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Soil quality — Sampling —

Part 203:
Investigation of potentially contaminated sites

Qualité du sol — Échantillonnage —

Partie 203: Investigation des sites potentiellement contaminés

Reference number
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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 190, *Soil quality*, Subcommittee SC 2, *Sampling*.

This first edition of ISO 18400-203, together with ISO 18400-104 and ISO 18400-202, cancels and replaces ISO 10381-5:2005, which has been technically and structurally revised.

The new ISO 18400 series is based on a modular structure and cannot be compared to ISO 10381-5 clause by clause.

A list of all parts in the ISO 18400 series can be found on the ISO website.

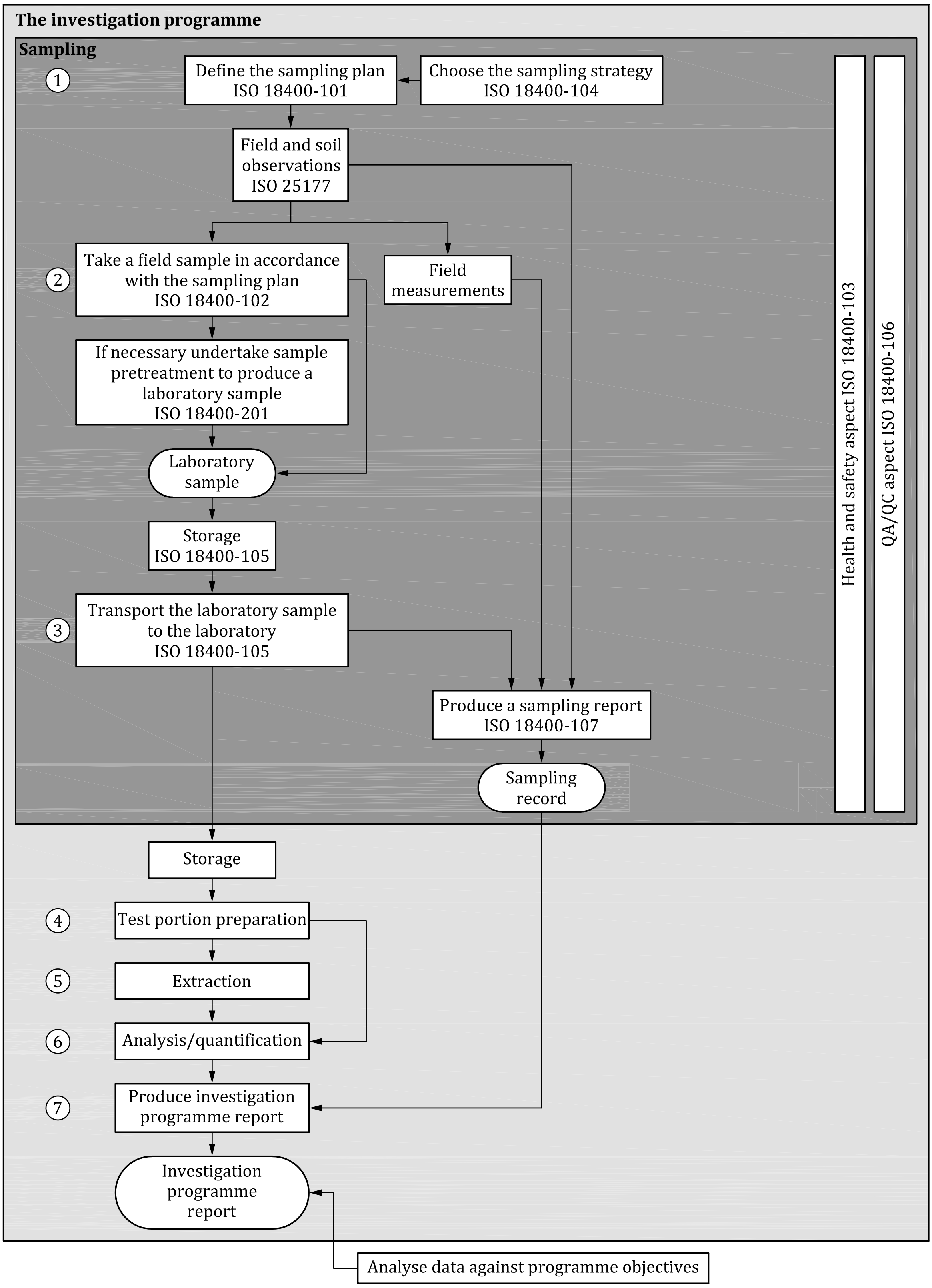
Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

This document is one of a series of standards dealing with various aspects of site investigation and sampling. It is intended to be used in conjunction with the other parts of the ISO 18400 series. The role/position of the individual standards within the total investigation programme is shown in Figure 1.

While serious cases of soil contamination mostly occur on urban and industrial sites, serious contamination of agricultural land can also occur (for example, due to pesticides usage, long-term irrigation and application of organic wastes). In addition, it is important to recognize that agricultural, near-natural and wooded sites, etc. are sometimes developed on deposited wastes or suffer severe aerial deposition when close to industrial sites. In such cases, a combination of the methodologies described in ISO 18400-205 and in this document would be appropriate.

An understanding of the surface water, groundwater and soil gas regimes is essential to the assessment of the potential risks to human health and safety and to other potential receptors including, for example, groundwater resources. However, the provision of detailed guidance on the investigation of groundwater, surface water and soil gas falls outside the scope of this document. For more information on groundwater and surface water sampling, see ISO 5667. Guidance on the sampling of soil gas is provided in ISO 18400-204.



NOTE 1 The numbers in circles in this figure define the key elements (1 to 7) of the investigation programme.

NOTE 2 This figure displays a generic process which can be amended when necessary.

Figure 1 — Links between the essential elements of an investigation programme

Soil quality — Sampling —

Part 203: Investigation of potentially contaminated sites

1 Scope

This document gives guidance on the:

— investigation of sites, where either it is known that soil contamination is present, or the presence of soil contamination is suspected;

— investigation of sites where no soil contamination is expected, but the soil quality is to be determined (e.g. to make sure that there is no contamination present);

— investigation in anticipation of a need to manage re-use or disposal of excavated soil which might be contaminated;

— collection of information that is necessary for risk assessment and/or the development of remedial action plans (e.g. whether remediation is required and suggestions as to how this might be best achieved).

Although the information on soil quality for the risk assessment and/or the development of remedial action plans is gathered by applying this document, it does not give guidance on the decisions and actions that follow from a site investigation, for example, risk assessment and decisions about the requirements for remediation (if any).

