and that reinstatement does not leave contaminants exposed. Can generate more waste for disposal than boreholes. There is more potential for escape of contaminants to air/water. Might be necessary to import clean material to site for backfilling (to ensure clean surface).
Spike holes		
A small diameter hollow rod is driven to form a hole. Disposable tubing runs down the centre of the rod which connects to monitoring/sampling equipment.	Very cheap method of testing for the presence of soil vapours. Quick method of delineation and monitoring of near surface soil vapour concentrations. Easy to take samples. Allows assessment of immediate hazards.	Limited depth of penetration (typically 1.5 m to 2 m maximum). Negative result does not indicate absence of vapours at sample location. To be used in conjunction with other methods of soil vapour measurement (e.g. permanent monitoring wells).
Hand augering		
Many designs available for different soil types, conditions and sampling requirements. Preferred forms take a core sample.	Allows examination of soil profile and collection of samples at pre-set depths. Easier to use in sandy soils, i.e. where there are no obstructions such as stones. Portable and useful for locations with poor access.	Only limited depths can be achieved if obstructions present, e.g. stones. Ease of use very dependent on soil type. Can lead to cross-contamination from material falling down auger hole. This can be prevented by the use of plastics liners. Smaller sample volumes obtainable. Equipment can be physically difficult to operate. Samples are heavily disturbed

Table 6 **Methods of intrusive investigation** *(continued)*

Methods	Advantages	Disadvantages
Power driven auger boreholes		
Rotary drilling using solid stem auger.	Can achieve greater depths than hand augers. More rapid than hand augering for shallow investigations. Can be used to install shallow gas monitoring wells if hole remains open after withdrawal of auger.	Greater risk of physical injury to operator due to lack of guards and potential for snagging (due to obstructions). There is a need to avoid cross-contamination of samples and contamination due to fuel/ exhaust gases. Sampling is only possible when auger withdrawn and if borehole remains open.
Hollow stem auger boreholes		
Uses a continuous flight auger with hollow central shaft. Withdrawing centre bit and plug allows access down the stem for sampling.	Forms a fully cased hole avoiding potential problems of cross-contamination arising with cable percussion techniques. Soil samples can be taken through hollow stem allowing accurate estimation of depth. Can be used for installation of water and ground gas monitoring wells. Usually more rapid than cable percussion. Good recovery possible of very coarse samples (e.g. river terrace gravels) compared to cable percussion.	Less amenable to visual inspection of strata than cable percussion boreholes. Less suitable for deeper boreholes than cable percussion unless large rigs used.
Dynamic sampling using window or windowless sampling tubes		
Cylindrical steel tubes (often with an internal plastic sleeve) are driven into the ground by a percussive hammer. Hammers are usually mounted on small wheeled or tracked rigs, but may also be hand-portable. (Some dynamic sampling rigs are also capable of rotary drilling.)	Permits collection of continuous undisturbed samples. Can be used for installation of water and ground gas monitoring wells. Very compact rigs are available which can be used inside buildings or where space is limited. Can be used either for shallow sampling or at depths down to 10 m with appropriately sized equipment. Substantially faster than cable percussion. Does not require flush to be used, minimizing the risk of cross-contamination and waste generated. Effective at retaining volatiles, especially in cohesive soils where a plastic liner is used and because a relatively undisturbed sample can be cut from the extruded core.	Generally, poor recovery in dense sands and gravels, loose sands below the water table and certain types of made ground. Limited depth of penetration compared to other drilling methods, particularly for the smallest rigs. Sample volumes can be relatively small depending upon the diameter of the driven tube. A percussive hammer is noisy. Could be unsuitable in certain locations where noise is an issue. Cannot penetrate through obstructions (except where the drilling rig has a dual percussive and rotary capability). Can cause smearing of hole walls in some strata. Causes compression of some strata, e.g. peat. Holes not cased and could open up migration pathways. Casing can be inserted where the rig has adequate power and a removal system.

Table 6 **Methods of intrusive investigation** *(continued)*

Methods	Advantages	Disadvantages
Cable percussion boreholes		
Consists of a tripod derrick with a winch driven by a diesel engine. The cutting tool, which forms the borehole by gravity percussion, is attached to the winch via a steel cable. Steel casing can be used to support the borehole.	Allows greater sampling depth than trial pits or hand augers. Enables installation of permanent sampling/monitoring wells. Can penetrate most soil types. Less potential for adverse effects on above-ground environment than trial pits (but note there are potential risks to groundwater). Minimal surface disturbance Allows the collection of undistrubed samples. Allows integrated sampling for contamination, geotechnical and gas/water sampling and the installation of groundwater and ground gas monitoring pipes.	More time-consuming than trial pits and hand augers. Less amenable to visual inspection than trial pits. Waste from boreholes requires disposal and can cause surface contamination where groundwater or liquid contamination is present. Limited access for discrete sampling purposes. Smaller sample volumes than for trial pits. Can cause disturbance of samples and therefore loss of contaminants. Potential for contamination of underlying aquifers and groundwater flow between strata within an aquifer unless properly cased (see **8.2.3**). Samples from standing water can be subject to cross-contamination and therefore not representative of the groundwater (see **8.2.3.3**).
Sonic/Rota-sonic drilling		
Involves the use of high frequency energy which shears and displaces the soil particles. Two types of rig are generally available: sonic and rota-sonic. Rota-sonic combines rotary and sonic drilling capabilities in the same rig.	Permits at or near 100% core recovery in the majority of ground conditions. Faster drilling progress is possible where conditions permit compared with cable percussion boreholes. Permits recovery of undisturbed samples. The use of drilling flush is not always necessary. Rota-sonic drilling can penetrate all soil types and also hard rock, concrete and other obstructions (sonic drilling can be subject to refusal).	Some rigs do not have the ability to insert casing, which could result in the creation of migration pathways. Dry drilling (without flush) can result in heat being generated by the drill rod, which causes loss of volatiles. This can be reduced by changing the drilling process. Sonic drilling in weak rock can result in drilling-induced fracturing of the undisturbed samples, which could be of concern if an integrated investigation (see **7.2**) is required. Difficulties in measuring water strikes, particularly where water is used during drilling. Drilling flush requires containment and disposal.

Table 6 **Methods of intrusive investigation** *(continued)*

Methods	Advantages	Disadvantages
Cone penetration		
Static or dynamic	Some *in situ* testing possible (pH, redox, temperature and geophysical testing). No spoil brought to surface. Does not disturb groundwater. Can be used in conjunction with downhole monitoring equipment to provide field screening, e.g. remote laser-induced fluorescence meter for organic compounds.	Can be expensive. High mobilization costs for the most powerful equipment. Driving the probe can cause smearing of hole walls in some strata. Causes compression of some strata, e.g. peat. Poor recovery in non-cohesive granular material. The holes formed cannot be sealed to prevent cross contamination.
Environmental cones	Cost-effective method of delineating contamination plumes to enable effective targeting of sampling and monitoring wells. Push-in water sampling cones enable sampling from discrete layers. Can be used in conjunction with conventional cone penetration tests (CPT) to locate zones of high permeability, etc.	Not suitable for widespread, diffuse, solid contamination detection. Requires intrusive sampling to establish site correlation.

8.2.3.2 Environmental considerations

When selecting the sample collection technique, consideration should be given to preventing the creation of routes for migration of contamination (hence, spreading the problem and incurring liability). The migration of contamination can be exacerbated by the formation of preferential pathways within the ground, but the possibility of migration at the surface due to wind blow or exposure of contaminants should also be considered. In general, the deeper the sampling requirement, the greater the risk. All deep borehole sampling locations should be backfilled with clean, low permeability material (for example, bentonite grout), unless monitoring wells are to be installed. Techniques that form uncased boreholes should be avoided and monitoring wells or systems should have response zones that are sealed into individual aquifers or strata. Particular care should be taken where low permeability strata (aquicludes) are penetrated.

NOTE 1 The use of a double penetration technique (forming a larger borehole with, for example, a bentonite seal which is then penetrated by a smaller borehole through the seal) to prevent boreholes forming a contamination migration pathway is likely to be necessary where a low permeability stratum is penetrated.

NOTE 2 Guidance on the design and installation of groundwater monitoring points is provided in BS ISO 5667-22 and Environment Agency Science Report SC020093 [57].

When forming trial pits, the initial surface layer should be separated from other excavated material. Excavated material should be reinstated as closely as possible to the depth from which it was removed. The surface material should then be replaced to provide a cover.

In order to prevent the site surface becoming contaminated it might be necessary to place the excavated material on, for example, strong sheeting to prevent contact. The sheeting should then be safely disposed of on completion of the backfilling.

Reinstatement of the excavated material in a trial pit involves placing the material in layers and firmly tamping this down, for example, with the machine bucket. The material should be compacted as much as possible to minimize post-reinstatement settlement. Where the arisings are uncontaminated, excess material should be heaped over the trial pit so that the ground will settle to near its original level. In areas where vehicles are used and where reinstatement of trial pits could cause a problem, an alternative technique should be considered to ensure the area will accept likely loadings without settlement.

Care should be taken to ensure that the surrounding area is not affected by contaminated excavated spoil left after reinstatement. Excavated surface material should be replaced over the trial pit to provide cover and, if necessary, clean material should be imported to provide adequate surface cover on completion of backfilling.

Where there is a risk of contaminated groundwater or other liquid, e.g. oil, being brought to the surface, special care should be taken to prevent dispersal of the contaminated water or other liquid during the investigation and also during subsequent backfilling. Trial pits should not be excavated after water is encountered for this reason and also because the sides become unstable when the water table is reached in permeable strata.

For drilling methods requiring the use of water flush, the water should be contained at the surface to avoid cross-contamination and should be disposed of appropriately (see **8.2.3.3**).

NOTE 3 Where air flush is used during drilling, aerosols can be created which can distribute contaminants to a similar extent as water flush.

NOTE 4 Where impermeable cover (for example, a concrete hardstanding) has been penetrated it could be necessary to reinstate with a suitable low permeability cover to prevent the location becoming a source of ingress of rainwater, resulting in potential contamination migration.

Where there is surplus excavated material or arisings after backfilling, these should be disposed of with care; if necessary, being sent to a suitable disposal site.

Examination of a potentially contaminated site could pose a risk to the general environment. The work should therefore be planned to prevent the spread of contaminated material by site working clothes, samples, machinery and vehicle wheels. The creation of environmental nuisances such as noise and dust should be avoided.

8.2.3.3 Avoidance of contamination during sampling

Samples collected for analysis should be representative of the area or material being sampled (see **7.7.2**, **8.3.2**, **8.3.3** and **8.3.4**). Care should be taken to ensure that:

a) equipment and sample containers do not cause contamination or loss of contaminants due to adsorption or volatilization;

b) cross-contamination does not occur.

When taking samples below surface level at a site it is important that the sample is not affected by debris (soil or water) falling from more shallow depths. Thus, where trial pits are used the base of each pit should be cleared of debris before obtaining a sample of the material at the base. With a borehole or driven sampler the base of the hole should be cleared of debris before the sample is taken; otherwise, it could be necessary to reject material in the upper portion of the sampling tube which is potentially affected by debris.

Lubrication of casings and linings should be avoided as this could contaminate the equipment and sample. Where water has to be added to a borehole in order to assist the drilling process, only clean mains water should be used and the volume should be recorded. When lubricant is required to assist with drilling, an inert or non-contaminative type such as vegetable oil may be used, but complete records should be kept of the use of lubricants to allow consideration any potential effects on groundwater quality and on the results of subsequent chemical analysis of samples to be assessed.

During the investigation provision should be made for cleaning the equipment between sampling locations and more frequently, if necessary. Drilling equipment should normally be cleaned using, for example, pressure jet or steam-cleaning equipment.

If samples need to be taken by hand, clean gloves should, as a minimum, be used in between each sample. A hand trowel of stainless steel may, where appropriate, be used to place samples into sample containers. Prior to taking a sample, the sampling tool should be cleaned using, for example, deionized water (or alcohol wipes where organic contamination is present) to avoid cross-contamination.

NOTE 1 Further guidance is provided in BS ISO 10381-2.

NOTE 2 Contamination (or loss of contaminants) can occur, for example, due to the use of incorrect flexible tubing, incorrect plastic materials and the use of unsuitable metal in the sampling equipment or installations. The operation of equipment, due to poor maintenance, lack of cleanliness or carelessness during refuelling, can result in the contamination of samples due to exhaust fumes, lubricating oils or fuel.

8.3 Sampling

8.3.1 General

Site investigators should liaise with the laboratory carrying out the analysis to ensure that appropriate preservation techniques are used and that samples are presented in a suitable form and quantity for analysis.

Selection of suitable investigation methods should be carried out using Table 7 and Table 8.

Table 7 **Selection of suitable investigation method for different ground types**

Suitability of investigation method	Ground type			
	Natural ground			Fill/made ground
	Hard rock	Granular	Cohesive	
Boreholes	No [A)]	Yes	Yes	Yes
Trial pits	No	Yes [B)]	Yes	Yes [B)]
Dynamic sampling	No	Yes [C)]	Yes	Yes [D)]
Hand augers	No	Yes [B) C)]	Yes	Doubtful
Geophysics	Yes	Yes [E)]	Yes [E)]	Doubtful
Cone testing	No	Yes [F)]	Yes	Yes [D)]

A) Except by rotary coring or open-hole drilling, cable percussion chiselling or sonic/rota-sonic drilling.
B) Subject to stability of the ground.
C) Subject to grain size and degree of cohesion.
D) Subject to physical obstructions such as brick and concrete.
E) Guidance on effectiveness in certain ground conditions should be sought.
F) Except in very dense sands and in gravels.

8.3.2 Collection of soil samples

The samples collected should be of one of the types in Table 9 and be as representative as possible of the zone or material of interest at the location and depth being sampled.

When collecting samples for the determination of volatile compounds the sampling technique employed should minimize the loss of volatiles.

NOTE 1 A methodology for the collection of soil samples to minimize the loss of volatiles is given in BS ISO 18512:2007.

For a contamination investigation, a sample of 1 kg to 2 kg should be taken which should be adequate for most analytical suites. Where the sample is of coarse grained material, for example gravels, or is of a low density material such as spent oxide, a larger sample may be required. More sample than is required for the testing suite envisaged should be taken, in case additional, further or duplicate analysis is required [the sample should be stored appropriately in the interim (see **8.6**)]. The size of samples should be agreed with the testing laboratory to ensure that the sample is of an appropriate size. With smaller volumes of sample, it could be more difficult to ensure that the sample is representative. Larger samples could be necessary for geotechnical testing (see BS 5930:1999+A2:2010, Clause **22**) and for specialist testing (e.g. for volume instability in steel-making and old blast furnace slags). When surface samples (e.g. surface to 0.1m depth) are being taken, consideration should be given to taking "cluster" samples because these can reduce sampling uncertainties (see Table 9).

NOTE 2 Spent oxide is a waste found on coal carbonization sites and can contain a large proportion of wood fibre.

Table 8 **Physical requirements of different investigation methods**

Physical requirements	Investigation method									
	Excavator	Hand dug pit	Hand auger	Percussive sampler	Driven samplers		Borehole			
					Hand operated	Vehicle mounted	Cable percussion	Rotary	Sonic	Rota-sonic
Footprint required	20 m^2	3.0 m^2	1.0 m^2	$5m^2$-$15m^2$	2.0 m^2	20 m^2	30 m^2	30 m^2	$20m^2$	
Ease of surface penetration A)										
Concrete	Yes	No	No	No	Moderate	Yes	Moderate	Yes	No	Yes
Soil	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Compact aggregate	Yes	Moderate	Moderate	No	Yes	Yes	Yes	Yes	Yes	Yes
Depth restriction	4.5 m B)	1.2 m C)	1.0 m to 5.0 m	30 m	3 m	7 m	30m B)	None	30m	None
Restricted by height	Yes	No	No	Yes	No	3 m	Yes	Yes	Yes	Yes
Surface disturbance	Great	Small	Minimal	Minimal	Minimal	Moderate	Moderate to large	Moderate to large	Minimal to moderate	Minimal to moderate
Width restriction	Yes	1.0 m	1.0 m	Yes	1.5 m	Yes	Yes	Yes	Yes	Yes

A) Different techniques are available for breaking out the hardcover and any buried obstructions on a site. The technique selected should be determined by the nature of the hardcover/obstruction and the area necessary to breakout for the purpose of the investigation. A careful assessment of the risk to buried services should be made.

1) Hand-held power breakers may be used, but these require an experienced operator and a source of compressed air and are not appropriate for penetrating thick concrete (250+ mm) or below-ground obstructions. The impact of vibration effects on operators should be considered with this type of equipment.

2) In some cases the equipment selected for the site investigation could be capable of also breaking out.

- Cable percussion equipment can chisel through concrete (less than 100 mm thick) and tarmac. Rotary and rota-sonic drilling can penetrate reinforced concrete and obstructions.
- Excavators can be fitted with hydraulic breakers which can break through substantial thickness (up to 500 mm) of concrete.

3) A specialized coring drill could be required to drill a suitably-sized hole, particularly through thick concrete. This may be used for borehole and probing methods of investigation, but is not suitable for excavations. This method has the advantage of forming a neat hole, which can be easily reinstated to the original surface. With this method, risks to services cannot be reduced by hand excavation

B) Deeper with larger machines, but difficult to properly inspect and sample deep pits from the surface. Entry would require shoring and atmosphere verification.

C) Deeper with shoring.

Precautions should be taken to prevent samples undergoing any changes during sampling, including cross-contamination (see **8.2.3.3**), or during the interval between sampling and analysis (see BS ISO 18512:2007). Samples for biological testing should be taken in accordance with BS ISO 10381-6.

Disturbed samples may be taken by any of the three basic methods outlined in Table 9, since such samples do not require maintenance of the original ground structure. Such samples should be transferred to the appropriate sample container using an inert tool, such as a clean trowel.

Where loss of soil structure is likely to affect the subsequent examination, e.g. microbiological examinations, certain physical measurements and determination of volatile organic compounds, undisturbed samples should be collected.

Undisturbed samples should be taken either by a drilling method which is capable of obtaining undisturbed samples (see Table 6) or with a Kubiëna Tin [a small (c. 100 mm × 70 mm) metal box with removable ends used for micro morphology sampling]. The sampling device should be pushed into the soil and removed complete with the sample so that the original physical form of the soil is maintained as closely as possible.

Table 9 **Types of sample**

Type of sample	Uses	Means of sampling
Spot sample A sample of material collected from a single point (disturbed or undisturbed spot sample).	Suitable for identifying distribution and concentration of particular elements or compounds in geological or contamination investigations involving disturbed samples.	Samples can be collected using one of a variety of sampling techniques (see **8.2.3** and Table 6). Where undisturbed samples are required, specific drilling methods or special equipments (see **8.3.2**) are used to collect the sample whilst maintaining the original ground structure.
Cluster sample A representative sample formed from small incremental point samples taken within a defined area e.g. 1 m^2 (cluster disturbed sample) (see **7.7.2.4**). Material sampled is taken from within the same strata or from material with the same characteristics.	Suitable for identifying distribution and concentration of particular elements or compounds in geological or contamination investigations involving disturbed samples.	Samples are typically collected using hand tools on exposed surfaces but may also be taken from locations within a bucket of excavated material [for example, a nine point sample (see BS 10381-2:2002)].
Spatial composite sample A composite sample formed from evenly spaced samples of the same size taken over an area, which are then bulked together.	Not normally recommended for investigations of land potentially affected by contamination (see **7.7.2.4**). However, some jurisdictions specify the use of a form of composite sampling for the assessment of surface and near-surface soils.	Samples normally collected using auger, trowel or similar implement for speed and repeatability.