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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.

ISO 11074, *Soil quality — Vocabulary*

ISO 18400-104, *Soil quality — Sampling — Part 104: Strategies*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 11074 and ISO 18400-104 apply.

NOTE When the definitions in these two standards differ, those in ISO 18400-104 take precedence.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

4 Objectives

4.1 General

This document provides a framework for the various phases and stages in the investigation of potentially contaminated sites. The resulting determination of the contamination status can then lead to risk assessment and, where necessary, facilitate the selection and application of appropriate remedial actions. Guidance on data and information requirements for particular purposes is provided in a number of International Standards including ISO 11504, ISO 15175, ISO 15176, ISO 15799 and ISO 15800.

Investigations for contamination could be required:

— when the purpose is to identify and deal with contamination (e.g. site where it is known or believed there might be unacceptable risks to humans or other receptors – sometimes called "problem" sites);

— incidental to plans for the redevelopment of sites (e.g. of an industrial site for housing); or

— especially in urban areas, because it is known that possibly contaminated soils will have to be excavated and removed from the site (e.g. because basements are to be formed, utilities installed or underground infrastructure built).

The guidance provided in this document should be adapted as appropriate for these and any other circumstances where potential contamination is an issue.

NOTE 1 Contamination is defined in ISO 11074 as a result of human influences; however, the methods described for investigation are also applicable where there are naturally high concentrations of potentially harmful substances.

NOTE 2 With respect to remediation, this document only provides guidance on the information required in general. Specific remediation methods could need additional information.

NOTE 3 This document deals only with the investigation of the ground. On old urban and industrial sites, there could be derelict buildings and/or industrial plants awaiting demolition, dismantling or refurbishment. Failure to investigate these buildings before demolition could put the safety of workers at risk or lead to the spread of contamination on and around the site. The investigation of derelict buildings or remnant foundations falls outside the scope of this document.

NOTE 4 In many situations, there is a close relation between the contamination of the soil, groundwater, soil gas and, to a lesser extent, surface water. Consequently, an understanding of the surface water, groundwater and soil gas regimes is essential to the assessment of the potential risks to human health and safety and to other potential receptors including, for example, groundwater resources. However, the provision of detailed guidance on the investigation of groundwater, surface water and soil gas falls outside the scope of this document. For more information on groundwater and surface water sampling, see ISO 5667. Guidance on the sampling of soil gas is provided in ISO 18400-204.

4.2 Definitions of objectives

The reasons for an investigation and hence the objectives can vary widely but are generally to:

— identify and assess the risks to those using the site, and in the event of redevelopment, to subsequent users and occupiers of the site;

— identify and assess the risks presented to the environment including adjacent land, surface and groundwater, ecosystems and public health;

— identify and assess the risks which could be presented to workers who are involved in investigation, remediation, redevelopment or maintenance of the site;

— enable proper management of excavated materials especially on urban sites;

— identify and assess the potential for adverse effects on building materials;

so that decisions can be made about the importance of the risks and whether it is necessary to take any form of action to deal with them.

From the principal objectives of the investigation, a number of subsidiary objectives can be derived. These might include the following:

a) determine if any immediate action is required to protect exposed receptors;

b) identify compounds that are, or might be, present that might represent a risk to one or more actual or potential receptors;

c) identify receptors (e.g. human, ecosystems, groundwater) that are or might in the future be at risk;

d) identify pathways by which particular receptors might be exposed to the contaminants;

e) provide the data and other information to use in a risk assessment;

f) provide information to aid the design of protective or remedial measures;

g) provide information to aid the management of excavated soil and other materials;

h) enable characterization of contaminated soil and other materials to ensure safe and suitable handling and disposal;

i) provide reference data against which the achievement of remediation performance can be judged;

j) enable judgements to be made about the likely impact of continued use of the site on the environment including soil quality;

k) provide information to assess the risk of (legal) environmental liabilities and the effect on the value of the property.

These generalized objectives will be formulated into specific requirements depending upon the purpose of the investigation.

EXAMPLE A site investigation prior to the purchase of a site for redevelopment could have one or more of the following objectives:

— establish the history of the site and the potential for the presence of contamination;

— establish the nature, extent and distribution of contamination within the site boundaries;

— identify the potential for migration of contamination beyond the site boundaries including surface and groundwater (this could indicate there are potential legal environmental liabilities);

— identify any immediate dangers to public health, safety, and the environment;

— identify contamination-related constraints in relation to a proposed development (e.g. human and environmental risks) and any remedial works necessary and provide data from which to develop cost estimates;

— provide information to facilitate the formulation of a full interpretative report with conclusions, recommendations and budget costing for remedial actions, if required;

— provide information to facilitate the advice to the client about how to address the issues raised by any off-site migration of contamination.

5 General strategy of site investigation

5.1 General

Determination of the extent of a contaminated area and, particularly, the assessment of human and environmental risks caused by contamination can be complex. Because of this complexity, the process of identifying, quantifying and evaluating the risks associated with contaminated land should be an iterative process with several phases of investigation (each with specific objectives to be achieved), in order to obtain sufficient relevant data to characterize the potential risks, pathways and receptors of concern. The objectives should be reconsidered at each stage, and the requirements for further investigation reviewed as the investigatory and assessment processes are developed.

NOTE 1 General guidance on the development of site investigation strategies and sampling strategies is provided in ISO 18400-104. Guidance on the preparation of a sampling plan is provided in ISO 18400-101.

The principal phases are

— preliminary investigation (see 5.2 and Clause 6),

— exploratory investigation (see 5.3, Clause 7 and Clause 8), and

— detailed (main) site investigation (see 5.4, Clause 7 and Clause 9).

The relationship between these phases is illustrated in Figure 2.

Supplementary investigations could be required subsequent to the detailed site investigation in order to provide information relevant to the selection of remedial methods, or design of remediation or construction works.

On completion of the on-site work during any phase or stage of investigation, a sampling report should be prepared in accordance with ISO 18400-107.

Following completion of any phase or stage of investigations, a report giving its results should be prepared (see 8.4 and 9.6).

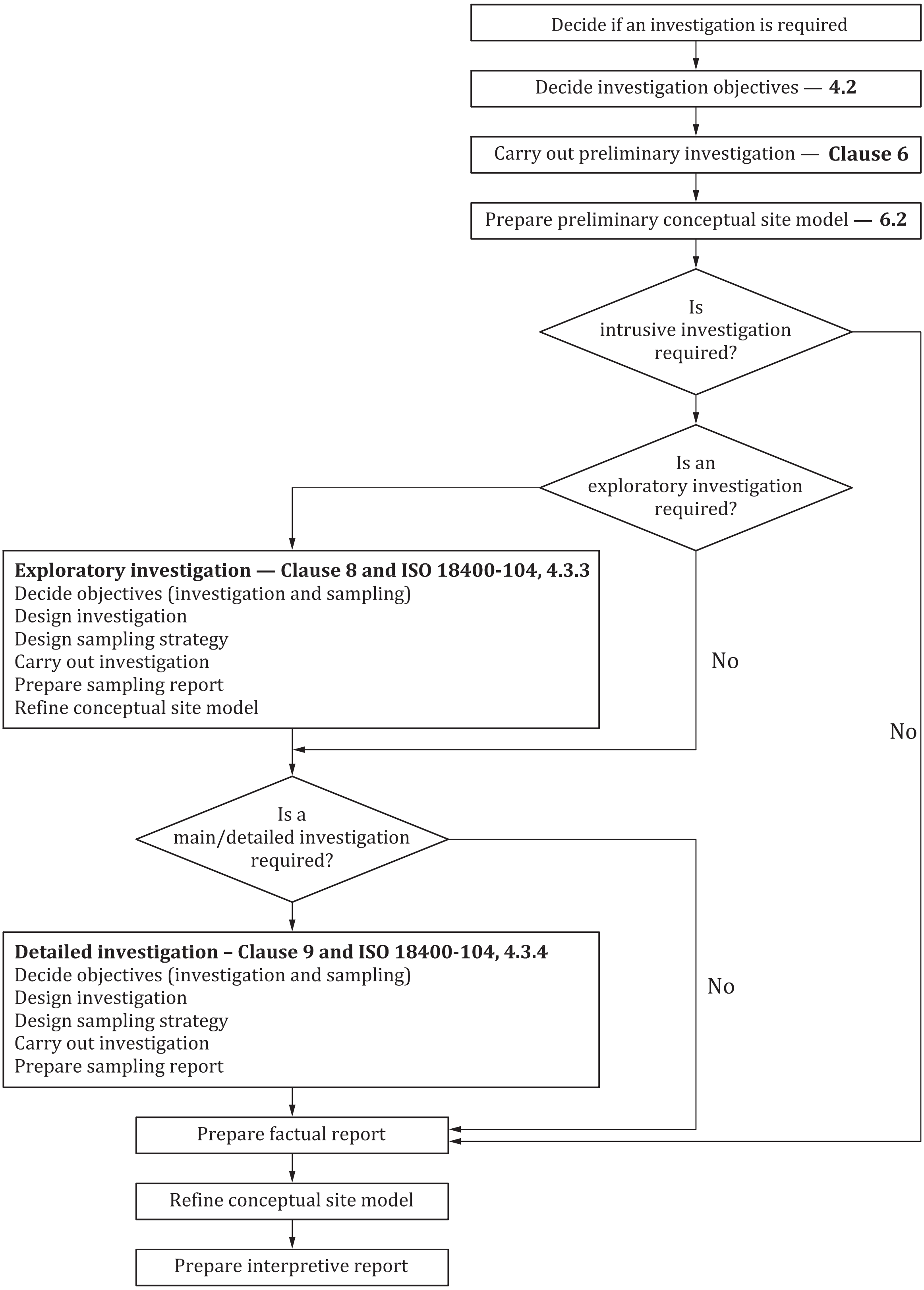


Figure 2 — Process of site investigation

Before embarking on any phase or stage of investigation, it is important to set data quality objectives in terms of the type, quantity and quality (e.g. analytical quality) of the data and other information that is to be collected. These data quality objectives will depend in part on the nature of the decisions to be made on the basis of the investigation, and the confidence required in those decisions. The strategy for the investigation (whether preliminary, exploratory or detailed) will be determined by the objectives. For example, the different requirements of site investigations for the purpose of selling, determining whether contamination is present as suspected, or redevelopment will influence the spacing of sample locations and the number of samples analysed, and hence the cost of the investigation.

Failure to set data quality objectives at the outset can lead to considerable waste of money, if, for example, the data collected are not suitable or sufficient for a reliable risk assessment, or leave too many uncertainties about the “conceptual site model” developed for the site (see 6.2 for the description of the conceptual site model).

When deciding on the strategy, consideration should be given to the applicability and use of on-site analysis and/or *in situ* measurement techniques.

NOTE 2 Guidance on the selection and application of on-site methods is provided in ISO 12404.

5.2 Scope of preliminary investigation

The preliminary investigation comprises a desk study and site reconnaissance (walk-over survey, site inspection). It is carried out using historical records and other sources to obtain information on the past and present usage of the site together with information about local soil properties, geology, geomorphology, pedology, surface hydrology, hydrogeology and environmental setting. It should be carried out in accordance with ISO 18400-202 and the guidance in Clause 6.

From this preliminary investigation, the possibility of contamination can be deduced, and hypotheses can be formulated on the nature, location and distribution of the contamination, such as those listed in Annex A.

These hypotheses form part of the overall conceptual site model of the site that should be developed, encompassing not only the contamination aspects but also the geology, geomorphology, pedology, hydrogeology, surface hydrology, geotechnical properties and the environmental setting. The current and planned site uses are also important aspects of the conceptual site model.

NOTE Guidance on the development of conceptual site models is provided in ISO 18400-202.

The preliminary investigation should provide sufficient information:

— for initial conclusions about potential risks to actual or potential human and other receptors;

— to determine whether there is a need for further action (e.g. intrusive investigation).

The amount and type of information required will depend on the objectives of the investigation. The amount of work required will vary with the age of the site, the complexity of its historic usage, and the complexity of the underlying geology, etc.

It should be remembered that the contamination on a site could be more complex than initially indicated (for example, by current usage) and adequate information on the history of the site should always be obtained in the preliminary investigation.

5.3 Scope of exploratory investigation

The exploratory investigation involves a limited on-site investigation, including collecting samples of soil or fill, surface water, groundwater, and soil gas, where appropriate, and the subsequent analysis or testing of the collected samples. The data and information produced are then assessed to determine if the hypotheses from the preliminary investigation are correct, and, where appropriate, to test other aspects of the conceptual site model. An exploratory investigation can identify areas of contamination (essentially a qualitative process) but would not be sufficient to identify its extent or the variation of contamination within it (i.e. quantify the contamination), which is the function of the detailed site investigation.