NOTE 3 Guidance on the size of sample required in relation to particle size grading and methods for sub-sampling to obtain representative sample is provided in BS ISO 23909 and BS 10381-8.

COMMENTARY ON ***8.3.2***
It is important to ensure that the sample is actually from the depth recorded and is free from debris which has fallen into the hole from shallower depths.

Samples collected for the purposes of investigating soil and ground conditions are generally disturbed samples. These are obtained from the ground without any attempt to preserve the soil structure, i.e. the soil particles are collected "loose" and are allowed to move in relation to each other.

Undisturbed samples are samples obtained from the ground using special sampling equipment or techniques to minimise the disturbance to the soil structure, i.e. the soil particles and voids are not allowed to change from the distribution that existed in the ground before sampling.

The term "undisturbed sample" is used to align this document with current British, European and International standards. It corresponds to "disturbed sample", as used in BS ISO 10381-2 and other soil quality standards.

8.3.3 Collection of water samples

8.3.3.1 General

Appropriate sample pre-treatment should be carried out to ensure that the sample is suitable for analysis of the phase (dissolved or free phase) of interest within the water body. For example, for analysis of the dissolved phase the sample should not contain suspended soil particles.

If organic materials (oils, solvents, etc.) are not present, the sample may be collected using a bailer. However, undue aeration of the sample (resulting in misleading dissolved oxygen results, or the induced oxidation of certain components) can occur if a top-filling bailer is used.

Surface water sampling should be carried out in accordance with BS EN ISO 5667-1, BS EN ISO 5667-3, BS ISO 5667-5 or BS ISO 5667-6.

Groundwater sampling should be carried out in accordance with BS ISO 5667-11. Care should be taken in the selection of appropriate equipment for sampling volatile contaminants, for example, peristaltic or inertial pumps can cause loss of volatile contaminants from the sample and filtering can also lead to the loss of volatile contaminants.

NOTE Water samples collected from trial pits and boreholes at the time of formation are unlikely to provide a reliable representation of groundwater quality due to the ground disturbance affecting the composition of the water. However, such samples can provide some preliminary information which assists in the design of a subsequent groundwater monitoring programme. The water can contain a substantial amount of suspended particles that require field filtration or settlement before analysis. To overcome this, a larger than required volume of sample may be taken to compensate for the volume of material that will be removed by settlement or filtration.

8.3.3.2 Monitoring wells

Where the potential or actual impact of contaminants on groundwater quality is an issue, monitoring wells should be installed.

A monitoring well should be perforated within the groundwater zone (saturated zone) over the depth of the zone which is to be sampled. Where samples are required from several depths, an open monitoring well (i.e. one that passes through several water horizons or a deep saturated zone) should not be used. An open monitoring well will allow mixing of different water layers and also the transfer of contamination. In such circumstances, several separate monitoring wells or a single multi-level sampler capable of measuring discrete horizons should be installed.

Where the monitoring well penetrates deep into the saturated zone the perforations may be limited to the lower part of the well. In most situations, the perforated pipe section should be surrounded with screening material. The screening material should be inert, clean and of a suitable pore size to avoid blockage, but prevent ingress of suspended particles that can cause build-up of sediment in the well. A geotextile wrap should be applied to inhibit ingress of fine particles into the well when this is considered likely (this might be a problem, for example, if 10% of the formation material is finer than 2mm). The effects of the screening material on the measurement of aquifer properties should be assessed, e.g. if permeability tests are to be carried out on the monitoring well. A grout seal should be placed around the unperforated well pipe above the screened sampling zone to prevent migration of contaminants via the well, if present (see also **7.7.3.4**).

Where light non-aqueous phase liquids (LNAPL) are present, the screen intake of monitoring wells should extend from just above to below the full distance of water table fluctuation. Where dense non-aqueous phase liquids (DNAPL) contamination is suspected, monitoring points should penetrate the full thickness of the permeable strata.

The sampling well should be constructed from materials that do not react with, and that do not release or adsorb, contamination.

NOTE BS ISO 5667-22 and Environment Agency Science Report SC020093 [57] also give guidance on the design and installation of groundwater monitoring points.

8.3.3.3 Well cleaning and development

After installation, monitoring wells should be developed using a pump, bailer or surge block to remove any materials or contaminants that might have entered during installation (see also BS ISO 14686). This development should also settle the granular surround and ensure free flow of liquids through the well screen. The rate of pumping should be substantially greater than that proposed for subsequent purging or sampling. Development should continue until the water is visibly clean and/or of constant quality, e.g. in terms of its electrical conductivity.

Adequate provision should be made for the disposal of contaminated water from monitoring wells resulting from well development and purging operations (see **8.3.3.4**).

Samples of groundwater should be collected after allowing sufficient time for equilibrium to be reached. At least 14 days should be allowed for equilibration, but when this is not possible the time allowed should be as long as practicable.

NOTE The use of cement/bentonite or similar materials in monitoring well construction can affect the water chemistry, e.g. pH. A sufficient equilibration period and the use of alternative materials minimize the likelihood of any such effects occurring.

8.3.3.4 Purging

One of the most important aspects of monitoring is to collect a representative sample. Water within a monitoring well that has not been recently purged is not always representative of water in the surrounding strata for a variety of reasons, including oxidation and loss of volatiles. Purging should therefore immediately precede any sampling, to remove stagnant water.

The impact of purging should be assessed alongside the benefits of improved sample integrity.

NOTE 1 Where contaminants are present at discrete locations or free phase contamination involving LNAPLs and DNAPLs is present, purging can redistribute or spread the contaminants. This can lead either to misleading results or an exacerbation of the initial problem. In such cases micro-purging (see Note 3) may be considered. In addition, or alternatively, samples of pre- and post-purge water may be collected during the early stages of an investigation to compare results. This information can then be used to optimize subsequent sampling.

Purging should be undertaken at a flow rate less than that used for development of the well and greater than that proposed for sampling. The volume of water to be purged should vary according to the monitoring well type, its construction and the hydrogeological conditions.

The purge volume will be dependent on the design of the monitoring point, e.g. the diameter and depth of the water column. The water level should therefore always be measured prior to purging. Additionally, measurement of the water level during purging can give an indication of the drawdown.

NOTE 2 For the purpose of this standard the well volume is the volume of water within a standpipe and the gravel pack surround.

To ensure that purging has been effective, monitoring of chemical parameters, such as electrical conductivity (EC), pH, temperature, redox potential (Eh), dissolved oxygen (DO) turbidity and specific parameters, should be carried out during the purging operation. A flow cell may be used for measurement of these parameters. As a minimum, EC should be measured.

NOTE 3 Guidance on groundwater purging volumes and strategies is provided in BS 6068-6-11:2009.

NOTE 4 If the well purges dry prior to sufficient water being removed, it might need to be sampled at a later date to allow it to recharge.

As purging can generate large quantities of potentially contaminated groundwater requiring disposal or affect contaminant distribution in the ground, the use of low-flow purging or micro-purging may be considered as an alternative in order to reduce disposal volumes.

NOTE 5 Low-flow purging or micro-purging is where the water column above the pump intake is not disturbed and water is drawn locally at a very low flow rate. Purging by this means may be carried out using a non-displacement pump (such as a bladder pump) at a flow rate that minimizes drawdown to the system. Typical flow rates at the pump intake for both low-flow purging and sampling are in the order of 0.1 L/min to 0.5 L/min, depending upon the site-specific hydrogeology.

When using micro-purging techniques, purging should continue until successive readings of conductivity, pH and temperature have stablilized.

NOTE 6 The time or purge volume required to achieve stablilzation when micro-purging is not related to the well depth or well volume.

Micro-purging should be carried out using dedicated pumps, as passing a pump through the water column causes mixing and disturbance. Bailers, grab samplers and inertial pumps should not be used for micro-purging.

Water level and depth of well measurements should be taken after sampling in order to avoid disturbance of the water column.

8.3.3.5 Sampling

Samples may be taken by pump, bailer, depth sampler or similar device depending on the depth of the groundwater and the parameters to be determined (for further guidance, see BS 6068-6-11). Where a permanent sampling pump is installed, samples of groundwater can be readily collected at intervals over a period of time, for example, to identify gradual changes in groundwater quality.

Disposable bailers may be used to avoid cross-contamination.

If oil or other immiscible liquids (LNAPLs) are present floating on the water, the thickness of the floating layer should be measured with an interface meter and the floating product sampled prior to purging (if purging is appropriate given the presence of free-phase contaminants, see **8.3.3.4**). A sample of the free phase product layer may also be taken for examination.

NOTE 1 The thickness of a LNAPL floating in a monitoring well can be greater than the actual thickness of the layer in the aquifer due to the tendency for accumulation to occur in the well.

Due to the nature of DNAPLs, the detection of free-phase liquid can be difficult unless supporting evidence and data can focus the investigation. Sampling for DNAPL should be carried out using a bottom-loading bailer.

NOTE 2 The thickness of DNAPL in a well can be measured using a weighted oil-water interface probe.

It is difficult to obtain a sample that accurately represents the proportion of free phase product to water. It could be appropriate to collect a sample of the water above or beneath the free phase product for analysis of dissolved content (using a depth sampler or permanently installed pump, for example, an inertial pump). When sampling through the thickness of oil or other immiscible liquid, a "vertical" column sample should be taken using a sampling tube. The tube should be inserted to a measured depth and sealed at top and bottom before removal. The sampling device should then be returned to the laboratory for analysis due to the difficulty of removing the oil quantitatively.

Samples of groundwater should be analysed for pH, dissolved oxygen, temperature and conductivity in the field. Other parameters, for example nitrite, may also be determined in the field. The advice of the analytical laboratory should be obtained, and the laboratory should be informed of any field results.

Where it is necessary to obtain samples of pore water in the unsaturated zone, special equipment, such as a piezometer with a ceramic or plastic tip, should be installed. Care should be taken to avoid the installation penetrating the saturated zone. Alternatively, a large undisturbed soil sample may be collected and the pore water removed by filtration, or by using a diaphragm or centrifuge.

When sampling waters for dissolved gases such as methane, the samples should be taken with a minimum of disturbance using a peristaltic pump or equivalent sampling device. The samples should transferred to a container having no headspace.

Special sampling and sample preservation techniques should be used when sampling for certain contaminants, e.g. VOCs (such as solvents), inorganic compounds which are affected by oxidation (iron and sulfides) or exhibit volatility (cyanides), and metals which could require filtration and acidification on site. Some guidance is given in BS EN ISO 5667-3). The analytical laboratory should be informed of the special sampling and sample preservation techniques used.

8.3.4 Collection of gas samples

Detection and determination of vapours and gases may be undertaken by (see **7.7.4**):

a) monitoring in the field;

b) sampling the ground gas and subsequent analysis in the laboratory or field.

[A1⟩ The guidance in BS 8576 should be followed when collecting gas samples for off-site analysis. ⟨A1]

8.3.5 Collection of samples of slag for expansion tests

When slags are to be sampled for expansion tests specialist advice should be sought. These tests commonly require samples of about 50 kg or more to be taken.

NOTE Some steel slags (both current production and old) and some old blast furnace slags can expand. This expansion can occur decades after the slag has been deposited and can be triggered by disturbance that admits water and air, or by changing water levels (e.g. following a burst water main). Modern blast furnace slags are, however, inert stable materials. Information and guidance can be found in the Environment Agency Technical Reports P5-035/TR/01 [67] and P331 [68].

8.4 Field testing

In most investigations, the samples collected from the site should be sent to a laboratory for detailed examination and the production of robust analytical data. There are, however, some occasions when testing may be carried out on the site itself, including:

a) the detection and initial assessment of contaminants (such as toxic or flammable gases and volatile solvents) at locations identified during the preliminary investigation and which could present hazards for further work on the site;

b) the determination of concentrations or properties that can alter between collection and laboratory analysis, e.g. pH, redox potential, dissolved oxygen content, electrical conductivity, or turbidity of liquid samples;

c) the rapid analysis of soil, fill materials or groundwater excavated during site clearance, development or remediation (in order to inform decisions on disposal or retention);

d) the initial delineation of possible localized areas of high concentrations of contaminants;

e) screening of a large number of samples to reduce the number of samples which require more comprehensive laboratory analysis, for example, screening soil samples for VOC using a photo-ionization detector to ensure that only samples of relevance are submitted for analysis;

f) helping to determine the positions of further sampling points.

NOTE A description of commonly used field measurement methods is provided in Annex F. ISO 12404 (in preparation March 2011) also *provides guidance on the selection of rapid field (screening) methods of analysis and guidance has also been published by the Environment Agency (EA 2009 RMT [69]). The uncertainty of field measurements can be estimated using the duplicate method (Annex D).*

8.5 Sample containers

Any sample container used should not cause contamination of the sample, should not absorb any sample components (for example, organic compounds) and should not allow losses of volatile components.

NOTE 1 The containers usually used for routine work with soils are plastic (polyethylene or polypropylene) tubs with fitted lids, with a capacity of 1 kg to 2 kg of solid sample. Guidance on the suitability of sample containers is given in Annex H.

Different sizes and types of container should always be available on site so that if unexpected materials are encountered they can be properly sampled.

Where organic compounds are to be determined, inert containers, which prevent loss by absorption or volatilization, should be used. Where no VOCs are present a wide-mouthed amber glass jar may be used, but if VOCs are present, the container should not only keep the samples secure, but also allow the sample to be accessed for analysis without loss of volatile components. Screw caps with a pierceable septum may be used where headspace analysis is to be carried out. The laboratory carrying out the analysis should be consulted before selecting the container.

Water samples should be collected in PET (polyethylene terephthalate) bottles (or polyethylene/polypropylene bottles if acidification is needed for sample preservation), or in amber glass bottles where organic compounds are to be determined. Water samples could require the addition of chemical preservatives for some parameters of interest and these will require separate and appropriate dedicated sample containers. The laboratory carrying out the analysis should be consulted before selecting the container.

NOTE 2 Failure to provide samples in suitable containers, with prescribed preservatives, within laboratory defined holding times will result in them being classified as deviant on any report issued in accordance with ISO 17025, and could result in the cited results being considered invalid.

NOTE 3 More information on appropriate sampling procedures, preservatives and containers for waters is given in BS ISO 5667-1 and BS ISO 5667-3.

8.6 Sample labelling, preservation and handling

Sample handling and preservation for soil samples should be carried out in accordance with BS ISO 18512.

Once a sample is obtained, it should be clearly and uniquely labelled, for example on the side of the container and the lid (but not on the lid alone).

One of the following labelling methods should be used:

a) tie-on labels or adhesive labels (providing there is adequate adhesion of the label under field conditions);

b) writing directly on the sample container.

The labels used should be resistant to external influences (rain, contamination, etc.) and to future treatment (abrasion, handling, contact with chemicals, etc.). The labels should be large enough to contain all the relevant information in a legible form. Some commercially available adhesive labels and marker pens contain organic solvents, so care should be taken to avoid absorption of these solvents.

NOTE 1 Absorption of organic solvents is not likely to be a significant problem with soil samples, but in the case of gas or water samples can result in contamination of the sample.

NOTE 2 Some analytical laboratories operate a barcode scanner system, where pre-labelled bar-coded containers are provided together with a barcode scanner, which can be used to record the sample details on site.

Before samples are dispatched from the site (and also upon receipt at the laboratory), the details on the container (and lid if necessary) should be checked against the sample report and chain of custody documents.

The preservation and handling of water should be carried out in accordance with BS EN ISO 5667-1, BS EN ISO 5667-3 and BS 6068-6.14.

The laboratory performing the analysis should be consulted before sampling to ensure that appropriate preservation and handling techniques are used and that any requirements specific to the analytical method can be taken into account.

NOTE 3 Additional specific guidance on groundwater samples and the potential physical and chemical changes that can occur is provided in BS ISO 5667-3, BS ISO 5667-11 and BS ISO 18512.

Preservation and handling of soil and other solid samples should generally be dealt with on a method-specific basis. If not all potential contaminants have been identified prior to sampling, soils should be refrigerated at (5 ± 3) °C and kept in darkness during storage and transit to the laboratory. When cooled, the samples are more likely to retain their field composition and properties.

All staff who handle samples, including any labelling and packaging, should be aware of their nature and possible hazards resulting from their handling. Samples should be transported to the laboratory and scheduled for analysis as quickly as possible to minimize any potential for chemical and biological changes before examination, and in any case within 24 hours for time-dependent analytes such as COD and BOD.

NOTE 4 Certain sample types require certain permits and/or have to conform to packaging rules. For example, samples suspected of containing biological hazards, radioactive hazards or asbestos.

8.7 Sampling report

The person taking the samples should record details of the samples at the time of collection, for example, whether they were targeted or non-targeted, in accordance with the requirements of the investigation.

The ground strata should be described in the field during the formation of the trial pit, auger, borehole or probe hole. Location within the site should be recorded as the samples are taken. The descriptions of ground used for recording the strata should conform to the categories used in BS EN ISO 14688, but should also include any additional observations that are relevant to the contamination investigation. Descriptions of made ground should be formed in accordance with BS 5930:1999+A2:2010, **41.4.5**, or BS EN ISO 14688. If additional or special samples are taken, the reasons should be recorded. A description of each sample taken should also be recorded.

Where a scheduled or pre-arranged sampling location could not be used, and an alternative location was used, the actual location should be noted and the reason for the relocation stated.

Any other field observations should also be included in the report, as these can be useful in the subsequent interpretation of analytical data. Where gas sampling has been carried out, the various observations required (see **8.3.4**) are particularly valuable and should be recorded on site and as a part of the sampling report.

The following information should be included, as appropriate, in the sampling report.

a) Location and name of the sampling site with coordinates and other relevant locational information, including ground levels.

b) Details of the actual sampling locations, including coordinates and depth.

c) Date of collection.

d) Method of collection.

e) Time of collection.

f) Name of collector.

g) Weather conditions.

h) Nature of any pre-treatment.

i) Barometric pressure.

j) Ambient temperature.

k) Any other data or observations gathered during the sampling process.

9 Off-site analysis of samples

9.1 General

Methods validated for the analysis of contaminated sites should be used whenever possible.

The specific parameters that the laboratory is commissioned to analyse should be agreed in advance. Consultation with an analytical laboratory (preferably the one that will eventually carry out the chemical testing) is advisable to assist in the selection of appropriate testing methods. It is good practice to comply with the MCERTS standard [36] (where relevant). Methods should be validated for all relevant soil or water matrices. The method used should be able to determine the contaminant(s) of interest with adequate accuracy and precision, over the concentration range expected to be present as outlined in the MCERTS standard [36].

NOTE 1 Under MCERTS, "total" analyte measurements can be carried out by any fit-for-purpose fully validated method, e.g. manganese in groundwater can be competently analysed using flame atomic absorption spectrometry (FAAS), ICP-OES or ICP-MS techniques to obtain equivalent results.

The results from an empirical method critically depend upon the method protocol adopted [e.g. biochemical oxygen demand (BOD), chemical oxygen demand (COD), leaching tests]. Many empirical methods represent a partial extraction/measurement of the analyte from the sample matrix. These leaching tests need very prescriptive unambiguous extraction protocols in order to obtain consistent and reproducible results. For many water leaching tests significantly less than 1% of the "total" analyte concentration is extracted.