In some cases, where the information required according to the objectives has been achieved sufficiently, no further investigation might be needed. However, it could become apparent as a result of the exploratory site investigation, for example, that the contamination pattern is more complex, or concentrations of contamination are higher than anticipated, and already present, or in the future might present, a hazard(s) and hence a risk to one or more potential receptor. In this situation, the information obtained might be insufficient to make decisions with a satisfactory degree of confidence, and it will be necessary to either

— carry out a further stage of exploratory investigation before proceeding to the design and execution of a detailed investigation, or

— carry out a detailed site investigation to produce sufficient information to enable a full risk assessment to be carried out, the need for protective or remedial measures to be determined, and in due course and possibly following further stages of investigation, to select, design and apply protective or remedial measures.

5.4 Scope of detailed site investigation

The detailed site investigation provides the basis for the quantitative determination of the amount and spatial distribution of contaminants, their mobile and mobilizable fractions and possibilities of them spreading in the environment. This includes possible future development of the contamination situation.

It could require, depending on the objectives, the collection and analysis of soil or fill, surface water, groundwater, and soil gas samples in order to obtain the information necessary to enable a full assessment of the risks presented by the contamination to humans and other potential receptors, and also to enable appropriate containment or remediation actions to be identified, together when required with an initial estimate of costs. The intrusive investigation can be supported by model calculations and investigation techniques that do not require samples to be taken such as those described in Annex B. Detailed design of protective or remedial works could require further supplementary investigation.

NOTE It could be appropriate to investigate ambient air, vegetation, potable water supplies and a variety of other media depending on the findings of the preliminary investigation.

The amount and nature of the information required from the detailed site investigation (or any particular stage of it) will vary depending on the nature of the site, and the objectives of the investigation. The implications for the decisions on what actions should be implemented on a site will vary from site to site. Additionally, the amount and quality of the information required will also vary according to the requirements of the decision making processes (e.g. the risk assessment, decisions regarding the need for and type of remedial actions). All parties involved in the decision making process should be kept fully informed as information is produced to ensure that the information is sufficient for the purpose intended.

After completion of the interpretation of the information generated, including any risk assessment, it should be possible to determine whether protective or remedial measures are required and to make generalizations about the type of measures that might be appropriate.

6 Preliminary investigation

6.1 General

A preliminary investigation in accordance with ISO 18400-202 should be carried out before any intrusive or other field investigation.

The results of the preliminary investigation should be used to prepare an initial conceptual site model, including the development of contamination-related hypotheses, as described in 6.2.2 and Annex A.

6.2 Development of the conceptual site model

6.2.1 Overall conceptual site model

The conceptual site model is a representation and/or description of the site incorporating all that is known and anticipated about the site (e.g. contamination, geology, pedology, environmental setting). It should identify pathways by which current and future receptors could be affected by contamination currently or in the future. An important aspect of the conceptual site model is the formulation of contamination-related hypotheses. Note that its preparation requires some interpretation of the available information and explicit recognition of the uncertainties in that information.

The development of a conceptual site model can aid greatly understanding of the site and the risks it might present to human and other receptors as well as the design of future phases of investigation. It also aids decisions on how remediation (if required) might be achieved and other works carried out.

The conceptual site model is also an aid to communication between the different parties involved and with the public.

6.2.2 Formulation of contamination-related hypotheses

Based on the results of the preliminary investigation, hypotheses should be formulated in relation to the probable nature, variation and spatial distribution of contaminating substances that are anticipated on the site (see Annex A). In arriving at appropriate hypotheses, it will be frequently necessary to identify different zones of a site to which different hypotheses are applicable. This will normally be essential for a large site but is also frequently appropriate for small sites.

Before deciding on the sampling strategy, it is essential to determine for each zone (and for the site as a whole) from the information available, whether it is reasonable to expect the zone or site to be contaminated or not, i.e. whether the zone (or site) should be considered as “probably uncontaminated” or as “probably contaminated”.

Hypotheses relating to individual substances should be developed, it can then be incorporated into a conceptual site model, taking into account all the information available, and translating the information into the most likely overall scenario with respect to the contamination status of a zone. The conceptual site models for individual zones can be combined into a conceptual site model for the site as a whole. This site-wide conceptual site model is used to design the sampling strategy to be employed in the next phase or stage of investigation.

6.3 Reporting the preliminary investigation and the conceptual site model

The preliminary investigation should be reported in such a way that the initial formulation of the conceptual site model and individual hypotheses will stand out as a clearly recognizable, identifiable, section of the report as described in ISO 18400-202:2018, Clause 9.

7 Design of intrusive investigations

7.1 Overview

This clause, which should be applied in conjunction with ISO 18400-104, provides guidance applicable to the design of all types of intrusive investigations of potentially contaminated sites (e.g. exploratory and detailed investigations). Subsequent sections provide guidance relating to specific types of investigation. Guidance is provided on overall design, sampling soils, preparation of laboratory composite samples, and analytical and testing strategies.

7.2 General aspects of field work

It is important to understand that field work on contaminated sites can present a significant risk to the health of the investigators. ISO 18400-103 should be consulted for further information on the possible risks and precautions to control those risks.

ISO 18400-102, ISO 18400-104 and ISO 18400-105 should be consulted for information on specific aspects of sampling including sampling patterns, methods of collecting samples including boreholes, probe holes and trial pits, sample preservation, and the potential risks to investigators and the environment which could result from a site investigation. It should be noted that other, non-intrusive, investigation techniques can contribute significantly to the understanding of the spatial distribution of contamination (see Annex B).

Instead of taking samples for laboratory analysis, it might be advantageous to use on-site and/or *in situ* methods for testing and analysis (see ISO 12404 and ISO 13196).

Once the investigation has been designed and planned (7.3.2.1) a sampling plan should be prepared in accordance with ISO 18400-101.

It is advisable to ensure from the start of the field work that sufficient samples will be collected. It will sometimes not be necessary to analyse all the samples that have been taken, but that it could be (very) expensive to have to return to the location to obtain additional samples. This will particularly be the case if samples are taken at a considerable depth in the soil profile. However, analysis for volatile and semi-volatile components should be carried out as quickly as possible after sampling, and for these components it might not be possible to preserve the samples for later analysis.

If at any time during the investigation it becomes evident that the implemented strategy has not been optimal (e.g. on the basis of site observations), the strategy should be altered immediately. In some cases, it might be necessary to take additional samples on the basis of the adjusted strategy or to take into account the unforeseen conditions. However, where this situation is not clearly evident, the original strategy should be followed.