Thus, for the empirical part of a method (e.g. leaching or bioavailability testing) it is essential that a documented standard protocol is used and closely followed. This might include sample pre-treatment, shaking apparatus and its operating conditions, leaching temperature, etc. The actual final "total" measurement stage (e.g. FAAS, ICP-OES, ICP-MS) of the relevant analyte in the actual leachate solution does not need to be prescribed as long as it is suitably validated.

The test method should provide a detection limit substantially below the concentration of interest for a given parameter. Ideally, the detection limit should be at least ten times lower than the concentration of interest, but this is not always possible for certain organic contaminants, especially when testing water samples.

NOTE 2 Further information on method verification, MCERTS and analytical methods is provided in Annex G. MCERTS accreditation of soil testing is required by the Environment Agency in England and Wales and many local authorities.

Where several analytical methods are available for the determination of a particular parameter, the choice of method should take into account chemical interferences and matrix effects. The choice should be based upon the ability of the selected method to determine the contaminant of interest with adequate accuracy and precision, over the concentration range expected to be present.

Whenever comparisons are to be made with formal guidelines or standards, the specified analytical methods (if any) should be employed.

NOTE 3 Variation from any previously agreed method can only be justified if the alternative technique can be demonstrated to have an equivalent performance and that its use will not significantly influence the interpretation or risk assessment outcome.

Guidance on suitable methods of analysis for particular substances should be drawn from authoritative texts. However, the principle of fitness for purpose has to be applied to any method chosen.

*COMMENTARY ON **9.1***
There is a wide range of methods for the determination of chemical, physical and biological characteristics of soil and water (see the "Further reading" section of the Bibliography). Suitable methods of soil testing for civil engineering purposes are contained in BS 1377 and the characterization and measurement of air quality are contained in BS 1747 and BS 6069.

Further guidance on methods suitable for the analysis of samples from potentially contaminated sites can be found in the following publications.

a) Methods for the Examination of Water and Associated Materials, *published by the Environment Agency Standing Committee of Analysts [70].*

b) Methods for the determination of hazardous substances*, published by the Health and Safety Executive [71].*

c) Special Digest 1, published by the Building Research Establishment [72].

d) BS EN 12457-1, BS EN 12457-2, BS EN 12457-3 and BS EN 12457-4.

e) ISO TC 190 Series on soil quality (http://www.iso.org/iso/iso_technical_committee.html?commid=54328).

9.2 Choice of laboratory

The laboratory chosen should be competent in the analyses to be carried out. Competence can be demonstrated by third party accreditation (e.g. UKAS BS EN 17025 accreditation), but it should be noted that such accreditation is usually on a method-specific basis. A check that the laboratory is specifically accredited for the test parameters of interest should be undertaken before commissioning any analysis.

*COMMENTARY ON **9.2***
A laboratory's accreditation can be checked on the UKAS website (http://www.ukas.org/testing/). It is desirable that the laboratory participates in external proficiency testing schemes relevant to the work being commissioned and uses reference materials to validate and check analytical methods (note that this is a requirement of any laboratory participating in the MCERTS scheme). Obtaining brief method statements for the proposed method of analysis gives an opportunity to check that it will be possible to interpret results correctly at a later date. Guidance on the requirements for competence of testing laboratories is provided in BS EN ISO 17025 and in the MCERTS standard [36].

9.3 The assessment and control of uncertainty in sub-sampling and analysis

9.3.1 Sub-sampling uncertainty

Where a heterogeneous sample is submitted for analysis, the component parts should be recorded. Any material removed from the sample should be described, photographed (if feasible) and recorded as a percentage of the sample.

Procedures for the preparation (drying, grinding, etc.) or stabilization of samples, where appropriate, should normally be carried out in the laboratory before a portion of the homogenized sample (i.e. the sub-sample) is taken for analysis (see **9.5**).

Care should be taken to avoid cross-contamination during preparation to prevent uncontaminated samples being adversely affected by highly contaminated samples.

Measurement uncertainty arising from sub-sampling procedures should be quantitatively assessed in exploratory and main investigations when this is suspected of being a significant cause of the overall measurement uncertainty (see Annex D, Eurachem/EUROLAB/ CITAC/Nordtest/AMC Guide, *Measurement uncertainty arising from sampling* [73]).

*COMMENTARY ON **9.3.1***
Samples submitted to the laboratory could require preparation or pre-treatment. It can be relatively straightforward to prepare a representative sub-sample if the whole sample can be dried and ground, for example for metals determination. However, it is much more difficult if it is a wet heterogeneous sample (for example, a mixture of clay and granular ash) for the determination of volatile components.

Loss of any components whilst preparing a sub-sample can result in misleading results. Where volatiles are to be analysed, it is advisable to collect the original sample (a known amount) into a known volume of solvent for subsequent analysis. Guidance is provided in BS ISO 18512.

Some SVOCs can vaporize at comparatively low temperatures. For example, naphthalene sublimes at normal ambient temperatures (i.e. the solid changes to vapour), although it does not melt until 80 °C. Consequently, if samples containing naphthalene are allowed to heat up in the field or the laboratory, loss as vapour will occur.

9.3.2 Analytical uncertainty

The analytical laboratory should be asked to demonstrate that the methods used are validated for the analysis of contaminated sites and are suitable and appropriate to the needs of the investigation. The analytical laboratory should also be asked to demonstrate that adequate quality control procedures are applied routinely to the methods in use and that the performance of the method is well established.

In the absence of suitable certified reference materials for quality control procedures, recovery estimates relevant to the matrix and parameter under investigation should be determined by spiking experiments at the laboratory. Where possible these experiments should cover the entire method (including pre-treatment, extraction and determination). The laboratory should demonstrate that its use of spiking experiments and the spiking procedures employed are appropriate.

NOTE 1 The addition of a parameter to a sub-sample followed by immediate extraction is not a satisfactory test for estimating spiking recovery, as sufficient time has to elapse to allow possible matrix-parameter interactions to occur.

In order to ensure traceability, the analytical report should include details of the quality control procedures adopted for the analyses reported. This should include the analysis of control samples, reference samples and blanks, as well as:

a) the location of the sample, including depth where necessary;

b) the unique sample code or reference;

c) the date and time the sample was taken;

d) the name of laboratory;

e) the name of any sub-contracting laboratories, if used;

f) the date sample analysis was completed;

g) the parameter analysed, including whether the sample was preserved or stabilized at the sampling site;

h) whether the analysis was carried out on naturally or forced air-dried samples at a specified maximum temperature or on an "as submitted" basis;

i) the result of analysis on dry-weight basis;

j) any other relevant comments, for example, visual characteristics of the sample.

The analytical laboratory may be requested to produce a data quality report containing the results of all quality control procedures run with a particular batch of samples.

NOTE 2 Further guidance on analytical quality control for water analysis can be found in DD ENV ISO 13530. Errors associated with the use of analytical methods are usually well documented and less significant than the variability associated with sampling and sub-sampling (see Annex D). However, when analytical data are reviewed they ought to be checked critically for consistency (questioning whether the data correspond with the sample description, etc.).

NOTE 3 If a statement of uncertainty for the tests is required it is prudent to discuss this need with the laboratory prior to submitting samples, in order that appropriate reporting arrangements can be made in advance. Delays can be encountered due to requesting such reports retrospectively from modern laboratory information management systems.

9.4 Selection of contaminants for analysis

Selection of the parameters to be included in the analytical programme should be based on the objectives of the investigation, the conceptual model and on any observations made during subsequent investigations and sampling.

The analytical programme selected should also take into account the potential for migration from off-site sources to affect the site.

The specific analytical programme for a particular site should only be decided upon after detailed consideration of the site history in conjunction with information sources that provide information on likely contaminants, e.g. Industry Profiles (see the "Further reading" section of the Bibliography).

Testing or retesting of retained samples should only be carried out where preservation and handling techniques that prevent deterioration have been used (see BS ISO 18512).

NOTE 1 Further guidance on the selection of contaminants and methods for soil analysis is given in ISO DIS 11504, BS ISO 15175, BS ISO 15176 and ISO 15800.

NOTE 2 The use of laboratory and field screening techniques can form part of a detailed and site-specific analytical programme (see Annex F and Annex G).

9.5 Preparation of samples for analysis

9.5.1 Soil samples

A visual examination of the sample should be made during the preparation stage, and any unusual features noted and brought to the attention of the analyst. These observations should supplement those made in the field, which could have been made in difficult working conditions.

Laboratory samples should be prepared in accordance with BS ISO 11464 or BS ISO 14507, as appropriate, unless there are method-specific requirements (e.g. because otherwise the chemical form might change or volatiles be lost). Any deviation from the agreed method should be recorded and explained in the analytical report.

NOTE 1 Guidance on the pre-treatment of samples by freeze-drying is provided in BS ISO 16720.

The laboratory report should include a description of, and the percentages of, material removed from the sample submitted to the laboratory, and whether this material has undergone separate analysis.

When the sample is unstable and cannot readily be stabilized, preparation and analysis should be carried out as soon after collection as possible and the reason recorded.

NOTE 2 BS ISO 18512 provides guidance on the storage of soil samples and includes a table of maximum soil storage times dependent on the chemical test objective and condition of the sample. BS ISO 10381-6 provides guidance on the storage of soil samples for the assessment of microbiological parameters.

The method to be used for leaching tests should be agreed between all parties who could be involved in subsequent discussions arising from the results. BS EN 12457 details the methodology for leaching tests on waste materials. Similar methodologies for leaching tests for subsequent chemical and ecotoxicological testing of soils materials are provided in BS ISO 18722 (the sample preparation differs from that in BS EN 12457). The exact procedure described in BS EN 12457 or BS ISO 18722 (as appropriate) should be followed as even minor changes can lead to significant variation in the results obtained.

*COMMENTARY ON **9.5.1***
Samples from a potentially contaminated site can contain a variety of materials, including ash, brick and stones. If any components are particularly absorbent or abundant (for example, non-geological materials), they could require separate analysis.

Analytical laboratories do not all follow the same sample preparation procedures. An understanding of the actual procedure followed might be important for later interpretation of the results.

9.5.2 Water samples

The need for physical pre-treatment prior to analysis is dependent on the nature of the sample and the purpose of the analysis, for example, for the determination of metals in solution, filtration is necessary typically using a 0.45 µm filter. This should be carried out in the field, followed by acidification of the filtrate with appropriate fixing agent.

When using filtration techniques, consideration should be given to the potential for filters to release compounds, such as ammonia or nitrate.

Removal of oil, with separate analysis of oil and water, can be appropriate (see **8.3.3.5**). If carried out, the relative volumes should be determined before separation.

NOTE 1 The requirements for pre-treatment differ according to whether the sampling is part of a long-term monitoring programme, or to assess water quality for disposal purposes.

Where any pre-treatment is carried out on site, it should be clearly identified on the sample container and within any sample records so that the analysing laboratory is fully informed.

As a matter of good practice, but particularly where unstable contaminants are present, precautions should be taken to minimize physical, chemical and biological reactions within the sample and to undertake analysis without delay. In many cases, the preservation technique of cooling the sample to between 1 °C and 5 °C is sufficient.

NOTE 2 Guidance on the preservation of water samples is given in BS EN ISO 5667-3, BS 6068-6.3.

9.5.3 Gases and vapours

When determining gases or vapours, ground gas samples should be analysed directly using appropriate instrumentation, or absorbed into liquids, or adsorbed on to solids prior to analysis or identification of individual constituents, in the laboratory. The adsorption/desorption method can introduce bias (for example, due to incomplete recovery of the vapour), so account of this should be taken when reporting results.

NOTE 1 Suitable methods for the analysis of ambient air are given in BS 1747 and BS 6069-6.3.

[A1⟩ *NOTE 2 Further guidance on determining gases or vapours can be found in BS 8576.* ⟨A1]

9.6 Sample screening

When selecting a screening method for use either within the laboratory or for use in the field, the capabilities and limitations of the method should be clearly understood.

NOTE For example, use of chemical oxygen demand determination for organic contamination of water is not sufficiently sensitive to identify an unacceptable pesticide content.

Test kits should be validated for the purpose for which they are being used, for example, a test kit validated for water testing should not be used for soils leachates until verification for this purpose has been successfully completed.

*COMMENTARY ON **9.6***
*Screening tests may be used to produce a rapid indication of the presence of a specific compound, closely-related compounds or a group of compounds. Some of these methods are suitable for field application (see **8.4**) and others can only be carried out within a laboratory facility. Laboratory screening methods are normally more accurate. Laboratory analysis is discussed further in Annex G.*

10 Reports

10.1 General

There can be substantial differences in report content depending upon whether it covers the preliminary, exploratory and/or main investigation, and whether it is factual or includes interpretative aspects. However, the general layout of reports should follow a broadly uniform style with details of the work covered logically.

Factual information should be clearly separated from interpretative material, whether in the same volume or produced as separate volumes. If split into two volumes, the factual report may describe the work carried out, any field observations and the analytical data, together with any other relevant factual information. A separate interpretative report may then be produced giving details of the risk assessment carried out or detailed remediation proposals.

Where a simple interpretative report is required, the two aspects of reporting may be incorporated into one volume.

Preliminary and field investigation reports should be prepared in accordance with **10.2** and **10.3**, respectively. The recommendations of **10.3** principally apply to the structuring of a factual field investigation report, though the underlying principles are the same for interpretative field investigation reports.

If a parallel investigation has been carried out, for example a geotechnical investigation, these may be reported as separate entities, although it can be convenient in some instances to cover the preliminaries together in the first chapters of the factual report.

Regardless of the report structure, the report should be properly cross-referenced.

Reference should be made to any specific regulatory requirements, e.g. a Planning Condition requiring a preliminary investigation and/or a field investigation (exploratory or main investigation), and a description provided as to how these have been addressed. The report should make clear which element(s) of a complex regulatory condition is being addressed and whether the design was approved in advance by the appropriate regulator. Relevant correspondence with regulators should be referenced and, where appropriate, included in an annex.

NOTE Conditions relating to contamination frequently have a number of elements. For example, the requirement for a field investigation might be dependent on the outcome of the preliminary investigation. They also frequently require the consent of the Local Planning Authority to the design of the investigation.

The report should record the need for any urgent action to avoid danger to human health or the environment, irrespective of whether the responsible party(ies) has already been informed of this.

10.2 Preliminary investigation report

The preliminary investigation should be reported in such a way that the conceptual model stands out as a clearly recognizable element.

The preliminary investigation report should contain:

a) information collected on past and present uses of the site, together with details on geology, archaeology, ecology, hydrogeology, hydrology and geochemistry; a list of all sources that have been consulted, even if no useful information was obtained; indications of any possible gaps in the information that has been obtained;

b) a discussion of the information obtained, leading into a description of the contamination-related hypotheses that have been formulated, including conclusions about the presence (or absence), type, spatial distribution and nature of the contamination, and details of any division of the site into sub-areas or zones for which different hypotheses have been formulated;

c) conceptual model (see **6.3.1**);

d) in the case where contamination is suspected (or not as the case may be) the arguments that support this suspicion, and, where relevant, the following:

   1) the nature of the contamination and its source(s);

   2) the manner in which the contamination was introduced;

3) a list of the contaminating substances (and their chemical speciation, if appropriate);

4) the anticipated spatial distribution and location of the contamination in, on or under the site;

e) the terms of reference for the investigation (or a synopsis) in either the introduction or an annex;

f) details of any discussion with regulators and of any formal requirements regarding the investigation (e.g. conditions attached to a planning permission), with key correspondence included in an annex.

The report should adopt a formal structure, incorporating the following sections:

i) contents;

ii) summary;

iii) introduction;

iv) objectives;

v) scope of work;

vi) site setting;

vii) details of research (including the sources of information consulted, site inspections carried out);

viii) physical details of site investigated (including location, access, topography, surface conditions, drainage);

ix) information on past and current activities on the site and the surrounding area;

x) information on geology, geochemistry, hydrology, hydrogeology and related designations;

xi) information on any other relevant aspects of the site (such as ecological or archaeological features, mining features);

xii) conceptual model, or models for different zones of the site;

xiii) uncertainties and limitations;

xiv) conclusions;

xv) recommendations;

xvi) annexes.

10.3 Field investigation report

10.3.1 General

The format of the report should follow the same layout, whether it covers an exploratory investigation or a main investigation. As indicated in **10.2** the factual report and the interpretative report may be produced as separate documents or combined in a single document.

The factual report should include at least the following sections:

a) contents;

b) summary;

c) introduction;

d) objectives;

e) scope of work;

f) site description;

g) summary of preliminary risk assessment including how the issues this raises have been addressed;

h) fieldworks:

   1) methodology (including sampling strategy);

   2) field observations;

   3) analytical and testing strategies;

i) results;

j) uncertainties and limitations,

together with supporting annexes as necessary.

The order in which information is presented may vary from that in a) to j).

NOTE 1 The Environment Agency has also provided summary check lists focusing on risks to water [74]. This contains eight example checklists corresponding to the key reporting stages. These checklists describe important elements of a report but are not exhaustive.

NOTE 2 Some local authorities have their own reporting requirements.

If an interpretative report is required, this should additionally include, as appropriate, the following.

1) Summary of the previous preliminary investigation and field investigations, and the preliminary risk assessment.

2) Assessment of the results of the field investigation.

3) Updated conceptual model.

4) Recommendations for further investigation or monitoring.

NOTE 3 Guidance on structure and contents is given by the AGS Guide to Good Practice in Writing Ground Reports *[75].*

10.3.2 Contents

The contents should clearly list the various headings in the report, with page numbers identified for ease of reference. Annexes should preferably be numbered sequentially with the report, but at least the number of pages in each annex should be given in the contents list so that loss of any page can be readily identified.

10.3.3 Summary

The report summary should briefly describe the work carried out and indicate, where appropriate, that no interpretation has been carried out. Where an interpretative report is included in the same volume, the summary should highlight the salient findings and associated implications and provide a brief account of the conclusions and recommendations.

10.3.4 Introduction

The background to the investigation should be described and should include:

a) the name, ownership, location and description of the site, including site location (grid reference) and general layout details;

b) who required the site investigation with the overall reasons behind, aims of and basis for the instruction to carry out the work;

c) background information [with specific reference to any preceding preliminary investigation and earlier intrusive investigation(s)], clearly referenced, with any other relevant reports and information (details may be incorporated as annexes to the factual report for ease of reference);

d) the date the investigation was carried out and the personnel involved;

e) the intentions for the future of the site (where relevant to the investigation);

f) details of any discussion with regulators and of any formal requirements regarding the investigation (e.g. conditions attached to a planning permission), with key correspondence included in an annex.

Reference should be made to any specific regulatory requirements, e.g. a Planning Condition requiring a preliminary investigation and/or a field investigation (exploratory or main investigation), and a description provided as to how these have been addressed. The report should make clear which element(s) of a complex regulatory condition is being addressed and whether the design was approved in advance by the appropriate regulator. Relevant correspondence with regulator(s) should be referenced and, where appropriate, included in an annex.

NOTE Conditions relating to contamination frequently have a number of elements. For example, the requirement for a field investigation may be dependent on the outcome of the preliminary investigation. They also frequently require the consent of the Local Planning Authority to the design of the investigation.

10.3.5 Objectives

The investigation's objectives should be clearly and briefly described. Where there have been changes from those within the original investigation proposal, details should be given.

10.3.6 Investigating strategy

A broad statement of the investigation strategy should be given, together with an explanation of how the strategy was derived from the preliminary investigation and exploratory investigation (if carried out). Further detail may be provided in later sections of the report as necessary. Any aspects of the investigation or features of the site that require particular consideration should also be described.

Any previous investigation reports issued may be incorporated as annexes to facilitate reference.

Full details of the design strategy are normally given in the proposal for the site investigation (which can be incorporated as an annex for completeness). However, where such a document does not exist, an outline of the strategy should be incorporated at this point in the report [detailed information can be provided in the Fieldworks section(s)].

10.3.7 Site description

Information should be provided on the site investigated, including:

a) physical details of the site investigated (including location, access, topography, surface conditions, drainage);

b) information on past and current activities on the site and the surrounding area;

c) information on geology, geochemistry, hydrology, hydrogeology and related designations;

d) information on any other relevant aspects of the site (such as ecological or archaeological features, mining features).

10.3.8 Previous field investigations

Summaries of the scope of work and findings of any previous field investigations should be included.

10.3.9 Summary of previous risk assessment(s)

A summary of the initial conceptual model and preliminary risk assessments carried out to date should be provided in the interpretative report, with a description of how issues raised have been addressed in the field investigation, e.g. i) the preliminary risk assessment might have indicated that landfill gas could be present and thus a number of monitoring wells were installed, and ii) the preliminary investigation might have indicated that phytotoxic elements could be present and thus appropriate soil samples have been taken for appropriate chemical analysis.

10.3.10 Fieldworks

The fieldworks (covering the practical application of the proposed methodology) should be described, together with the chronology of the investigation (as far as this is relevant) and identification and explanation of any deviations from the proposed methodology.

The methodology adopted should be described, including the number and locations of investigation points, method(s) of forming exploratory holes and collecting samples. Details should also be included of any additional works that were carried out as a result of the field observations during the course of the investigation.

10.3.11 Field observations

All the field observations (whether of a factual or subjective nature) should be recorded. Information gained from the strata logs or ground gas profiling and monitoring should be summarized within the main text. Full print-outs of the data may be incorporated into an annex, with cross-reference details included in the main text.

Other observations, such as the presence and depth of any groundwater encountered or specifically identifiable areas of contamination, should be described in detail. The use of photographs (if permitted by the site owner) to record site conditions and investigation activities is a valuable approach. Whilst full sets of photographs may be included in an annex, any particular aspects of interest or particular relevance should be illustrated within the main text.

10.3.12 Samples, analysis and other tests (analytical and testing strategies)

This section of the report should identify the actual numbers of samples taken and the selection of relevant samples for analysis or other tests, together with confirmation of the analytical requirements previously identified and any variations resulting from the field observations.

Sample preparation and sub-sampling procedures should be described, together with any relevant details relating to sample preservation and transport to the laboratory(ies) used. While it is not necessary to give full details of the analytical and test methods, unless unusual, a general indication of the methods (together with the relevant references) should be provided.

10.3.13 Analytical and other test results

Depending on the size of the investigation the results should be either included in the main text or presented in an annex or annexes. Whether the results are presented in the main text or in an annex(es), copies of the original analytical test reports and calibration certificates should be provided in annexes.

NOTE 1 "Results" refers here to the results abstracted from the original analytical test reports by the person preparing the report, not to the collection of test certificates etc included as annexes.

When the results are provided in an annex(es), appropriate summary tables should be included in the main text.

When the results are not provided in the main text the location and format of the detailed analytical and other test results should be clearly indicated. This may include, for example, giving details of whether all the analytical results are in a single annex, or whether trial pit results are separated from borehole and probe hole results and soil results from groundwater results, etc.

In all cases, data should be presented in as clear and easily assimilated way as possible, so that readers do not have to search through pages of results to see what is relevant or to find the results relating to a particular sample.

The main text should include summary information, sorted as necessary by zone, sampling location, sampling depth or type (e.g. made ground, each natural ground stratum) to provide the reader with a clear understanding of the data. Where it is necessary for practical reasons to include the main tables of results in an annex, appropriate summary tables should be included in the main text. It could be appropriate to provide tables showing ranges and mean values for suitably grouped data. When comparisons are being made with assessment criteria, suitable means should be employed to highlight when criteria have been exceeded.

Factual observations on the results should be included when considered appropriate.

Whether or not a particular value exceeds an assessment criterion is a fact and therefore appropriate information to include in a factual report. Whether this matters is a question of interpretation and should therefore be confined to an interpretative report or interpretative sections of a combined factual and interpretative report.

10.3.14 Annexes

*NOTE For the type of information to put into annexes, see **10.3.2** to **10.3.13**.*

Annexes should include, as appropriate:

a) site location plan, site plan including sampling locations;

b) field investigation records (such as strata logs, geophysical measurements, site photographs, site inspection records and site meeting records);

c) field monitoring records (such as for ground gas measurements, water level monitoring, *in situ* permeability testing);

d) laboratory analytical and other test results (sub-divided into soil, water and gas sample testing, etc.) if not included in their entirety in the main text;

e) copies of original analytical and other test certificates and reports (sub-divided into soil, water and gas sample testing etc.);

f) site investigation proposal;

g) copies of previous site investigation reports (where appropriate);

h) copies of key correspondence with regulators.

NOTE Site location plans and the plan showing sampling locations, etc., may alternatively be included in the main text.

Annex A (informative) Examples of site investigations

A.1 General

The examples given in this annex are intended to illustrate site investigation scenarios and demonstrate how the recommendations of this standard can be applied. These examples are not intended to be prescriptive. Particularly in the case of a main investigation, the spacing of sample locations and the number of samples analysed are determined by the objectives of the investigation, the risk assessment requirements and the confidence level with which the contamination needs to be characterized.

A.2 EXAMPLE 1 – Former industrial site

A.2.1 Objectives (see Clause 4)

A former industrial site is to be redeveloped. The site is roughly rectangular in shape with dimensions of 150 m × 300 m (4.5 hectares). A plan of the site is given in Figure A.1.

The objective of the investigation is to assess the nature and extent of contamination of the soil and groundwater, in sufficient detail to design remediation works to be undertaken as part of the site's redevelopment.

Two different redevelopment options are being considered:

Option 1: supermarket;

Option 2: private housing with gardens.

A.2.2 Strategy for the investigation (see Clause 4)

The investigation will be undertaken in phases. The first phase will be the preliminary investigation (see **5.2.7.1** and Clause **6**), comprising desk study, site reconnaissance, formulation of the initial conceptual model and preliminary risk assessment. The reconnaissance visit will be undertaken following the collection and review of readily available information, and following initial enquiries to parties with site-specific information.

It is very unlikely that the preliminary investigation will be sufficient to meet the investigation objectives, so an exploratory investigation (see **5.2.7.2**) will be undertaken. The scope and methods of the exploratory investigation will be based on the findings of the preliminary investigation. It will include soil and groundwater sampling and laboratory testing. Demolition of existing buildings on the site will not have taken place by the time the exploratory investigation is undertaken.

The exploratory investigation might (or might not) be sufficient to meet the objectives for redevelopment of the site as a supermarket. However, the results are very unlikely to be sufficient to design the remediation for housing redevelopment on the site. If further investigation is deemed necessary, a main investigation (see **5.2.7.3**) will be undertaken to collect all the outstanding information. The scope and method of this main investigation will be determined at the conclusion of the exploratory investigation. The main investigation will be undertaken after the existing buildings are demolished to slab level.

The requirements for the contamination investigations will be integrated with geotechnical investigations of the site (although these geotechnical investigations are not discussed below).

A.2.3 Preliminary investigation (see Clause 6)

A preliminary investigation has been carried out and has revealed the following historical information and initial conceptual model.

The site was progressively developed over a period of 60 years. Buildings now cover half of the site area, and hardstandings and internal roadways cover much of the remainder (see Figure A.1). Some drawings of the plant layout at different times exist, and this information has been supplemented with collection and interpretation of a sequence of historical aerial photographs.

The raw and process materials used at the site have encompassed a wide range of hazardous substances, many in liquid form. Of special note, either in relation to the quantities used or the degree of hazard, are trichloroethene (TCE) and other solvents, electroplating chemicals and heating oils.

The site has a complex system of chemical drains and sumps, as well as foul and surface water drainage systems (including an effluent treatment plant). An area of former waste disposal or dumping has been identified in one corner of the site.

Previous geotechnical investigations have revealed the following sequence of strata at the site.

Depth	**Comments**
0.0 m to 1.5 m	Fill, including demolition waste.
1.5 m to 3.0 m	Alluvial silty sands with varying proportions of gravel and clay in different areas of the site.
3.0 m to 6.0 m	Glacial till, generally comprising stiff clay but with occasional sandy lenses.
6.0 m to >20 m	Sandstone.

Groundwater occurs within the overlying alluvial sandy layer at a depth of 2.0 m to 2.5 m and also within the underlying sandstone bedrock at a piezometric head equal to 14 m below ground level. The sandstone is classified as a principal aquifer and several industrial abstraction licences are located within 1 km of the site. The groundwater in the overlying alluvial sandy layer is classified as a secondary aquifer with limited exploitation potential. The site and adjacent areas are essentially flat and groundwater level measurements made during the geotechnical investigations reveal a negligible groundwater gradient (and therefore flow) laterally across the site in the overlying alluvial layer.

The initial conceptual model indicates the existence of the following potential sources of contamination:

a) the storage areas for fuel, TCE and other chemicals;

b) the process areas where degreasing and plating have been carried out;

c) the waste disposal area and the wastewater drains;

d) the effluent treatment plant.

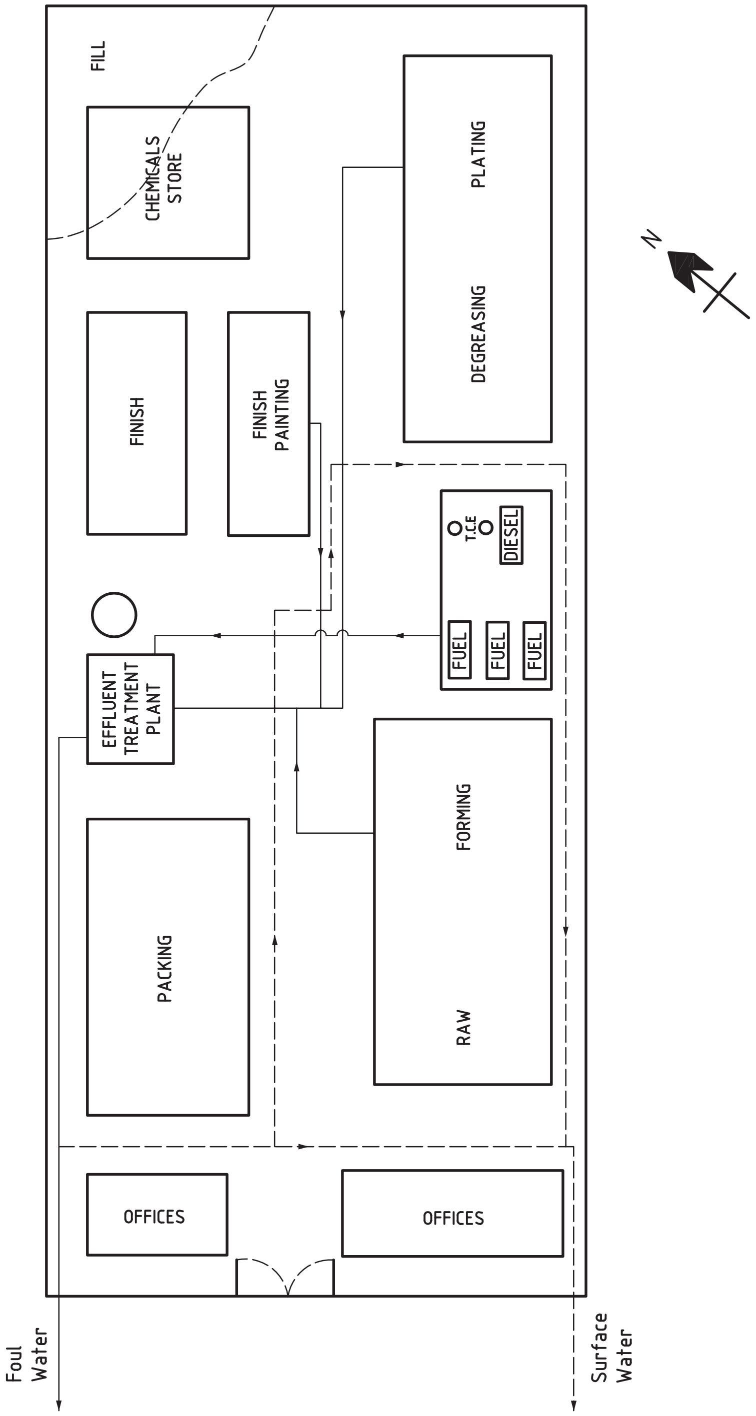


Figure A.1 **Site plan: Example 1**

Contamination in these areas can also be expected due to local spillage and indiscriminate discharges. The initial conceptual model therefore defines discrete areas of possible local impact of the fill and alluvial sands by the identified contaminants. The shallow groundwater is also expected to be affected, particularly locally to the sumps and drains and the process area. There could be areas of floating product as well as a variable vertical profile of contamination in the shallow groundwater, due to the relative densities and solubilities of the different potential contaminants on the site. There could also be VOCs, methane and carbon dioxide in the fill and sand above the groundwater level.

The water receptors identified in the initial conceptual model for the existing (derelict) site condition and for the redeveloped site are the shallow groundwater in the alluvial sands and the principal aquifer in the sandstone.

There are no streams crossing or adjacent to the site and the site is currently enclosed by secure fencing. Present adjacent land uses are commercial (warehousing), a major road and gardens of private houses on one side. Therefore, human receptors in the initial conceptual model for the existing condition are limited to persons off-site, notably residents of the adjacent houses, pedestrians on the road pavement and employees at the commercial premises. The initial conceptual model for the redeveloped site additionally has as human receptors employees and customers at the supermarket, residents and visitors to the private housing, and maintenance and services workers on both parts of the site. During the construction phase, both construction workers (in particular ground workers) and site neighbours will be human receptor groups.

There will be a direct pollutant linkage between ground contamination and the groundwater in the alluvial sands. However, the stiff clay layer is expected to provide a barrier to downward migration of contaminants, although pathways to the sandstone could exist due to sandy lenses in the glacial till and deep foundations. There is, therefore, the possibility of the deeper aquifer having been affected by the migration of contamination.

The proposal for redevelopment requires consideration of the potential for new migration pathways to be formed. The removal of the existing hard landscaping could result in exposure of workers during redevelopment, as well as exposure pathways for future users and occupiers. Removal of existing hard landscaping could also result in an enhanced pathway for leaching of contamination to groundwater. Pathways between residual contamination and the foundations and services for the new buildings and structures could also exist. These possibilities will all need to be addressed in the ensuing site investigation.

A.2.4 Design and planning of field investigations (see Clause 7 and Clause 8)

A.2.4.1 General

For a complex site of this size and nature, and with such a high potential level of contamination, a phased approach to investigation is to be adopted. The number of phases and their scope is likely to depend on a combination of technical and operational issues (such as access, planning permission, ownership, financing, etc.).

A.2.4.2 Option 1: supermarket

The first phase of intrusive investigation (the exploratory investigation) (see **5.2.7.2**) is expected to be sufficient to test the conceptual model and to provide enough information to assess the general suitability of the site for the proposed hard form of development (including indicative costs of remediation).

The conceptual model indicates the possibility of contamination associated with several identified localized sources, including electroplating chemicals (copper, nickel, zinc, cadmium, cyanide, chromic acid, acids and alkalis, etc.), solvent (TCE), fuel oil (diesel and heavy heating oil) and deposited waste. The contamination is assessed as likely to have impacted on the fill and alluvium and the superficial groundwater above the glacial till. Due to the uncertainty of the permeability of the alluvium and the glacial till, deeper penetration (of the TCE in particular) could be present. However, the possibility of migration of cyanides and metals also needs to be considered.

In terms of the proposed development with hard landscape, the areas of potential risk that require assessment are:

a) the possibility of ground gases (permanent gases, such as methane and carbon dioxide and VOCs) affecting the development after construction;

b) the possibility of chemicals (cyanides, chromates, metals, acids and alkalis), oil and solvents affecting workers during construction, and service maintenance workers post-construction;

c) the possibility of acids and other chemicals affecting the concrete and other construction materials and components;

d) the potential for contamination of the underlying aquifer.

The exploratory and subsequent main investigations (see **5.2.7.3**) are consequently designed to produce information on these identified hazards so that the actual risk can be assessed and the need for remediation determined.

The proposed development envisages demolition and removal of buildings, hardstandings and foundations. There is a proposal to crush all demolition material and use this as hardcore for the new development. However, this creates several additional potential risks. If brickwork or concrete in the processing area contains asbestos, or has been penetrated by the various chemicals, hazards could be presented during the crushing process and also during the subsequent re-use of the crushed material. Asbestos-containing material cannot be crushed or re-used. This aspect needs to be addressed as a part of the investigation process but is outside the scope of this illustration (see **7.5**).

Since particular sources of potential contamination have been identified by the preliminary investigation, the exploratory investigation will comprise targeted sampling of the overlying fill, alluvial soils, shallow groundwater and underlying groundwater at locations of potential contamination.

Boreholes are selected as the appropriate method of sample collection, taking into account:

1) the presence of existing buildings;

2) the presence of extensive hard landscape;

3) the need for collection of perched water samples;

4) the need for collection of samples of groundwater from the underlying aquifer;

5) the desirability of checking the ground for the presence of methane, carbon dioxide and VOCs;

6) the nature and geology of the ground to be investigated.

Initial borehole locations are selected on a targeted basis (see **7.7.2.2** and **7.7.4**). These are designed to investigate the areas of oil storage (three boreholes), TCE storage (two boreholes), trichloroethene (TCE) usage (only one borehole is possible due to access restrictions), the effluent treatment area (two boreholes) and the area of waste deposit (two boreholes).

Where the boreholes penetrate the glacial till they are formed with a bentonite plug at the base of the alluvium. Drilling is continued with a smaller diameter hole inside the original casing in order to minimize the possibility of forming contaminant migration routes.

Additional non-targeted boreholes are considered necessary to obtain a more general assessment of the site and to ascertain how the actual contamination correlates with the conceptual model. Locations for a further 18 boreholes are postulated on the basis of a 50 m centre grid. However, some of these locations are not accessible due to existing buildings and potentially live services. Some of the inaccessible locations can be accommodated by relocation by a few metres (from the original point), providing effective sampling in relation to the grid. As a consequence, only 14 of the postulated 18 boreholes are actually installed.

Thus, the exploratory investigation comprises 10 boreholes, located for targeted judgmental sampling and a further 14 located on an approximate 50 m centre grid. Samples are collected at 0.5 m depth intervals between 0.5 m below existing ground and 1 m into the glacial till. It is anticipated that, from that point to the base of the boreholes, samples will be collected at 1 m depth intervals. The field environmental scientist is given instructions to take additional samples as necessary on the basis of any field observations.