Whenever changes are required to the predetermined sampling plan, the project leader should be informed or consulted as required by ISO 18400-101.

Descriptions of ground strata should be drawn up in the field immediately after work at a sampling location has been completed if this has not been done during formation of the exploratory hole. Taking photographs with boards showing the sampling location designation, colour charts and scale markers is often a useful aid to ground strata descriptions.

7.3 Overall design aspects

7.3.1 General

The design of on-site (intrusive) investigations involving the collection of samples and on-site testing (if any) should be based on the results of the preliminary investigation and the objectives of the exploratory site investigation (Clause 8) or detailed site investigation (Clause 9) as appropriate.

The design will include the specification of the sample locations, the depth, sizes and types of samples to be collected, and the methodology by which the samples are to be collected. It is important that the positions of the sampling locations are determined before the site investigation commences, but with allowance for the sampling team to exercise professional judgement on-site, to vary locations and sample additional locations in the light of the on-site observations and local constraints such as the presence of underground services, subject to the requirement in ISO 18400-101 to consult and inform the project leader as appropriate.

NOTE While it is usual as recommended in ISO 18400-104 to determine sampling locations in advance, it is not always practical or desirable to do so. It could, for example, especially during exploratory investigations, only be practical to carry out convenience (ad hoc) sampling at locations determined on-site by the person carrying out the sampling (see ISO 18400-104:2018, 6.2.4). However, by the time a detailed investigation is to be carried out, sufficient information will be available from the exploratory investigation to permit most sampling locations to be designated in advance.

The hypotheses postulated could indicate some area(s) of potential contamination where preliminary information will be of assistance in designing the more detailed site investigation, e.g. preliminary information on the potential extent of spillage of chlorinated solvents could be of assistance.

The design of the exploratory site investigation can take such aspects into consideration, and so provide information to enable the detailed (and more expensive) site investigation to be designed to produce the necessary data required by the objectives, in the most efficient manner, and to minimize the possibility of unforeseen situations being encountered.

As discussed above, different hypotheses could be applied to different areas of a site (zones), and hence different sampling strategies applied for each zone within the overall investigation process.

7.3.2 Design of site works

7.3.2.1 Planning

The designer of the site works should take into account both the design of the sampling programme and practical aspects relating to its implementation. These include:

— location and number of sample locations and the sampling pattern;

— method of collecting samples (boreholes, trial pits, etc. sampling equipment);

— samples to be collected (soil, particle size fraction, water, gas);

— special sampling requirements (volatile compounds, preservation requirements);

— requirements for sample containers;

— requirements for on-site analysis and testing;

— analyses and other testing to be carried out and any particular requirements from the laboratory with regard to sample collection, preservation, and transport;

— procedures and precautions to ensure health and safety during the investigation and protective equipment required;

— environmental protection measures required including to prevent migration of contamination during and after completion of the investigation;

— requirements for disposal of arisings from the investigation and the possible need to bring clean material to site, for example, for backfilling trial pits;

— requirements for quality assurance including comprehensive documentation of sampling details;

— permission and ease of access to the site (and adjacent land where necessary);

— location and nature of any obstructions to sample collection on the site and how these will be overcome;

— location and status of services including both above and below ground services;

— consideration of the possible presence of unexploded ordnance (UXO);

— location of suitable areas for offices, decontamination unit, welfare and sample storage;

— management of contractors and subcontractors (e.g. surveyors, drillers);

— communications and accident and emergency plans and communications with the emergency services;

— disposal of (possibly) contaminated groundwater, excavation arisings and material used or contaminated in the course of the investigation.

7.3.2.2 Integrated investigations

There are sometimes benefits to be gained from investigations which combine the needs of the contamination and geotechnical aspects. This can be of assistance where there is a need to take health and safety and environmental protection into account in the design of geotechnical investigations.

A combined investigation has the advantage of:

— simplified project management;

— common use of equipment and procedures;

— use of exploratory holes for more than one purpose with resultant economies;

— being able to address health and safety implications for both investigations;

— allowing for combined consideration of resultant data.

However, the use of an integrated investigation should not result in compromising the achievement of the objectives of either investigation. For example, sample locations for contamination should not be moved from the selected grid pattern to accommodate the geotechnical requirements. Geotechnical sampling methods are not necessarily suitable for obtaining samples for chemical analysis and vice versa. In addition, requirements for recording soil profiles are often different.

7.4 Sampling patterns and spacing for sampling soils

7.4.1 General

The sampling strategy requires, among other things, consideration of the locations from which samples are to be taken, the depths at which samples will be collected and the types and sizes of samples to be collected. The guidance on the selection of sampling patterns and on other components of the sampling strategies given in ISO 18400-104 should be followed (see especially 8.2). Statistical considerations should be taken into account when selecting and designing sampling patterns, particularly the distance between sampling points.

Sample locations can be selected on the basis of a sampling pattern which is a defined layout of sampling locations (i.e. systematic) or on the basis of judgemental sampling. In most investigations, a combination of the two approaches should be used.

The reasons why the sampling strategy has been adopted should be set out in the sampling plan (this should be prepared in accordance with ISO 18400-101) and should be taken into account by those involved in the on-site investigation.

Decisions about the number of samples to take and sampling densities to meet different objectives, should be based on the guidance in ISO 18400-104 (see in particular ISO 18400-104:2018, 6.5, ISO 18400-104:2018, Clause 7 and ISO 18400-104:2018, 8.6). The examples described in Notes 1 and 2 below are illustrative of the sampling densities that might be appropriate and some of the considerations that should be taken into account.

The probability of detecting contamination should be independent of the surface area of the site that is under investigation. In other words, if the surface area of a site increases, more samples will be required to locate possible contamination with the same probability, or chance, depending upon the hypothesis of the distribution of contamination (see Annex A). The smallest volume of contaminated material, which should be detected to meet the objectives of an investigation, should be defined before the development of the sampling plan. Specifically, where an exploratory investigation is carried out on a "probably uncontaminated" site, it is important to define on what scale any contamination will be detected, since, if no contamination is detected, the hypothesis could be considered, possibly wrongly, to be correct and no further action taken.

The number of sample locations to be taken for each potentially contaminated zone should be proportional to the size of the zone, taking into account factors such as the origin of the contamination (along a pipeline, around an underground tank, spread all over, etc.), on the expected size of any hot spots, and the degree of certainty required. When required by the objectives of the investigation, a minimum number of samples should be taken that will provide an indication of the spatial variability within the zone.

The reliability of the estimate of the distribution of contamination will of course be increased when more samples are taken.