During borehole formation, atmospheres are monitored at 1.0 m intervals for methane, carbon dioxide and oxygen deficiency and also with a PID monitor with an 11.7 ev lamp (chosen to include sensitivity to chlorinated solvents). Sample containers suitable for analysis for volatile organic compounds such as TCE are used [for example, a septum screw-top vial for headspace analysis (see **8.5**)]. Sampling and analysis of at least five solid samples at each location plus analysis of groundwater will provide data on the anticipated localized sources of contamination and also on the general nature of contamination across the site.

On this spacing, significant areas of contamination (up to 2 500 m^2) could be missed. However, this is considered acceptable within the remit of the exploratory investigation.

The information from this exploratory investigation is used to:

i) substantiate, or otherwise, the conceptual model, including contaminant distribution formulated after the preliminary investigation;

ii) assess the technical feasibility of the proposed development;

iii) identify areas of the site that require more detailed investigation:
- for delineation of areas of high or specific contamination;
- for provision of information for a risk assessment;
- for the formulation of a suitable remediation strategy.

The results from the exploratory investigation show there is significant localized contamination of the overlying ground and the shallow groundwater aquifer, particularly around the fuel storage tanks in the area of TCE usage and in the electroplating area. The exploratory investigation did not, however, detect contamination of the deeper aquifer, nor was any contamination of the shallow groundwater detected at the area of TCE storage. Elsewhere across the site there are locally elevated levels of heavy metals and hydrocarbons in soils, but not generally significantly above generic screening levels for hard forms of development.

On the basis of the findings of the exploratory investigation it is determined that a further main investigation is required to provide more detailed information on the site for the risk assessment and remediation works, including delineation of contamination hotspots and plumes.

The main investigation (see **5.2.7.3**) is carried out when the whole site becomes available, after demolition of the buildings, but before removal of the hard landscape.

The main investigation involves:

- an additional 16 sample locations (boreholes) radiating from the fuel storage tanks (with provision for four further sampling locations if a plume of contamination is indicated);
- an additional 16 sample locations (boreholes) around the area of TCE usage (with provision for four further sample locations if a plume is indicated).

[The exploratory investigation did not detect groundwater contamination in the deeper aquifer, so at each of these locations the four outermost boreholes (of the 16) are formed into the underlying aquifer to confirm absence of contamination.]

The electroplating area is subject to more specific examination and the drains running to the effluent treatment plant are also targeted.

At the location of the TCE storage there was no indication of ground or groundwater contamination and so only an additional two boreholes are considered necessary to confirm the absence of TCE contamination at this location (see **7.7.3** and **7.7.4**).

Taking into account the 14 sample locations already installed on the 50 m grid, the main investigation entails a further 50 sample locations providing a 25 m grid. These can all now be accurately located on the 25 m grid pattern by breaking through the concrete hardstanding. In addition, nine trial pits are undertaken to provide a more detailed investigation of the electroplating area and the waste deposit area.

It is possible to carry out the targeted sampling of the drain runs using locations that coincide with the 25 m grid.

At grid points around the three locations where contamination of shallow groundwater was identified by the exploratory investigation, monitoring wells are formed within boreholes. Boreholes are also positioned upstream of, and at the downstream boundaries adjacent to, these locations so that a model of the groundwater contamination can be formulated.

Where contaminated shallow groundwater was identified, additional trial pits are formed 15 m from the original sampling location to help locate the source of the contamination. Provision is made during backfilling to prevent excessive rainwater penetration of the hardstanding. This minimizes the potential for contamination migration before remediation begins.

Samples are collected at the same depths following the strategy used in the exploratory investigation. As with the exploratory investigation, at least five solid samples, plus samples of groundwater, are analysed for each location. This analytical requirement is necessary to obtain sufficient data to be able to carry out the risk assessment with a satisfactory degree of confidence.

A.2.4.3 Option 2: housing with gardens

Investigation requirements for a housing redevelopment are more extensive than for a hard form of commercial development because of the higher potential health risks to human receptors on the redeveloped site. These higher risks arise from more direct source-pathway-receptor linkages in garden areas, greater exposure times and more sensitive receptor groups (e.g. children).

The potential for ground gases and VOCs to have an impact on a housing development through ingress into the buildings and the potential for chemicals to be present in garden areas requires thorough investigation and assessment. With a housing development, there will be a greater impact due to increased infiltration of rainwater compared to a supermarket development comprising mostly hard standing. This could adversely affect contamination migration, particularly to the shallow aquifer. Commercial and public perception issues might also affect the intensity of investigation and remediation undertaken on housing redevelopment sites.

For the exploratory investigation (see **5.2.7.2**) similar procedures to those used for Option 1 are followed. However, because there is a need to define the contamination status with a greater degree of confidence at an earlier stage, a greater intensity of sampling and testing is carried out.

The targeted sampling is not greatly increased. However, the non-targeted sampling is carried out on the basis of a grid at 25 m centres (rather than 50 m for Option 1), with the proviso that within building footprints this either will not be practicable or will involve the use of specialized equipment for sampling (for example, low headroom boreholing equipment, or sampling with portable equipment through pre-cored holes).

Because of the increased number of sample locations and the associated cost and relative importance of the overlying layer to future human receptors, a greater proportion of the sampling points are trial pits, in place of some of the boreholes. However, the siting of the trial pits has to consider the costs of breaking out concrete hardstanding and reinstatement of trial pit locations to ensure that the locations are satisfactorily sealed to prevent the formation of migration routes (due to rainwater infiltration). It is also necessary to reinstate the area to enable large articulated wagons to drive over the locations if parts of the site are still in use.

For the main investigation (see **5.2.7.3**) the targeted examination in the "hot spot" areas is carried out as already described, though additional non-targeted sampling points are required due to the need for greater confidence in the risk assessment findings.

Assuming a proposed development layout has been drawn up, the main investigation includes sampling at a maximum of 10 m centres in the garden areas, particularly in the suspect areas of TCE storage, chemical storage, electroplating and waste disposal. Locations that could not be previously investigated due to the standing buildings, are now included. This greater number of sample locations is investigated either by trial pits or window sampling. Samples are collected down to the top of the glacial till, unless there are indications of deeper contamination.

If the layout of the proposed development is not known, sampling and investigation of garden areas could be carried out as a supplementary investigation (see **5.2.7.4**) when a plan becomes available.

A.3 EXAMPLE 2: Previously developed site

A.3.1 Objectives (see Clause 4)

This site, adjacent to a major tidal river, is to be developed for leisure facilities which will include public open space, a sports hall and a boathouse. The site is approximately 90 m × 175 m (1.6 hectares) with a tidal river frontage at the southern end of the site of 90 m. A plan of the site is given in Figure A.2.

A.3.2 Strategy for the investigation (see Clause 5)

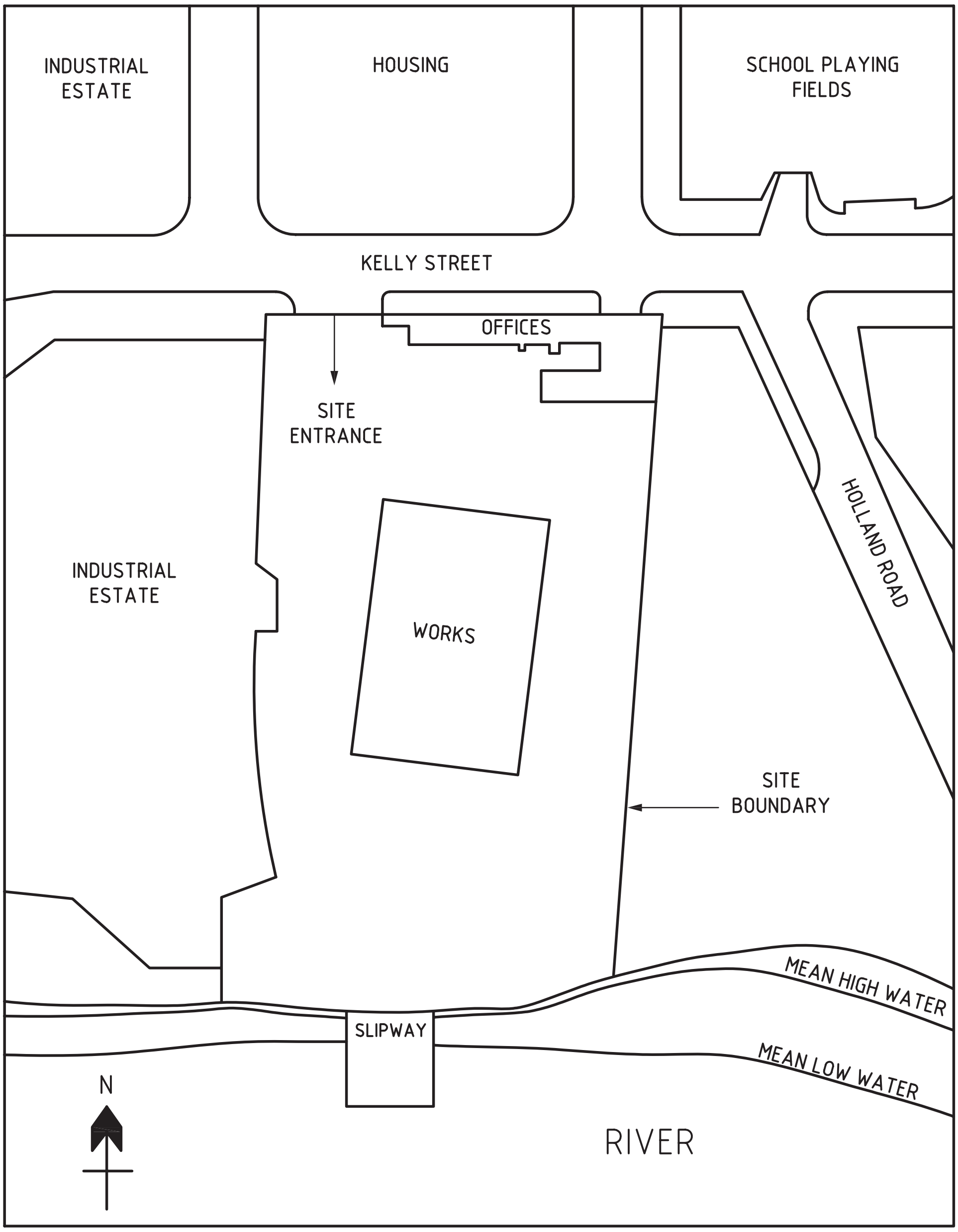
The investigation will be undertaken in phases. The first phase will be the preliminary investigation (see **5.2.7.1** and Clause **6**), comprising desk study, site reconnaissance and formulation of the initial conceptual model and risk assessment. The reconnaissance visit will be undertaken following the collection and review of readily available information and initial enquiries with parties with site-specific information.

It is very unlikely that the preliminary investigation will be sufficient to meet the investigation objectives, so an exploratory investigation (see **5.2.7.2**) is likely to be necessary. The scope and methods of the exploratory investigation will be based on the findings of the preliminary investigation. It will include soil and groundwater sampling, ground gas monitoring and laboratory testing of soil and groundwater samples.

The exploratory investigation is unlikely to be sufficient to meet the objectives for redevelopment of the site and a main investigation (see **5.2.7.3**) will be undertaken to collect all the outstanding information.

The requirements for the contamination investigations will be integrated with geotechnical investigations of the site (although these geotechnical investigations are not discussed below).

Figure A.2 **Site plan: Example 2**



A.3.3 Preliminary investigation (see Clause 6)

The preliminary investigation identified the following historical information and initial conceptual model.

The site was apparently undeveloped until 1935, with marshy ground shown on part of the site adjacent to the river. Approximately 100 m to the north east of the site the 1925 map shows an area identified as workings. However, these workings are not marked on the 1954 map and the area is shown to be occupied by a school and playing field. The 1954 map shows a large unidentified building in the middle of the site, with a slipway into the river and some smaller (unidentified) buildings on the road frontage. The large building is subsequently identified as "works" but the latest map does not show this building. Local history references and anecdotal evidence indicate that aircraft (seaplanes) were assembled in this area during the Second World War, but it is not possible to confirm this.

Most of the site away from the river is covered with concrete and tarmac in a poor state of repair. This ground cover is regarded as unlikely to be wholly impervious. Toward the river, between the building and the slipway, the ground is well compacted with hardcore material.

Examination of geological information indicates the existence of alluvial deposits over River Terrace Gravels lying over at least 60 m of London Clay. Beneath the London Clay lies chalk with a deep saturated zone, which is classed as a principal aquifer. The groundwater in the terrace gravels is classified as a secondary aquifer. There is the likelihood of the marshy ground having been raised before development with imported fill, possibly at the same time as the adjacent ground workings (1925 map) were infilled.

There are no specific data available for identifying strata thickness and estimates (based on British Geological Survey Maps) indicate alluvium overlying a likely thickness of the Terrace Gravel strata of 3 m to 4 m and also that the London Clay could be located at approximately 5 m below ground level.

The initial conceptual model for the site indicates 1 m to 2 m of imported material used for raising the site to the existing ground level. Given the possible date of development this could include ashy fill with associated sporadic contamination. There is nothing to indicate the presence of any tanks or other features but, given the possible previous use, it is considered that there could be contamination due to fuels and solvents, both from spillage and storage. Contamination from metalworking is also possible.

There is no information available on the nature of the alluvial material, which could be low permeability silt (clay) or higher permeability material, such as sandy material or peat. It is possible that mobile contaminants such as fuel and solvents could be retained by the alluvial layer or could have penetrated the underlying River Terrace Gravels. It is also likely that the water in the terrace gravels is in direct contact with the river and that the piezometric pressure in the gravels is similar to the mean river level. It is not known whether there is perched water in the made ground or if there is continuity with the gravels.

There is the possibility of significant concentrations of methane and carbon dioxide on the site. These gases could derive either from the alluvial material present, or as a result of migration from the potential infilled area to the north-east. This potential presence of ground gas could present a hazard within buildings and underground services of the proposed development.

There is the possibility of contamination associated with material-used for raising the ground and also because of previous activities on site. This contamination could include metals and organics such as phenols, polycyclic aromatic hydrocarbons and, in areas of former use, solvents. However, there is no indication of where such localized contamination could exist, other than around the area where the building existed.

Although there are existing areas of soft landscape toward the river, the redevelopment with public open space will increase the overall area where rainfall penetration could occur. This will increase the risk of contamination migration towards and into the river. The initial conceptual model indicates that there could be contaminated perched water above the alluvium, but there is no evidence of continuity with the River Terrace Gravels, which are likely to be connected to the river. The investigation therefore needs to provide information with which to assess the possible impact of contamination migration on the perched water. It also needs to establish if there is any continuity between perched water and the underlying water in the terrace gravels.

Any contamination present within the site could present a hazard to workers during construction and users after redevelopment. Certain contaminants could also affect the construction materials. It is necessary, therefore, to carefully determine the nature and distribution of contamination and to identify any localized areas.

A.3.4 Sampling strategy

A.3.4.1 General

Due to the uncertainties in the available site information revealed by the preliminary investigation, the intrusive investigation will be carried out in two stages. The limited exploratory investigation (see **5.2.7.2**) is designed to provide sufficient data to enable the main investigation to be focused (see **5.2.7.3**) on areas of potential concern and avoid unnecessary work.

A.3.4.2 Exploratory investigation

It is considered appropriate to use a mix of boreholes and trial pits, though window or windowless sampling could be used in place of the latter. It is thought better to ascertain the nature of the ground and obtain an indication of the location of the terrace gravels in the exploratory investigation to determine if window sampling will be successful. It is perceived that difficulties for window sampling, such as obstructions in the made ground and problems in collecting samples from the gravels, could exist.

The boreholes are used to:

a) determine the depth and thickness of strata to the top of the London Clay;

b) obtain solid samples of made ground and alluvium;

c) install gas monitoring wells and groundwater monitoring wells.

Construction of the boreholes is in two stages to minimize the potential for creation of contamination pathways from made ground to the underlying gravels. The boreholes are formed until the alluvium is encountered and then a 1 m plug of cement/bentonite installed and allowed to set, before continuing to drill through the terrace gravels using a smaller diameter shell inside the casing in the original borehole (see **7.7.3.4** and **8.2.3.1**). The final depth of the boreholes is 0.5 m into the London Clay, except if they are required to go to greater depth for geotechnical purposes.

During the formation of the boreholes, monitoring for ground gases allows an indication of the presence of hazardous gases (notably methane and carbon dioxide) at different depths to be made (see **7.7.4**). On completion of the boreholes, standpipes are installed to monitor and sample ground gases and groundwater quality and levels.

The installation of gas standpipes in completed boreholes enables monitoring of ground gas composition, flow rate and pressure. The standpipes for gas monitoring wells are installed separately in the made ground and alluvium.

Most of the groundwater monitoring wells are formed through the River Terrace Gravels down to 0.5 m into the underlying clay, with a well screen extending at least 2 m to 3 m across the terrace gravel for the purposes of sampling the secondary aquifer (see **7.7.3**). The response zone in the gravels is sealed off from the overlying made ground and perched water with a bentonite plug. Monitoring of water depth, in conjunction with tidal variation and river water height, provides information on the impact of tidal variation on the groundwater of the site and whether there is evidence of continuity between the gravels and the river. Above the bentonite plug, at the level of the alluvium, a combined gas monitoring and groundwater sampling well is in some cases installed in the same borehole to enable gas monitoring of the strata above the alluvial layer.

One of these combined wells is installed in the north-east corner of the site to check for evidence of gas migration from the suspected landfill. Three combined wells are placed centrally on the site at the northern end, in the middle and at the river end of the site.

Six trial pits are placed at 50 m centres across the site to sample the made ground down to the alluvium and, in conjunction with the boreholes, to check for the existence of perched water. The trial pits will enable collection of solid samples of the made ground and the upper 0.5 m of the alluvium.

On the basis of this proposed strategy a significant area of contamination could be missed (up to approximately 2 500 m^2 or 17.5% of the area of the site). The conclusions from the exploratory investigation are used to:

1) substantiate and enhance the conceptual model;
2) assess the technical feasibility of the proposed development;
3) identify aspects of the site that require more detailed examination to enable a risk assessment to be carried out and suitable remediation strategies to be formulated.

The results of the exploratory investigation indicate that the alluvial layer is 1.5 m to 2.0 m thick towards the river. At the northern (inland) end of the site, the alluvium was not encountered and only a thin layer of sandy, silty material lies between the terrace gravels and the made ground.

Perched water was only encountered in the three trial pits and two boreholes nearest the river. This could indicate that perched water flows away from the river until it percolates down into the terrace gravels where the alluvium thins. Water level monitoring indicates that the groundwater in the terrace gravels is affected by the tides and therefore is in direct continuity with the river. This effect was shown to occur 15 m into the site but was not detected at a distance of 90 m from the river.

Made ground thickness varied between 2 m to 3 m and the terrace gravels were also 2 m to 3 m thick. TCE and ethylene glycol ethers (solvents) were detected in the groundwater in the terrace gravels in the centre of the site but no free product was identified. Between the building and the slipway an elevated concentration (greater than 1%) of petroleum hydrocarbons was identified but the investigation team did not record any odours at this location. Methane and carbon dioxide were detected in the gravels at the north-eastern end of the site. Metals, including lead, cadmium and zinc and elevated concentrations of arsenic and sulfate, were detected in the made ground towards the river.

As a result of this information the initial conceptual model is reviewed and due consideration indicates that in overall terms it is correct, but that there is a need for greater detail. The information obtained during the exploratory investigation indicates the presence of ground gas contamination, contamination due to organic compounds (solvents and petroleum hydrocarbons), elevated concentrations of metals, arsenic and sulfate and the possibility of continuity between the perched groundwater above the alluvium and the underlying terrace gravels. This information requires elaboration by the main investigation (see **5.2.7.3**) in order to provide adequate information on which to base the risk assessments.

The main investigation needs to be designed to assess gas migration onto the site because of the potential risk to users resulting from any gas build-up in buildings.

The presence of solvents and petroleum hydrocarbons requires further investigation because of the potential for impact on perched groundwater and, if continuity is established, upon the water in the terrace gravels and subsequently the river. Solvent vapours could also build up within the building service ducts and both solvents and petroleum hydrocarbons could affect the building structures and services. Petroleum hydrocarbons also biodegrade to yield carbon dioxide (aerobic conditions) or carbon dioxide and methane (anaerobic conditions).

The metals, arsenic and sulfate are of concern due to potential effects on vegetation, on-site users and on the environment resulting from wind-blown dust. Sulfates can also affect the concrete used in buildings and other structures.

The presence of the contaminants poses a potential hazard to workers during redevelopment and will require careful methods of working during redevelopment to prevent effects on the environment and adjacent areas due to emissions or distribution of dust.

A.3.4.3 Main investigation

The next stage of investigation needs to address the potential source-pathway-receptor relationships identified. The investigation needs to examine the site to ensure that, if contamination is identified, it is not present at a concentration that will present a risk to future users of the site, construction workers, the groundwater or river, vegetation, the proposed redevelopment or the environment generally (for example, wind-blown dust).

The main investigation (see **5.2.7.3**) therefore has to be designed to produce additional information on these specific aspects of the site and also to characterize, to a greater extent, the general nature of the made ground so that risk assessments with a satisfactory degree of confidence can be carried out.

The overall strategy for the main investigation will be based on a 25 m grid using a window sampler to collect samples down to the alluvium and also a sample of the alluvium itself. Some locations will be sampled using boreholes where these are suitably located for the installation of monitoring wells.

In addition, groundwater monitoring wells will be positioned along the boundary with the river to determine water quality in this region (see **7.7.3**).

Monitoring wells will also be formed at the northern end of the site to check groundwater quality and at some locations will be duplicated with gas monitoring wells (see **7.7.4**).

Two additional (targeted) boreholes will be installed at 25 m centres along the eastern boundary at the northern end of the site to provide further monitoring locations for ground gas migration.

In the centre of the site, four monitoring wells will be installed down to the London Clay to assess the extent of organic contamination (by TCE and ethylene glycol ethers) and these will also be sampled and analysed to assess the overall groundwater quality. This is considered the most economic approach to the problem. However, it is sometimes necessary to carry out supplementary investigations if insufficient information on the distribution of organic contaminants in the groundwater is obtained.

Four further boreholes will be installed in the area of the building and the slipway to delineate and estimate the amount of contamination with petroleum hydrocarbons. As with the investigation of the organic contamination it is accepted that more boreholes could be required.

It is anticipated that all boreholes will be able to provide ongoing monitoring during the construction period and for a longer period if required by the regulators.

Samples will be taken at 0.5 m depth intervals to the base of the sampling location or the alluvium (whichever is the greater) and at 1.0 m intervals through the gravels, with a sample being taken 0.25 m into the clay where this encountered. All the samples of made ground and two samples from the alluvium will be analysed. Initially, two samples from the gravel strata will be analysed with provision for the analysis of more samples if contamination is detected. All groundwater samples will be analysed and at least one gas sample from each monitoring borehole will be analysed to confirm field testing results. Provision will also be made for collection of gas adsorption tube samples from boreholes to determine the concentration of solvents present. This strategy should identify contamination up to a minimum of 625 m^3.

Groundwater sampling is scheduled to be carried out on three occasions after installation of the monitoring wells. The monitoring programme will also include determination of depth of groundwater and height of the river at the same time.

Ground gas monitoring will be carried out over an extended time period including at least once when rapid reduction in atmospheric pressure occurs. When assessing the results of gas monitoring, it is necessary to have regard to the fact that alluvium and petroleum hydrocarbons can also be sources of carbon dioxide and methane.

Annex B (informative) Example investigation objectives and applications

The following are examples of the types of investigations that are carried out and the types of applications for which they are used.

Example 1

Objective of investigation: To provide information for the development of an initial conceptual model of the site and the potential source-pathway-receptor scenarios for the assessment of potential risk in a preliminary risk assessment report.

NOTE 1 The Environment Agency requirements for a preliminary risk assessment report are set out in [31].

The investigation would comprise a preliminary investigation (desk study and site reconnaissance) (see **5.2.7.1** and Clause **6**).

Typical application: The first stage in all assessments of land potentially affected by contamination. There could be a need for further investigation to confirm the conceptual model postulated, or the information obtained could be considered adequate for the decisions to be made, e.g. pre-purchase assessment.

*NOTE 2 Different conceptual models may be formulated for different zones and development stages of a site (see **6.3.1**).*

Example 2

Objective of investigation: To evaluate an initial conceptual model and confirm whether proposed source-pathway-receptor scenarios exist.

The investigation would comprise an exploratory investigation (exploratory investigation) (see **5.2.7.2** and Clause **7** and Clause **8**).

Typical application: To provide more information and better definition of the potential contamination identified in, for example, a pre-purchase survey or due diligence audit of property ownership liability.

Example 3

Objectives of investigation: To provide sufficient information so that, where source-pathway-receptor scenarios are known to exist, the risks can be quantitatively evaluated, a remedial options study undertaken, and a remediation strategy or remediation plan produced.

The investigation would comprise a main investigation (see **5.2.7.3** and Clause **7** and Clause **8**).

Typical application: Where preliminary and possibly exploratory investigations have indicated that unacceptable risks are likely to exist for the current use of the site, or a contaminated site is to be re-developed.

NOTE 1 The assessment of unacceptable risk could have been made by the client's professional team, or by the local authority under its duties in Part IIA of the EPA 1990 [1], or for Special Sites in England and Wales by the Environment Agency. In Scotland, the Local Authority assesses unacceptable risk for potential Special Sites.

NOTE 2 In the case of investigation of the site in the context of Part IIA of the EPA 1990 [1], the investigation has to provide sufficient information to allow the Local Authority to make a determination of whether, or not, the site is "contaminated land", according to the meaning of that Act.

Example 4

Objective of investigation: To provide additional information for the assessment of potential future geo-environmental liabilities.

The investigation would be an exploratory investigation, usually targeted at only part(s) of the site.

Typical application: To investigate potential areas of ground contamination and/or groundwater conditions at the site, following a preliminary investigation, for the pre-purchase investigation of a business acquisition which will continue to operate, i.e. part of a due diligence audit.

Example 5

Objective of investigation: To provide information for the assessment of contamination and subsequent remediation options appraisal.

This would require an exploratory and/or main investigation.

Typical application: Where land is already owned and a remediation strategy is necessary to manage existing contamination risks, to bring it into beneficial use or for a specific redevelopment.

Example 6

Objective of investigation: To report on the current potential for contamination at a site.

This would require a preliminary investigation, but could also require an exploratory investigation, depending on the site's history and the level of confidence required.

Typical application: Site condition report for the purposes of environmental permitting [29] or PPC licensing.

Example 7

Objectives of investigation: To delineate the extent of known soil and/or groundwater contamination and provide sufficient information on which to base the remediation implementation plan.

NOTE The Model Procedures for the Management of Land Contamination *[31] describe the process of risk assessment, options appraisal, remediation strategy and remediation implementation plan development, verification and monitoring.*

This would require a main investigation and/or a supplementary investigation.

Typical application: When the risk assessment, carried out on the basis of an exploratory and/or main investigation, has indicated that remedial action is required, but there is insufficient ground investigation information to carry out the remedial options appraisal.

Example 8

Objective of investigation: To validate successful completion of remediation works.

This would be a supplementary investigation, comprising, for example, sampling on the sides and base of remediation excavations to ensure that all unsuitable contaminated soil has been removed, or sampling groundwater to demonstrate acceptable water quality concentrations.

Typical application: Validation of soil removal remediation works prior to backfilling.

Example 9

Objective of investigation: To demonstrate that, following agreed remediation works and other works to prepare the site for development, the site is "fit for the intended purpose".

This would be a systematic intrusive investigation of the whole site with sampling locations chosen without reference to the remediation works. It would permit application of statistical analysis of the data when making comparisons with the relevant assessment criteria.

Typical application. Applied once formation level has been achieved to demonstrate to interested parties that the site is now fit for the intended purpose and that construction can proceed. Often appropriate for staged discharge of Planning Condition(s) and/or to reassure commercial lessee that "all is well".

Annex C (informative) Health and safety in site investigations

C.1 General

Health and safety is a very important aspect of site investigation, since there is a very real risk of either toxic effects on, or physical injuries to, workers. It is a legal requirement to ensure as far as possible that workers and the public are protected from risks presented by the working environment. Detailed guidance is given in BS ISO 10381-3. Information is also given in BDA (2008) [47], CIRIA R132 [46], which provides a thorough review of legislation and safe working practices, and the following.

a) AGS *Safety Manual for Investigation Sites* (2002) [76].

b) AGS *Loss Prevention Alert No. 17: The Obligations to Conduct Risk Assessments* (2002) [77].

c) BDA *Health and Safety Manual for Land Drilling* (2002) [78].

d) BDA *Guidance Notes for the Protection of Persons from Rotating Parts and Ejected or Falling Material involved in the Drilling Process* [79].

e) CIRIA C681 [37].

f) CIRIA Report C682 [60].

g) HSE HSG47 [48].

h) HSC Approved Code of Practice, *Managing health and safety in construction: Construction (Design and Management) Regulations 2007* [80].

i) HSE *Personal Protective Equipment at Work* [81].

j) HSE Approved Code of Practice, *Safe Work in Confined Spaces Regulations 1997* [82].

k) HSE Approved Code of Practice, *Provision and Use of Work Equipment Regulations 1998* [83].

NOTE Attention is drawn to the Construction Design and Management (CDM) Regulations [18], which place explicit duties on clients, designers and contractors to plan, coordinate and arrange health and safety.

C.2 Safety policy

Any organization involved in site investigations and sampling is required to have a safety policy that sets out the requirements for safe working. The safety policy is required to:

a) emphasize the need for alertness and vigilance on the part of site personnel to protect themselves and others from hazards during investigation and sampling;

b) emphasize the need to follow standard operating procedures where these exist;

c) prescribe the responsibilities of each member of the investigation team (including the responsibilities to any sub-contracted personnel and to the general public);

d) include a mandatory ban on smoking, eating, or drinking whilst on site carrying out a sampling exercise or other site investigation;

e) emphasize the need for checking for the presence of services at all sampling locations before commencing work;

f) require personnel to comply with all client requirements when working on sites with a potential for spark and explosive risks, for example, forbidding the use of mobile phones and other electronic devices, requiring arrestors on mechanical equipment and earthing wires.

The policy has to be supported by standard procedures setting out the requirements for safe working in general and in specific locations, such as confined spaces. These standard procedures have to cover the provision and use of protective clothing and equipment and the minimum number of personnel who need to be involved in site work. The standard procedures are also required to specify the requirements for advising local emergency services and the methods of communications and methods of washing and decontamination.

C.3 Planning and managing for safety

To safeguard personnel in site investigations or sampling exercises, it is necessary to plan and manage for safety. This could cover:

a) assessment of the hazards arising from the site (including services, physical hazards and contamination);

b) avoidance of hazards where possible;

c) selection of sampling methods with safety in mind;

d) provision and use of personal protective equipment;

e) provision of equipment for the detection of hazardous environments;

f) provision of appropriate welfare facilities;

g) provision of decontamination facilities for personnel and equipment;

h) appointment of an individual to take responsibility for implementation of safety plan and measures;

i) clear assignment of responsibilities;

j) documentation of safe working procedures;

k) permit to work system;

l) provision of information to all concerned;

m) training;

n) provision of first aid facilities;

o) planning and use of emergency procedures;

p) installation of a system of record keeping of incidents and possible exposures;

q) health surveillance;

r) compliance with company safety policy;

s) compliance with legislation concerning the health and safety of the personnel and the general public.

Some measures for protection, monitoring and control are given in Table C.1.

Prior to undertaking any form of investigation on a site, it is essential that a risk assessment of hazards and a COSHH [19] assessment are carried out. This is particularly important on former industrial sites and waste sites. In the case of the site reconnaissance, the hazard assessment has to be based on the results of the desk study. It could be possible to refine the assessment once the preliminary investigation is completed. This has to be kept under review as the investigation proceeds but where there is any doubt as to the presence or degree of contamination then protective equipment needs to be used.

Table C.1 **Health and safety measures for site investigations**

Protective clothing and equipment	Monitoring equipment	Safety procedures
Overalls, boots, gloves and helmets	Hand-held gas monitors	Training
Eye protection	Automatic gas detectors	Permit to work systems
Ear protection	Personal monitors	Notification to emergency services
Face masks and filters	Environmental monitoring equipment	Check mobile network coverage
Breathing apparatus	Cable avoidance tool	Decontamination facilities for plant
Safety harness and lanyards		Decontamination facilities for personnel
Safety torches		Safe sampling procedures
Fire extinguishers		Safe sample handling procedures
First-aid equipment		Access for emergency vehicles
Mobile telephone		

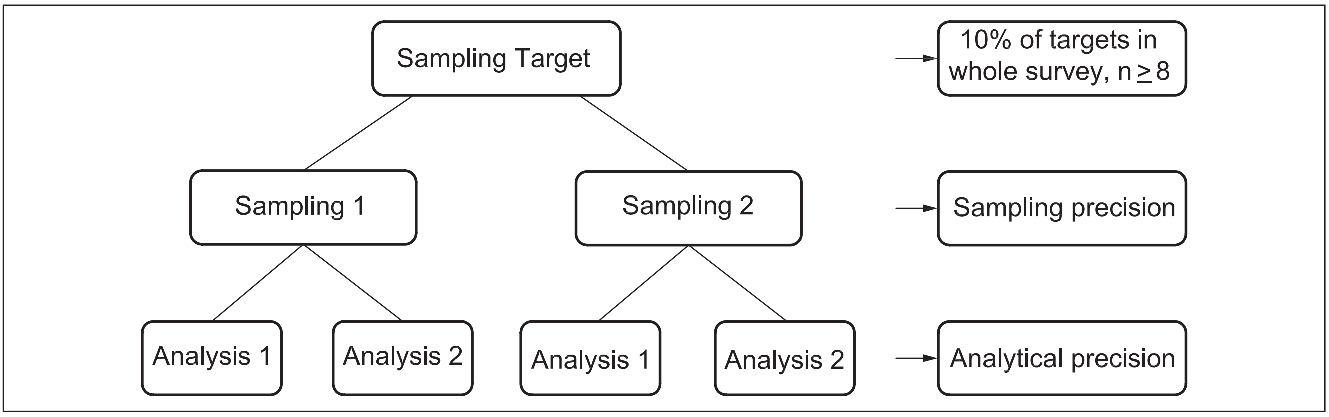
Annex D (informative) The assessment and control of sampling uncertainty

Total measurement uncertainty includes random (precision) and systematic (bias) effects from sampling in the field, sample preparation (e.g. sub-sampling within the laboratory, also discussed in **9.3.1**) and from chemical analysis. The uncertainty arising from sampling is generally greater than that arising from the analysis.

Methods to estimate the systematic effects of sampling are not well established and are generally ignored when assessing sampling uncertainty [methods do exist for estimating systematic effects of analysis (see **9.3.2**)].

Methods for estimating the random sampling uncertainty can involve the collection of duplicate samples at a number of sampling locations (called sampling targets) across a site. A minimum of eight duplicate samples is recommended to ensure that the uncertainty estimates are suitably robust. For larger investigations duplicates are taken at 10% of the targets, selected at random. The duplicate samples are taken by a fresh interpretation of the sampling protocol, and are not simply two splits of one sample. Two test portions are then taken at the laboratory from both duplicate samples, prepared separately, to give four test materials for analysis.

Figure D.1 **Duplicate method sampling design [84, modified]**



The analytical data from the four samples are then used to estimate sampling uncertainty by a technique called "analysis of variance". Further details on how to estimate sampling uncertainty are provided in Eurachem/EUROLAB/ CITAC/Nordtest/AMC Guide, *Measurement uncertainty arising from sampling* [73, Example A2], and six worked examples are given in CL:AIRE report RP4 [85]. The uncertainty from the sample preparation can be estimated separately using a modified sampling design [73, Appendix D].

Estimates of total measurement (and sampling) uncertainty are useful for the following purposes.

a) Judging, demonstrating and, if necessary, improving the fitness-for-purpose of the measurements for any particular site (e.g. in an exploratory investigation). The resulting uncertainty estimates can be used to minimize overall expenditure of site development (CL:AIRE RP4 [85]).

b) Making a probabilistic interpretation of the contamination at a site that allows for the uncertainty of the measurements, for either lab or field methods (EA 2009 RMT [69]).

c) Improving the confidence, robustness and transparency of decisions based on the information from a site investigation.

Estimating sampling uncertainty using the duplicate method might be particularly appropriate when:

1) the analytical results are close to the critical level of interest;

2) the ground is expected to be highly heterogeneous.

Annex E (informative) A1⟩ *Annex E deleted* ⟨A1

A1⟩ *Text and Figure deleted* ⟨A1

Annex F (informative) Rapid field measurement methods

F.1 General

This annex describes various commonly used rapid field measurement methods and identifies some inherent limitations. The selection is not definitive or exhaustive, but highlights considerations to be taken into account when using these tests.

Rapid field measurement methods (RFMMs) of analysis include a range of methods that can be used to provide qualitative results, semi-quantitative results or fully quantitative results: in the latter case sometimes comparable to those that can be achieved in an off-site laboratory. The term "screening methods" is in common use, for example in BS ISO 12404, but whilst applicable to qualitative and semi-quantitative methods, it does not do justice to the performance that can be achieved using some RFMMs. "Screening" is thus better restricted to the activity of making rapid decisions in the field, rather than the methods employed, which as indicated can range from those permitting simple go/no go answers (qualitative) to those capable of providing quantitative data.

One of the main criticisms of the use of portable instruments and test kits in the field is the lack of training given to staff who use them. Hence, inconsistent and erroneous results often arise from their misuse. Only staff trained by competent, experienced and appropriate persons ought to be permitted to use field measurement methods. Calibration and recording of field equipment is also important. Operating and calibration procedures ought to be fully documented and available in the field for users. As the analytical systems are used outside of a controlled laboratory environment, particular care needs to be given to their cleaning, storage and maintenance. Care also needs to be given to avoid cross contamination during field analysis.

The benefits of carrying out field screening can only be achieved if the quality of the work is controlled in the field and reported in the same manner as it would be in a permanent laboratory. The results produced by field instrumentation are reported in conjunction with calibration information and records of quality control performance. The QA/QC requirements of such work ought to be no less demanding than those for work undertaken in a laboratory. Detailed guidance on the use of field measurement methods is provided in EA 2009 RMT [69] and ISO 12404.

Much effort has been expended on the development of a number of robust rapid screening tests that will help to screen large numbers of samples quickly and allow prioritization of the samples that require further investigation.