When choosing the sampling pattern, it should be borne in mind that contamination rarely exists with sharply defined boundaries and increasing concentrations can be used as indicators of contamination, even though the areas of highest concentration have not been sampled.

NOTE 1 The distances between the nodes of regular sampling grids, typically varies between 30 m for an exploratory investigation and 10 m or 15 m for a detailed site investigation. Greater density of sampling grid could be required where very heterogeneous contamination is hypothesized, for example, on a former gasworks site where in localized areas a 10 m grid could be considered to be necessary. A high-density sampling grid could also be necessary where the level of confidence required for the outcome of a risk assessment requires such density in soil quality data (for example, for a housing development).

NOTE 2 Lower density sampling (i.e. a wider sampling grid) could be acceptable where the area to be sampled is large, and based on preliminary investigation, the potential contamination is expected to be diffuse and no hot-spots are expected (e.g. large areas affected by point source air pollution).

7.4.2 Judgemental sampling

Sampling locations may be chosen on the basis of judgemental sampling, where a specific source of contamination is known or suspected, and confirmation of the presence or extent is required (see ISO 18400-104:2018, 6.2.2). Alternatively, an area of contamination might have been detected in the exploratory site investigation, and further delineation is required as one of the objectives of the detailed site investigation.

Where a plume is being targeted, sampling locations should be selected according to the hypothesis relating to the location and nature of the contamination.

During exploratory site investigations, judgemental sampling may be used when specific locations of visually contaminated material or suspected contamination are encountered and require sampling to confirm suspicions prior to more detailed sampling in the subsequent detailed site investigation.

NOTE Sampling locations can be selected on an ad hoc basis (e.g. in the general vicinity of a source), but are better located following consideration of the properties of the contaminant concerned, the mode of release, and the need to be able to interpret the results in a meaningful way. The sampling locations could be related to a regular pattern which is being used for other areas of the site, or as an alternative to sampling at ad hoc locations, the sampling locations can be placed along radii from the suspected source or point of high concentration.

7.4.3 Systematic sampling

Site investigations (both exploratory and main) should usually be carried out, using systematic sampling (in conjunction with judgemental sampling when appropriate), preferably using a regular sampling pattern so that the sampling locations are distributed throughout the site (or zone) in a uniform manner.

7.4.4 Detection of hotspots

The guidance on the detection of hot spots provided in ISO 18400-104 (in particular ISO 18400-104:2018, 7.4) should be followed.

7.4.5 Depth of sampling and the strata to be sampled

The guidance on sampling depths provided in ISO 18400-104:2018, 8.4 should be followed.

The sampling strategies described in ISO 18400-104 apply only to a single contaminant in a single plane. The distributions of different contaminants on a site could vary with depth because they have different origins and, even if they originate from the same source, because they behave differently in the ground. Consequently, appropriate strategies should be developed for sampling at depth.

It is important to take into account, for example:

— varying physical and chemical soil properties over depth, particularly where substantial thicknesses of made ground (e.g. reworked natural materials or materials deposited in the past to raise ground levels, form embankments, dispose of wastes, etc.) are present or where large differences are present in natural deposits;

— contamination sources (e.g. solid, leachable and gas- or vapour-generating materials, leaking pipe) that might be located at any depth in the soil profile;

— that the relevant depth in exposure terms can be at any level in the soil profile (e.g. in redevelopment projects, the final formation level might be lower than existing site level; close contact between soils and site services can be at some depth below ground level);

— movement of gases and liquids along vertical (and perhaps deep lateral) pathways will be determined by physical soil properties at the relevant depths;

— the current or future usage of the site.

7.4.6 Sample sizes

The guidance in ISO 18400-104:2018, 6.6 regarding sample sizes should be followed.

7.4.7 Sample types

The guidance on different types of samples, including composite samples, and their application in ISO 18400-104 (in particular ISO 18400-104:2018, 6.4, ISO 18400-104:2018, 8.3 and ISO 18400-104:2018, 8.6.2) should be followed as appropriate.

7.4.8 Number of samples

The total number of spot samples taken, the number of separate samples taken at individual sampling locations and the number of composite samples taken from a zone or site should be in accordance with ISO 18400-104 (see in particular ISO 18400-104:2018, 6.5, ISO 18400-104:2018, Clause 7 and ISO 18400-104:2018, 8.6).

7.5 Analytical and testing strategies

7.5.1 General

The samples taken from soil, groundwater, surface water, sediments, and soil gas should be examined for

— the substances that are expected, based on the results of the preceding investigation phases or stages (the hypotheses), and

— a selection of substances of general significance.

7.5.2 Analysis of soil samples

7.5.2.1 Approaches to deciding on components to be analysed

There are two distinctive approaches in deciding on the components to be analysed:

— a component specific approach;

— a broad spectrum approach.

Both approaches can be used in both the exploratory investigation and the detailed site investigation, depending on the objective of the investigation and what is already known about the site.

A component specific approach is a logical choice if the contaminating substances are well known, and the investigation is only aimed at defining the volume of contaminated soil.

On the other hand, a broad spectrum approach, although likely to be more expensive, might be the best choice if information is required about the treatment potential of the contaminated soil, or indeed, if general information about the soil quality is required.

7.5.2.2 Selecting parameters for testing and analysis

ISO 18400-202:2018, Annex A should be consulted for information about potential contaminants that might be of concern because of possible adverse effects on human health or the environment, etc. and about substances used in particular industries and which might therefore be present as contaminants.

Local knowledge about likely contaminants or naturally occurring potentially hazardous substances should be taken into account.

Determination of the proportion of organic material (humus) and the proportion of fine-grain size fraction could be necessary in connection with the objectives of the investigation, including (where they exist) the application of reference, threshold or assessment values which are accepted to be applicable at the site (these could, for example, include local background values).

NOTE Contaminants such as heavy metals (Cd, Cr, Cu, Hg, Ni, Pb, Zn), arsenic, petroleum hydrocarbons, VOCs (volatile organic compounds) and PAHs (polycyclic aromatic hydrocarbons) are the contaminants most often encountered on urban and industrial sites. Determination of these common contaminants can often be sufficient when testing the hypothesis of a “probably uncontaminated” site, and when contamination is suspected but little is known about the form it might take.

7.5.2.3 Using separate or laboratory composite samples

Combining of samples (if permissible), after pre-treatment, according to ISO 11464 and ISO 14507 or other relevant standards, should be carried out in the laboratory.