The consequences of false negative or positive results have to be fully appreciated by investigation staff and clients. The potential financial liability resulting from false negative results can be very significant. Avoiding false negative results is very important; a few false positive results can be tolerated as subsequent laboratory back-up testing will identify these.

It is often desirable to compare field and laboratory data to ensure that the field method is performing to specification and to provide a correction factor to use when making decisions on site based on the field data. This is often done using linear regression analysis, where the field data are plotted on one axis and the lab data on the other. The R(sq) value provides a measure of degree of correlation and the first degree equation provides a correction factor that can be applied to the field data. When making statistical comparisons, sampling and sample splitting is critical to ensure satisfactory comparison data. Due to the heterogeneous nature of soil samples, it is recommended that discrete samples are used for this, rather than composites.

F.2 Soil samples

F.2.1 Field portable X-ray fluorescence

Field portable X-ray fluorescence (FP-XRF) using a portable energy dispersive XRF spectrometer is typically used to analyse samples for a wide range of metals without the need for sample preparation. The equipment is capable of detecting multiple elements simultaneously. The technique is subject to bias, e.g. from moisture content and some interelement effects. Detection limits for some metals, such as cadmium and mercury, are not always sufficiently low to provide adequate field information. Where the x-ray source is an isotope, the operator requires a licence and the HSE require notification under the Ionising Radiation Regulations 1999 [86]. Further information is provided in ISO/DIS 13196.

With careful sample preparation and application in the field, XRF instruments have been found to be of value in the provision of rapid analysis of a large number of soil samples for a variety of toxic metals at low cost. When the results are used in conjunction with laboratory analysis, it can confirm the levels and distribution of contaminants in the context of highly sensitive sites such as allotments, thereby enabling the assessment of risk to be carried out with greater confidence and a reduced level of uncertainty.

F.2.2 Toxicity and immuno-assay methods

Bio-luminescence and toxicity test methods can indicate the presence of potentially toxic substances. This is a holistic approach that detects toxic effects on species employed as biological indicators in the test used. These require the preparation of an aqueous leachate of soil sample. The results of such tests are purely qualitative, but allow rapid assessments to be made and are useful for indicating the likelihood of the presence of contamination which requires sampling and laboratory analysis.

Competitive reverse chemistry immuno-assay techniques can be used for organics and pesticides. They provide contaminant-specific information and many are quantitative. Immuno-assay techniques are usually based on selected concentrations so that the presence of contamination is identified as, for example, less than 1 mg/kg, between 1 mg/kg and 20 mg/kg, or greater than 20 mg/kg. Sample preparation and extraction in the field is required, which will not be as efficient as the equivalent laboratory process.

F.2.3 Colorimetric methods

Test kits with colorimetric detection provide semi-quantitative or quantitative results for metals and organics which allow rapid, low-cost screening of soil (after a suitable extraction step) and water samples which are useful for indicating whether a target value has been reached, e.g. in a remediation scheme. The method requires the use of acid or solvent extraction in the field, which will not be as sensitive as laboratory extraction techniques. The results can be influenced by chemical and physical parameters.

A dye shake test (using SUDAN IV dye) can be used as a non-quantitative method for detecting the presence of low concentrations of DNAPL in disturbed soil samples. The test involves mixing a small quantity of SUDAN IV dye with the soil sample in a vessel. The dye will partition to any non-aqueous phase liquids present, which will then show up as red globules within the soil matrix [87].

The technique requires suitable disposal methods to be identified for the reagents used.

F.2.4 Mobile laboratories

Some analytical laboratories offer a mobile laboratory system, in which a cabin or trailer is equipped with gas chromatography/mass spectrometry (GC/MS) and other specialized analytical equipment. This can be useful on very large projects, e.g. remediation schemes. Field laboratories can be accredited and operate to a set quality assurance procedure, but tend to be expensive.

F.3 Water samples

All of the techniques listed in **F.2** are also applicable to water samples.

In addition, portable direct-reading analysers (often based upon electrochemical principles) can be used to measure sample properties that change rapidly after removal from the local environment and following atmospheric exposure. The instruments use sensors or probes that are either placed directly into the liquid, or into the sample bottles after collection. The following properties and constituents can be determined with such instruments: pH, electrical conductivity, redox potential, temperature, turbidity, dissolved oxygen concentration, ammonia concentration.

Such devices always have to be operated in accordance with the manufacturer's recommendations and by suitably trained operatives. Probes have to be doused in an analyte-neutral solution and/or distilled water between sampling as suggested by the manufacturer's instructions. It is important to regularly check all machines against a known calibration solution as readings can become less accurate over time.

F.4 Gas/vapour samples

Field testing of gases, vapours and atmosphere enables detection and measurement of easily oxidized and reactive vapours and gases without risk of decomposition in the sample container during transportation to a laboratory.

Monitoring of gas and vapour composition can be carried out with instruments in a mobile laboratory. This equipment is connected by sampling tube to different sample locations, and then continuously records changes in the composition.

Permanent gases will also be monitored continuously using an in-borehole gas monitoring device, which is a sealed unit capable of fitting within a 50 mm standpipe and measuring and recording gas concentrations, water level and atmospheric pressure at defined time intervals.

Headspace testing for volatiles (e.g. testing a small air pocket within a soil sample container) can be undertaken using hand-held devices in the field. Headspace testing is often undertaken with photo-ionization detectors (PIDs) [see item b)].

More typically, monitoring is carried out in the field using portable instruments with samples also being collected and returned to a laboratory for compositional confirmation analysis (see **8.3.4**). The following instruments can be used.

a) *Flame ionization detectors (FIDs) and flammable gas detectors*

   These portable instruments respond to the presence of VOCs in soil, water and gas samples and are used for monitoring and quantification. The concentration recorded is expressed in terms of the compound used for calibration. For example, when monitoring for methane, the equipment is calibrated with methane. A drawback is that other volatile organic compounds will also give a response. Confirmation that the response is actually due to the presence of methane and not due to other organic compounds would have to be carried out in a laboratory using more sophisticated equipment. The response is related to the vapour pressure of the compound and some materials such as diesel or gas oil, although odorous, will not necessarily give a large response.

b) *Photo-ionization detectors (PIDs)*

   These instruments can be fitted with different lamps to vary the response to different groups of compounds based on ionization potential of the detected compound, e.g. chlorinated hydrocarbons or aromatics (benzene, toluene or xylene). However, the equipment does not measure these groups of compounds exclusively and results, therefore, have to be interpreted with great care. As with FID, the instrument reading is presented in terms of the vapour used for calibration, and diesel and gas oil will not necessarily give a large response. A PID is not suitable for the detection of methane.

c) *Infra-red analyzers*

   These instruments are typically used to detect the presence of methane and carbon dioxide. They measure the absorption of infra-red radiation by gases as they pass through the instrument, which is then converted into a concentration of gas. These instruments can be subject to interference from non-methane hydrocarbon vapours which can be falsely reported as methane. If hydrocarbon vapours are present, infra-red analysers can be used in conjunction with another detector, such as a PID.

More information on gas and VOC measurement techniques in the field is provided in C665 [59] and C682 [60].

F.5 Radioactivity

If the site history indicates that radioactive substances have been, or are, present it is essential that appropriate precautions are taken during any work on the site, including the reconnaissance visit [88]. Most significant radioactive contamination on the surface of the site can be identified using portable instruments to detect alpha, beta, gamma and, if necessary, neutron emissions. Gamma emissions from buried material can also be detected by such instruments. Soft beta emissions (particle energy less than about 200 keV) cannot be detected with such equipment and require a laboratory assay of samples, as do specific activity determinations. A negative field test result does not necessarily mean that there is no radioactivity present. This can only be confirmed by suitable laboratory testing.

All testing for radioactive contamination has to be carried out by suitably trained personnel and, if necessary, specialist advice obtained from the Radiation Protection Adviser Service of the Health Protection Agency[4)].

NOTE Guidance on the investigation and assessment of radioactivity in soils is provided in the ISO 18589 series.

Annex G (informative) Laboratory analysis

G.1 General

Using a specialist analytical laboratory allows the samples to be analysed using accredited methods, e.g. ISO 17025/MCERTS [36], in accordance with strict quality control procedures, which provides confidence in the reliability of the analytical results. This is of particular importance if the data are to be used to inform a risk assessment or to validate remediation.

The selection of an appropriate analytical method will depend on the analytes, sample matrix and limit of detection required. The analytical laboratory can advise on appropriate methods for analysis.

Further guidance on the various key aspects of chemical analysis of contaminated soil (QA/QC; sample preparation; metal, inorganic, petroleum hydrocarbons; PAHs; VOCs; SVOCs; leaching tests and ecological assessment) is given in Thompson and Nathanail 2003 [89].

G.2 Quality assurance

The biggest problem in the analysis of land potentially affected by contamination is the very wide range of matrices encountered (e.g. clay, peat, limestone, sandstone, steel slag, waste materials, demolition debris, made ground, etc.). It can be difficult to ensure that unacceptable biases do not arise for a small percentage of extreme samples when using a given contaminated soil analysis method with a single calibration function. Various QA/QC protocols are used to minimize these effects.

Figure G.1 and Figure G.2 depict the concepts of precision and bias. A repeat analysis of a highly biased yet precise method result will give a similar, but inaccurate, result. **The more complex the sample matrix, the larger the likely bias**. This is why careful and comprehensive

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4) Health Protection Agency Radiation Protection Division: http://www.hpa-radiationservices.org.uk/rpa Telephone: 01235 822670.

method verification and consistent on-going QC is a key requirement for the analysis of land potentially affected by contamination.

Figure G.1 **Good precision, negligible bias**

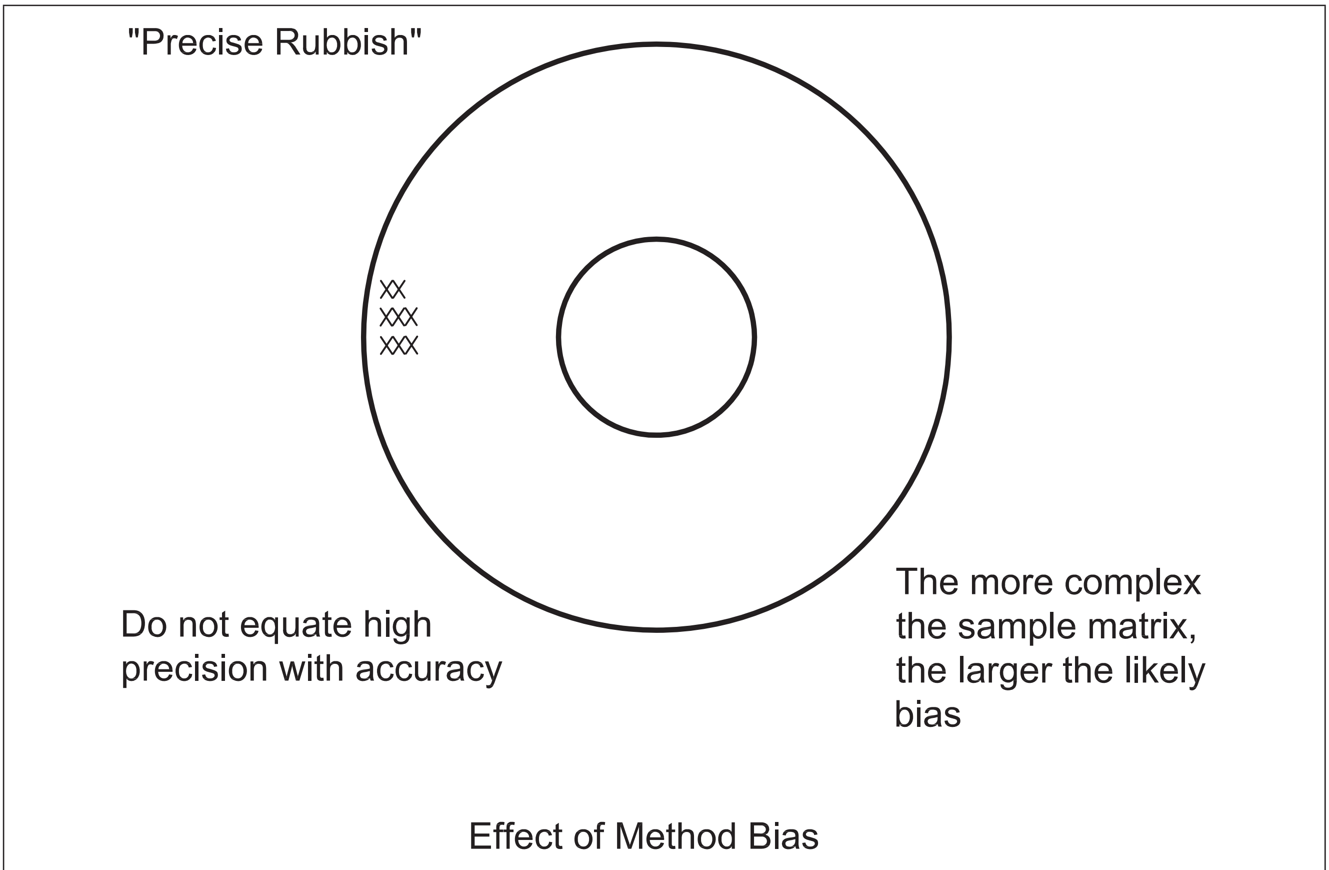

Figure G.2 **Good precision, significant bias**

G.3 MCERTS accreditation

The introduction of the MCERTS performance standard [36] has improved the quality of soil analysis of land potentially affected by contamination as accredited laboratories have to demonstrate comprehensive verification data for all matrix types that are covered by the accreditation and consistent on-going QC data.

MCERTS-accredited analysis requires laboratories to be accredited to BS EN ISO/IEC 17025 for the MCERTS performance standard [36]. Accreditation is undertaken by an appropriate national organization, which in the United Kingdom is the United Kingdom Accreditation Service (UKAS). The MCERTS performance standard [36] covers:

a) performance targets;

b) the selection and verification of methods;

c) sampling pre-treatment and preparation;

d) participation in proficiency testing schemes;

e) the reporting of results and information.

If soil chemical testing results are to be submitted to the Environment Agency for regulatory purposes, MCERTS-accredited analysis is required (see [36] and www.mcerts.net). Any MCERTS-accredited method can be used as long as it has been validated for all relevant soil matrices. SEPA welcomes the submission of MCERTS-accredited data. However, SEPA does not stipulate that only MCERTS-accredited analytical methods are used. SEPA expects all data, and methods used for generating data, to be fit-for-purpose. Other Scottish regulators may require submission of MCERTS-accredited data (see also **9.1**, Note 2).

Currently, MCERTS accreditation does not include water (other than sampling and chemical testing of untreated sewage, treated sewage effluents and trade effluents) or air monitoring methods.

G.4 Typical laboratory analyses

Generally, the laboratory test method used depends on the specific parameter being determined, the detection limit specified and the method of accreditation required. For example, the selection of an analytical method for the detection of petroleum hydrocarbons depends primarily on whether a total petroleum hydrocarbon screen or a more detailed, speciated petroleum hydrocarbon analysis with carbon banding and aliphatic and aromatic separation is required (see Table G.1).

Most laboratories have only one accredited method available for a specific parameter and matrix. Consequently, the selection of appropriate testing methods is normally undertaken in consultation with an analytical laboratory (preferably the laboratory that will eventually carry out the chemical testing).

A summary of some laboratory analyses is provided in Table G.1 (please note that this list is not exhaustive).

Table G.1 **Laboratory analyses**

Parameter	Common analysis methods	Comments
Metals and metalloids	Inductively coupled plasma – optical emission spectrometry (ICP-OES) or induction coupled plasma – mass spectrometry (ICP-MS)	It is important to make allowance for the matrix, either by matching standards or other suitable means. It is necessary to avoid spectral interferences in ICP-OES and isobaric interferences in ICP-MS.
Anions	Ion chromatography, high performance liquid chromatography (HPLC) and spectrophotometry	Methods depending on the required analyte and limits of detection. It is important to use an appropriate analyte extraction method prior to the final measurement step.
Total petroleum hydocarbons (screen)	Fourier-transform infra-red spectroscopy (FTIR)	For total petroleum hydrocarbons (TPHs) measurement only (no speciation possible). The method is subject to interference from various sources and a positive result can be obtained from non-petroleum sources, making interpretation difficult.
Total petroleum hydrocarbons (with carbon banding)	Gas chromatography (GC) with flame ionization detector (FID)	This technique can provide total TPH and carbon-banded results [90]. The sample extract can be pre-treated to achieve class separation of aromatic and aliphatic fractions, which is commonly used for numerical risk assessment. Can also detect benzene, toluene, ethylbenzene and xylenes (BTEX), methyl-tert butyl ether (MTBE) and "total volatiles".
Polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), pesticides	Gas chromatography/mass spectrometry (GC/MS). GC with electron capture detector (ECD) for PCBs and some pesticides GC with flame ionization detector (FID) for PAHs	Analysis of specific compounds or groups of compounds. It requires an experienced scientist to interpret the results. The use of MS detection, as opposed to non-selective detection techniques such as FID and ECD, normally significantly reduces interference effects and is therefore generally preferred.
VOCs and SVOCs	GC/MS	GC/MS combined with headspace analysis or purge and trap is used to detect VOC species (e.g. USEPA headspace analysis method 5021; purge and trap method 5030B and closed system purge and trap method 5035). See http://www.ehso.com/ehso3.php?URL=http%3A%2F%2Fwww.epa.gov/epahome/pdf.html and [91].
Phenols	Colorimetric analysis	Relatively cheap screening method for the determination of monohydric phenols after a suitable distillation step
	High performance liquid chromatography (HPLC) using electrochemical detection (ECD)	Information on speciated phenolic compounds can be obtained.
	GC/MS	Can be used to quantify chlorinated phenols and speciated phenolic compounds after suitable derivatization.
Asbestos	Microscope	Carried out by a trained analyst. There are various levels of asbestos analysis, the most basic level being visual screening, which determines whether fibres are present within the sample. Following on from this, the individual fibres can then undergo identification to determine whether they are of asbestos and, if so, the type of asbestos present. Quantitative analysis involves the reporting of a quantity of asbestos as a percentage of the soil sample.
Soil leachate preparation	Empirical methods carried out using BS EN12457-2 or BS EN12457-3	Not suitable for VOCs. It is essential that the exact BS EN 12457 procedure is followed, as even minor changes in the test protocol can lead to significant variation in the results obtained.

G.5 Biological assessment

Testing may also be carried out to determine the presence of biological hazards (such as anthrax, pathogenic fungi such as *Aspergillus spp.* and pathogenic *Legionella spp*) within soil and site structures, e.g. old water tanks and water systems. Testing may also be carried out to determine the ecotoxicological effects of contaminants in soil (ecotoxicity testing). The microbial population within soil samples may also be assessed to determine whether species are present which could be used in biological remediation. The addresses of internet sites containing published lists of relevant biological methods standards are located in the "Further reading" section of the Bibliography. ISO 15799 provides guidance on the selection of experimental methods for the assessment of the ecotoxic potential of soils and soil materials. BS ISO 10381-6 gives guidance on the collection of samples for the assessment of microbial processes, biomass and biodiversity under aerobic conditions.

Advantages of biological analytical approaches include:

a) direct measurement of effects on biota, rather than inferring these from comparisons of residue data and the results of laboratory toxicity tests;

b) responding to all contaminants present rather than only those in a predefined analytical suite;

c) accounting for contaminant interaction with soil factors;

d) integrating the combined effects of simple and complex mixtures;

e) providing powerful tools for risk communication by demonstrating the presence/absence of the components and functions of a healthy ecosystem.