Samples which clearly differ, for example, on the basis of organoleptic evidence, should in general not be mixed with other samples, but should be analysed separately. Composite samples should normally not be created from samples that derive from different horizons or from different depths in a soil profile. However, in both cases the sampling strategy based on the conceptual site model of the site will determine what the most appropriate strategy for analysis is.

If composite samples are used, the original samples should be stored separately. This will ensure that, if necessary, they can be used for a repeat analysis at a later stage [this is not possible of course for parameters that change over time (e.g. volatiles) or due to sample handling (e.g. pretreatment)].

7.5.2.4 Storage and transport of samples

Storage and transport of samples should be in accordance with ISO 18400-105.

7.6 Quality assurance and quality control

Quality assurance and quality control procedures should be employed covering of all aspects of the investigation in accordance with ISO 18400-106 as appropriate.

8 Exploratory investigation

8.1 General

8.1.1 Basis of the exploratory investigation

The exploratory investigation follows on from the preliminary investigation and is carried out principally to test the correctness of the hypotheses which have been formulated in relation to the contamination of the site, or, in more general terms, to check the correctness of the conceptual site model that was developed for the site. Careful design of the exploratory investigation should result in the ability to demonstrate the correctness of the hypotheses within a minimum of resources and time.

NOTE While it is usually advantageous to precede a detailed investigation by an exploratory investigation, this is not always necessary.

The exploratory investigation will usually give limited information only. However, depending on the objective(s) for the specific case, the information obtained could be sufficient for decision making, particularly when the following has been achieved:

— high quality of the results of the preliminary investigation;

— appropriate planning and performance of the investigation;

— not too high demands concerning the reliability of the results.

In other situations, the exploratory investigation should be followed by a detailed site investigation (see Clause 9).

8.1.2 Steps to be incorporated

The exploratory investigation should incorporate the following steps:

— design of an investigation strategy according to ISO 18400-104;

— carrying out the site investigation and associated analysis of samples;

— determining the validity of the hypotheses;

— determining the requirements for possible further investigation.

8.1.3 Aspects to be considered when drawing up a strategy

Aspects which should be taken into consideration when drawing up a strategy (see also ISO 18400-104) for the exploratory investigation are:

a) the hypotheses;

b) uncertainties in relation to the contamination and the distribution hypothesized, which require clarification in order to facilitate the most effective design of the detailed site investigation;

c) any indicated risks to human health or other potential receptors.

NOTE These aspects will have been characterized in the preliminary investigation (see Clause 6).

These aspects determine:

— the media to be sampled (soil, surface and groundwater, soil gas);

— the depth of sampling and sampling techniques to be used;

— the sampling patterns;

— the number of samples to be taken;

— the possible use of composite samples;

— the number of samples to be analysed;

— the potential contaminants to be determined.

During an exploratory investigation relatively few sample locations will be investigated, compared with the detailed site investigation. It is however important for economy to, as far as possible, ensure that the sample locations selected, and the resultant information collected, can be utilized in the subsequent assessment deriving from the detailed site investigation.

In the exploratory investigation particularly, it might be prudent to collect samples representative of all evidence of contamination during the investigation but to subsequently only analyse selected samples. For example, analysis of all samples which are obviously contaminated (e.g. on the basis of appearance) might not be necessary at this stage. But in utilizing visual assessment or field measurements, it should be remembered that not all contamination can be identified in this manner.

On-site screening methods should also be used when appropriate (see ISO 12404 and ISO 13196).

The exploratory investigation, including the sampling and analytical strategies, should be designed and supervised by an experienced contaminated site investigator.

8.2 Sampling strategy

8.2.1 General

There is a distinction which can be made based on the results of the preliminary investigation and the formulated hypotheses between strategies for “probably uncontaminated” and “probably contaminated” sites.

For economic reasons, spacing and depth of sampling, during the exploratory investigation, should be chosen so that the results can be used for risk assessment during later phases of investigation. Relevant potential pathways for migration of contamination and exposure of human and other receptors should be taken into account when designing the strategy.

The investigation of potential soil contamination should be carried out in conjunction with the investigation of the other matrices in which the contamination might be present, specifically:

— groundwater (see ISO 5667-11);

— surface water (see ISO 5667-4);

— soil gas (see ISO 18400-204).

8.2.2 Sampling locations

Two basic approaches can be used in the exploratory investigation; judgemental sampling (7.4.2) and systematic sampling (7.4.3) (see also ISO 18400-104).

In exploratory investigations, the most common sampling strategy is judgemental sampling, when necessary supported by systematic sampling with a relatively wide spacing.

The spacing of the sampling depends on the objectives of the investigation and most of all on the hypotheses formulated. Note that a dependency of sample spacing on the overall size of the site is – in most cases – not justifiable (see 7.4). The sample spacing should be defined based on the desired probability of finding a contaminated area with a predefined size. Decisions about both the desired probability of finding (or missing) such a contaminated area as well as the size of it, are a matter for judgement.

Judgemental sampling is used when there is evidence for point source (heterogeneous) contamination. Systematic sampling is used for either homogeneously contaminated sites or probably uncontaminated sites. In order to obtain an overall characterization of the site when there is evidence of point source contamination, both approaches should be combined.

If there is strong evidence for serious contamination, sampling patterns employed for the exploratory investigation should also be designed to facilitate the design of the following detailed site investigation. It can be useful to plan the exploratory investigation in a manner that will assist in optimizing the detailed site investigation.

8.2.3 Depth of sampling

The depth of sampling should take into account the hypotheses and the scope of the investigation (see 7.4.5).

National or other relevant regulations might define certain depths of sampling in relation to specific objectives for the investigation or for application of guidance values.

8.2.4 Selection of soil samples for analysis

It is usually preferable to collect more samples than will be analysed. A number of representative samples and “suspect” samples should always be analysed. Thus, if samples of the same strata from a number of different locations appear similar, only a representative number might need to be submitted for analysis.

Sufficient samples should be analysed to test the hypotheses. It should be noted that the objective of an exploratory investigation is usually to identify the presence of contamination and not to delineate its distribution or full extent.

8.2.5 Selecting parameters for testing and analysis

In general, the selection of the contaminants should be directly related to the objective(s) of the investigation and the defined hypotheses. Local knowledge about likely contaminants (see NOTE in 7.5.2.2) or naturally occurring potentially hazardous substances should be taken into account.

Where a “probably contaminated” site is being investigated, the investigation might be limited to the substances that are expected (according to the hypothesis based on the results of the preliminary investigation). However, such a limited investigation might well be combined with a broader investigation (both in terms of contaminants as well as in sampling density) in order to obtain additionally information on the general quality of the site and to aid the management of materials within the site or which might need to be sent for disposal.