G.6 Physical assessment

In addition to chemical testing, it is sometimes necessary to carry out some geotechnical and physical testing in order to characterize the physical nature of the soils, particularly if numerical risk assessment is required to be carried out. This is necessary in order to understand how contaminants can be contained and migrate in the ground. Geotechnical information can also be required for designing remediation works. Geotechnical test methods are specified in BS 1377.

NOTE BS 1377 test methods will be withdrawn as replacement European Standards (ENs) are published.

Such geotechnical testing can include determination of:

a) particle size distribution;

b) plasticity index (Atterberg limits);

c) bulk density;

d) permeability.

A range of standard methods for determining such physical properties of soils as those in a) to d), and specifically intended for use in studies of soil quality, is also available. In some circumstances these methods will be used rather than those intended for geotechnical purposes. These methods are listed in the "Further reading" section of the Bibliography.

G.7 Oral bioaccessibility testing

Some laboratories in the UK offer oral bioaccessibility testing of soils (particularly for metals). Oral bioaccessibility tests aim to measure the fraction of a contaminant in soil that is soluble in the gastrointestinal tract of humans and is available for absorption [92]. The tests are described as "*in vitro*" as they are undertaken in the laboratory and attempt to mimic conditions in the human intestines (as opposed to "*in vivo*" animal studies which measure oral bioavailability, the fraction of an administered dose that reaches the blood stream from the gastrointestinal tract). A review of some of the bioaccessibility testing methods available can be found in references [92,93,94]. Further information on bioavailability testing can be found in ISO 17402 and DD ISO/TS 17924.

Processes which occur in the human gastrointestinal tract are complex and hard to simulate. There are significant limitations in the bioaccessibility testing methods currently available, such as the following.

a) Bioaccessibility is specific to the method, site, chemical and chemical form being tested, so there is considerable variability between different methods and samples.

b) A method developed and validated for one chemical or matrix cannot be used for other contaminants or matrix types.

c) No evaluation of *in vitro* bioaccessibility results against *in vivo* data for different soil types has been undertaken [and furthermore none of the available *in vivo* (animal study) data have been validated against human data]; consequently, there are no reference materials available to assess the accuracy or precision of in vitro bioaccessibility methods.

d) There are no internationally recognized standard methods for bioaccessibility testing.

As a result of the current limitations in bioaccessibility testing the Environment Agency currently considers that *in vitro* tests ought to be used cautiously in assessing risks to health from soil contaminants because the relationship between measured bioaccessibility and the relative human biological availability/toxicity of contaminants remains uncertain. However, provided that testing has been carried out in accordance with guidelines for good practice, the Environment Agency considers that the results of bioaccessibility may be useful for arsenic as part of a "lines of evidence approach" to evaluating site-specific risk including the sensitivity of any quantitative risk assessment [93]. The use of oral bioaccessibility testing ought to be discussed with the appropriate regulator in advance of works.

Annex H (informative) Suitability of sample containers

Table H.1 **Suitability of sample containers**

Container material	Contamination present					Analytical requirements					
	Acid	Alkaline	Oils/ tars	Solvents	Gas	Inorganic	Oils/ tars	Solvents and organic compounds	Volatile compounds	Advantages	Disadvantages
Plastic bag	++	++	—	—	—	++	—	—	—	Low cost	Difficult to remove excess air/easily damaged/difficult to seal completely and not recommended for these reasons
Plastic tub with snap-on lid	++	++	—	—	—	++ A)	—	—	—	Low cost/ standard equipment	—
Wide mouthed amber glass bottles B),C) (screw capped)	++	—	++	++ C)	—	++	++	++ C)	++ C)	Inert/ standard equipment	Fragile
Fluorinated polymer containers, e.g. PTFE	++	++	++	++	—	++	++	+	+	Inert	Cost/non-standard equipment
Tins with push fit lids	—	—	++	++	—	++	++	+	+	—	Rusting, affected by acids/non-standard equipment
Driven probe tubes (all need to be suitably sealed)	++	++	+	++	+	++	+	++	++	Standard equipment/ low cost	Obtaining sample from container/ samples in contact with a plastic liner might be unsuitable for organics
Specialized low pressure sampling bags/ tubes for permanent gases	—	—	—	—	++	—	—	—	—	Inert	Requires specialized sampling equipment
Adsorption tubes	—	—	—	++	—	—	—	++	++	—	Usually require specialized sampling equipment/have to be kept sealed when not in use

++ Very suitable + May be suitable — Unsuitable

It is recommended that the analysing laboratory be consulted to ensure that the appropriate sample container is used. Laboratories will typically prefer to supply the appropriate containers together with a cool box and ice packs for transport, to ensure the integrity of the samples is maintained. The laboratory's requirements for sample containers have to take precedence and might be required for MCERTS.

A) Should not be used for investigation of land potentially affected by contamination where it is possible that analysis for organic contamination will be required.

B) For optimum performance when VOCs are present, can require use of undisturbed sample with solvent such as methanol.

C) Use of PTFE or other non-reactive septum within the screw cap might be appropriate.

Annex I (informative) [A1⟩ *Annex I deleted* ⟨A1]

[A1⟩ *Text deleted* ⟨A1]

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Standards publications

For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

NOTE A list of standards for determining physical and biological characteristics is given in the "Further reading" section.

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BS 1747 (all parts), *Methods for measurement of air pollution*

BS 22475:2011, *Geotechnical investigation and testing – Sampling methods and groundwater measurements – Part 2: Qualification criteria for enterprises and personnel*

BS ISO 3534-1, *Statistics – Vocabulary and symbols – Part 1: General statistical terms and terms used in probability*

BS ISO 5667-22, *Water quality – Sampling – Part 22: Guidance on the design and installation of groundwater monitoring points*

BS ISO 15175, *Soil quality – Characterization of soil relating to groundwater protection*

BS ISO 15176, *Soil quality – Characterization of excavated soil and other soil materials intended for re-use*

BS ISO 18283, *Hard coal and coke – Manual sampling*

BS ISO 18589, *Measurement of radioactivity in the environment*

BS ISO 23909, *Soil quality – Preparation of laboratory samples from large samples*

DD ISO/TS 17924, *Soil quality – Assessment of human exposure from ingestion of soil and soil material – Guidance on the application of physiologically based extraction methods for estimation of bioaccessibility/bioavailability of metals in soil*

[A1⟩ BS ISO 10381-3:2001, *Soil quality – Sampling – Part 3: Guidance on safety* ⟨A1]

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ISO 12404 (in preparation), *Soil quality – Guidance on the selection and application of screening methods*

ISO 15799, *Soil quality – Guidance on the ecotoxicological characterization of soils and soil materials*

ISO 15800, *Soil Quality – Characterization of soil with respect to human exposure*

ISO 17402:2008, *Soil quality – Requirements and guidance for the selection and application of methods for the assessment of bioavailability of contaminants in soil and soil materials*

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Further reading

Standards for the determination of the chemical, physical and biological characteristics of soil and water

BS 7755-3.1:1994, *Soil quality – Part 3: Chemical methods – Section 3.1: Determination of dry matter and water content on a mass basis by a gravimetric method*

BS 7755-3.3:1995, *Soil quality – Part 3: Chemical methods – Section 3.3: Determination of effective cation exchange capacity and base saturation level using barium chloride solution*

BS 7755-3.4:1995, *Soil quality – Part 3: Chemical methods – Section 3.4: Determination of the specific electrical conductivity*

BS 7755-3.6:1995, *Soil quality – Part 3: Chemical methods – Section 3.6: Determination of phosphorus – Spectrometric determination of phosphorus soluble in sodium hydrogen carbonate solution*

BS 7755-3.7:1995, *Soil quality – Part 3: Chemical methods – Section 3.7: Determination of total nitrogen – Modified Kjeldahl method*

BS 7755-3.9:1995, *Soil quality – Part 3: Chemical methods – Section 3.9: Extraction of trace elements soluble in aqua regia*

BS 7755-3.10:1995, *Soil quality – Part 3: Chemical methods – Section 3.10: Determination of carbonate content – Volumetric method*

BS 7755-3.11:1995, *Soil quality – Part 3: Chemical methods – Section 3.11: Determination of water-soluble and acid-soluble sulfate*

BS 7755-3.12:1996, *Soil quality – Part 3: Chemical methods – Section 3.12: Determination of the potential cation exchange capacity and exchangeable cations using barium chloride solution buffered at pH = 8.1*

BS 7755-3.13:1998, *Soil quality – Part 3: Chemical methods – Section 3.13: Determination of cadmium, chromium cobalt, copper, lead, manganese, nickel and zinc in aqua regia extracts of soil – Flame and electrothermal atomic absorption spectrometric methods*

BS 7755-4.1.1:1995, *Soil quality – Part 4: Biological methods – Section 4.1: Biodegradability – Subsection 4.1.1: Guidance on laboratory testing for biodegradation of organic chemicals in soil under aerobic conditions*

BS 7755-4.2.1:1994, *Soil quality – Part 4: Biological methods – Section 4.2: Effects of pollutants on soil fauna – Subsection 4.2.1: Determination of acute toxicity to earthworms (Eisenia fetida) using artificial soil substrate*

BS 7755-4.2.2:1998, *Soil quality – Part 4: Biological methods – Section 4.2: Effects of pollutants on soil fauna – Subsection 4.2.2: Determination of effects on reproduction on earthworms (Eisenia fetida)*

BS 7755-4.2.3:1999, *Soil quality – Part 4: Biological methods – Section 4.2: Effects of pollutants on soil fauna – Subsection 4.2.3: Effects of pollutants on earthworms – Guidance on the determination of effects in field situations*

BS 7755-4.2.4:1999, *Soil quality – Part 4: Biological methods – Section 4.2: Effects of pollutants on soil fauna – Subsection 4.2.4: Inhibition of reproduction of Collembola (Folsomia candida) by soil pollutants*

BS 7755-4.3.1:1994, *Soil quality – Part 4: Biological methods – Section 4.3: Effects of pollutants on soil flora – Subsection 4.3.1: Method for the measurement of inhibition of root growth*

BS 7755-4.4.1:1997, *Soil quality – Part 4: Biological methods – Section 4.4: Effects of pollutants on microbes – Subsection 4.4.1: Determination of soil microbial mass – Substrate-induced respiration method*

BS 7755-4.4.2:1997, *Soil quality – Part 4: Biological methods – Section 4.4: Effects of pollutants on microbes – Subsection 4.4.2: Determination of soil microbial mass – Fumigation-extraction method*

BS 7755-4.4.3:1997, *Soil quality – Part 4: Biological methods – Section 4.4: Effects of pollutants on microbes – Subsection 4.4.3: Determination of nitrogen mineralization and nitrification in soils and the influence of chemicals on these processes*

BS 7755-4.4.4:1997, *Soil quality – Part 4: Biological methods – Section 4.4: Effects of pollutants on microbes – Subsection 4.4.4: Laboratory incubation systems for measuring the mineralization of organic chemicals in soil under aerobic conditions*

BS 7755-5.1:1996*, Soil quality – Part 5: Physical methods – Section 5.1: Determination of pore water pressure – Tensiometer method*

BS 7755-5.2:1996, *Soil quality – Part 5: Physical methods – Section 5.2: Determination of water content in the unsaturated zone – Neutron depth probe method*

BS 7755-5.3:1998, *Soil quality – Part 5: Physical methods – Section 5.3: Determination of particle density*

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BS 7755-5.5:1999, *Soil quality – Part 5: Physical methods – Section 5.5: Laboratory methods*

BS 7755-5.6:1999, *Soil quality – Part 5: Physical methods – Section 5.6: Determination of dry bulk density*

BS 8855-2:2000, *Soil Analysis – Part 2: Method for the determination of coal tar-derived phenolic compounds*

BS EN 12457-1:2002, *Characterisation of waste – Leaching – Compliance test for leaching of granular waste materials and sludges – Part 1: One stage batch test at a liquid to solid ratio of 2 l/kg for materials with high solid content and with particle size below 4 mm (without or with size reduction)*

BS EN 12457-2:2002, *Characterisation of waste – Leaching – Compliance test for leaching of granular waste materials and sludges – Part 2: One stage batch test at a liquid to solid ratio of 10 l/kg for materials with particle size below 4 mm (without or with size reduction)*

BS EN 12457-3:2002, *Characterisation of waste – Leaching – Compliance test for leaching of granular waste materials and sludges – Part 3: Two stage batch test at a liquid to solid ratio of 2 l/kg and 8 l/kg for materials with a high solid content and with a particle size below 4 mm (without or with size reduction)*

BS EN 12457-4:2002, *Characterisation of waste – Leaching – Compliance test for leaching of granular waste materials and sludges – Part 4: One stage batch test at a liquid to solid ratio of 10 l/kg for materials with particle size below 10 mm (without or with size reduction)*

BS ISO 11262:2003, Soil *quality – Determination of cyanide*

BS ISO 11269-2:2005, *Soil quality – Determination of the effects of pollutants on soil flora – Part 2: Effects of chemicals on the emergence and growth of higher plants*

BS ISO 11271:2002, *Soil quality – Determination of redox potential – Field method*

BSI ISO 11275:2004, *Soil quality - Determination of unsaturated hydraulic conductivity and water retention characteristics – Wind's evaporation method*

BS ISO 11461:2001, *Soil quality – Determination of soil water content as a volume fraction using coring sleeves – Gravimetric method*

BS ISO 13090: 2005, *Soil quality – Determination of pH*

BS ISO 14154:2003, *Soil quality – Determination of some selected chlorophenols – Gas-chromatographic method with electron-capture detection*

BS ISO 14869-2:2002, *Soil quality – Dissolution for the determination of total element content – Part 2: Dissolution by alkaline fusion*

BS ISO 15009:2002, *Gas-chromatographic determination of volatile aromatic hydrocarbons, naphthalene and halogenated hydrocarbons – Purge and trap method with thermal desorption*

BS ISO 15903:2002, *Soil quality – Format for recording soil and site information*

BSI ISO 16072:2002, *Soil quality – Laboratory methods for determination of microbial soil respiration*

BS ISO 16387:2004, *Soil quality – Effects of pollutants on Enchytraeidae – Determination of effects on reproduction and survival*

BS ISO 16703:2004, *Soil quality – Determination of content of hydrocarbon in the range C10 to C40 be gas chromatography*

BS EN ISO 16720:2007, *Soil quality – Pretreatment of soil samples by freeze drying for subsequent analysis*

BS ISO 16772:2004, *Soil quality – Determination of mercury in aqua regia soil extracts with cold-vapour atomicabsorption spectrometry or cold-vapour atomic fluorescence spectrometry*

BS ISO 17126: 2005, *Soil quality – Determination of the effects of pollutants on seedlings*

BS ISO 17155:2002, *Soil quality – Determination of abundance and activity of soil microflora using respiration curves*

BS ISO 17313:2004, *Soil quality – Determination of hydraulic conductivity of saturated porous materials using a flexible wall permeameter*

BS ISO 17380: 2004, *Soil quality – Determination of total cyanide and easily releasable cyanide content – Method by continuous flow analysis*

BS ISO 17616:2008, *Soil quality – Guidance on the choice and evaluation of bioassays for ecotoxicological characterization of soils and soil materials*

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

BS ISO 19258:2005, *Soil quality – Guidance on the determination of background values*

BS ISO 19730: 2008, *Soil quality – Extraction of trace elements using ammonium nitrate solution*

BS ISO 20280:2008, *Soil quality – Determination of arsenic, antimony and selenium in aqua regia soil extracts with electrothermal or hydride-generation atomic absorption spectrometry*

BS ISO 22030:2005, *Soil quality – Chronic toxicity test in higher plants*

BS ISO 22036: 2008, *Soil quality – Determination of trace elements in extracts of soil by inductively coupled plasma – Atomic emission spectrometry (ICP – AES)*

BS ISO 22155: 2005, *Soil quality – Gas chromatographic determination of volatile aromatic and halogenated hydrocarbons and selected ethers – Static headspace method*

BS ISO 22892:2006, *Soil quality – Guidelines for the identification of target compounds by gas chromatography/mass spectrometry*

BS ISO 23161:2009, *Soil quality – Determination of selected organotin compounds – Gas chromatographic method*

BS ISO 23470:2007, *Soil quality – Determination of effective cation exchange capacity (CEC) and exchangeable cations using a cobaltihaxamine trichloride solution*

BS ISO 23611-4:2008, *Soil quality – Sampling of soil invertebrates – Part 4: Sampling and extraction and identification of free-living stages of terrestrial nematodes*

BS ISO 25177:2008, *Soil quality – Field soil description*

PD CEN/TR 15584:2007, *Characterisation of sludges – Guide to risk assessment especially in relation to use and disposal of sludges*

DD 8855-1:1999, *Soil Analysis – Part 1: Determination of polycyclic aromatic hydrocarbons (PAH)*

DD 220:1994, ISO/TR 11046:1994, *Soil quality – Determination of mineral oil content – Method by infrared spectrometry and gas chromatographic*

ISO/TC 190 Soil quality methods

http://www.iso.org/iso/iso_technical_committee?commid=54328

http://www.iso.org/iso/iso_catalogue/catalogue_tc/catalogue_tc_browse.htm?commid=54328&published=on

ISO/TC 147/SC 2 Water quality physical, chemical and biochemical methods

http://www.iso.org/iso/iso_technical_committee.html?commid=52846

http://www.iso.org/iso/iso_catalogue/catalogue_tc/catalogue_tc_browse.htm?commid=52846&published=on

ISO/TC 147/SC 5 Water quality biological methods

http://www.iso.org/iso/iso_technical_committee.html?commid=52972

Standing Committee of Analysts (SCA) and Publications Catalogue, Chemical, physical, biochemical and microbiological methods.

http://www.environment-agency.gov.uk/research/commercial/32874.aspx

NOTE The Standing Committee of Analysts (SCA) exists to provide authoritative guidance on methods of sampling and analysis of waters and effluents, sewage sludges, sediments, soils (including contaminated land) and biota. The primary duty of SCA is to develop and publish recommended analytical methods. All methods considered should be capable of satisfying a regulatory demand, be fit for purpose and represent best practice within the United Kingdom (UK). However, it is still a requirement that users demonstrate their own capabilities when using such methods.

Useful websites containing publications on contaminated land

The following bodies regularly publish information on the assessment of contaminated land.

Construction Industry Research and Information Association

http://ciria.org.uk.

Health and Safety Executive

http://www.hse.gov.uk/

Environment Agency

http://www.environment-agency.gov.uk/

Scottish Environment Protection Agency (SEPA)

http://www.sepa.org.uk/

Department for Environment, Food and Rural Affairs

http://ww2.defra.gov.uk/

Contaminated Land: Applications In Real Environments (CL:AIRE)

http://www.claire.co.uk/

Industry profiles

Industry Profiles provide developers, local authorities and anyone else interested in contaminated land with information on the processes, materials and castes associated with individual industries. They also provide information on the contamination which might be associated with specific industries, factors that affect the likely presence of contamination, the effect of mobility of contaminants and guidance on potential contaminants. They are not definitive studies, but introduce some of the technical considerations that need to be in mind at the start of an investigation for possible contamination.

Industry profiles can be found on the Environment Agency website: http://www.environment-agency.gov.uk/research/planning/33708.aspx

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