When a site-specific reference value for a group parameter has been set and this is exceeded (for example, the reference value for extractable organic halogens or the phenol index or mineral hydrocarbons), further useful information can be obtained by determining the concentrations of the individual contaminants. However, not always increased group parameter values also mean increased concentrations of contaminants. Additionally, the analysis of specific contaminants might be part of the detailed site investigation instead of an additional stage in the exploratory investigation.

NOTE 1 Here “reference value” refers to a site-specific value that has been decided as the trigger for more detailed analysis. It might be one provided in authoritative guidance, or it might be one decided to be appropriate by those carrying out the investigation.

NOTE 2 Determination of the proportion of organic material (humus) and the proportion of fine-grain size fraction could be necessary in connection with the objectives of the investigation, including (where they exist) the application of reference, threshold or assessment values which are accepted to be applicable at the site (these could, for example, include local background values).

8.3 Evaluation of the exploratory investigation

8.3.1 Testing the hypotheses formulated during the preliminary investigation

The exploratory investigation provides information to test the hypotheses that were formulated on completion of the preliminary investigation. The testing procedure is carried out in the same way that was used to postulate the following hypotheses:

— Stage 1: Is contamination shown to be present on the site?

— Stage 2: Do the detected contaminants correspond to the expected contamination?

— Stage 3: Does the identified location of contamination correspond to the expected location?

— Stage 4: Does the spatial distribution correspond with the expected spatial distribution?

During this testing procedure, comparison should be made with published threshold values and/or with local background values to determine whether a site should be considered contaminated or not. Comparisons might also be made with other values (e.g. derived from the literature), but the use of these should always be justified in the report of the investigation.

NOTE Note that ISO 11074 defines contamination as the presence of a potentially harmful substance without any reference to whether its presence might cause harm to one or more receptors. Also that it is important to be clear whether any background value with which comparison is made is a "natural background concentration" or includes anthropogenic contributions as might occur from aerial deposition in urban areas.

Appropriate statistical and geostatistical methods should be used if it is desired to demonstrate that measured concentrations are statistically significantly above the value with which comparison is being made (see ISO 18400-104:2018, 7.3).

8.3.2 Risk assessment

If the site is contaminated, a subsequent risk assessment is likely to be necessary to establish the importance of the contamination. A risk assessment may be carried out if the quality and quantity of the data are adequate to accurately assess the contamination situation. Depending upon the objectives and the data available it is, however, probable that insufficient data (or other information) will be provided by the exploratory investigation to allow a detailed risk assessment, though it could be possible to carry out a "screening risk assessment".

8.3.3 Considering hypotheses by zone

If, based on the results of the preliminary investigation, the site was divided into a number of zones with separate hypotheses, each hypothesis has to be tested separately. The results of the investigation relating to these different zones should be considered to determine the possibility of inter-relationships.

8.3.4 Obtaining information on soil quality

Information on soil quality can be obtained from the descriptions of the ground made during the sampling process and the evaluation of the hypotheses should take this recorded information into account.

8.3.5 Checking if investigation strategy is adequate

A check should be carried out in all cases, to establish whether the investigation strategy has indeed been adequate in view of the nature of the results that have become available, regardless of whether the hypotheses have been proved valid.

8.3.6 Re-examining the hypotheses

Hypotheses should be re-examined using all available information including not only measured concentrations but also, for example, whether the source and the distribution of contaminants is as expected. Non-correspondences in any of these factors can provide grounds for rejection of contamination-related hypotheses. As far as concentrations alone are concerned the following rules should be followed:

— the hypothesis of a "probably uncontaminated" site should be rejected if some of the substances analysed exceed the corresponding threshold values or markedly exceed local background values [in this case, a new hypothesis of a "(probably) contaminated" site has to be formulated];

— if none of the set of potential contaminants analysed for were detected in any of the samples tested, in concentrations significantly above the threshold value/background concentration or other values considered relevant, the site should be ranked as uncontaminated (it should be kept in mind, however, that this is a relative judgement, the reliability of which depends on the design and intensity of sampling in the exploratory investigation – a complete proof of absence of contamination is not possible);

— if composite samples have been used in the investigation, possible dilution effects should be considered when testing the hypothesis;

— if a contaminant is found to be in excess of its corresponding threshold/background value, it should be concluded that soil contamination exists and the related hypothesis should be accepted.

NOTE What are "concentrations significantly above the threshold value/background concentration or other values considered relevant" is a matter for judgement in any particular case. ISO 18400-104:2018, 7.3 provides guidance on how to judge whether average concentrations are above or below a particular value.

Because of the limited objectives of the exploratory investigation, its usefulness to test the hypothesis regarding the spatial distribution of the contamination within a "probably contaminated" site is at best limited (see 8.2.4). Nevertheless, the hypothesis has to be adapted when possible, and refined with the increased amount of information available following the exploratory investigation.

8.3.7 Examples indicating if the hypothesis should be revised or rejected

The following examples indicate when it could be appropriate to revise or reject the hypothesis.

a) If the location of contamination was thought to be known and samples were analysed from the identified likely site of contamination but do not show concentrations of contaminants in excess of the threshold/background value, it should be concluded that the anticipated point sources either were not located correctly or do not exist.

b) If a "probably contaminated" site, with heterogeneous distribution where the location of pockets of contamination is unknown, was hypothesized, and in order to locate the contamination in the exploratory investigation, a systematic sampling pattern was applied over the entire site, it is possible that a greater proportion of samples were not taken from the pockets and therefore will show no significant contamination.

c) If a large number of samples are found to show contamination, this could indicate that either the hotspots of contamination are much more extensive than anticipated, or it could be that the contamination is more homogeneously distributed than was anticipated.

8.3.8 Possible actions if a hypothesis is not valid

If the results of the hypothesis testing indicate that a hypothesis is not valid, a number of possible actions can be taken:

— consideration should be given to whether the exploratory investigation was accurate and of sufficient extent. If required information has not been obtained or with insufficient degree of confidence, further exploratory investigation could be necessary;

— the preliminary investigation should be reviewed to determine whether the original hypotheses can be modified or whether a new hypothesis can be developed;

— if a new/modified hypothesis can be verified by the results of the exploratory investigation, a possible detailed site investigation can be planned on this basis;

— if a new/modified hypothesis cannot be verified sufficiently, further investigation should be carried out;

— a discussion should be included in the report on the discrepancy between the original hypotheses and the results of the investigation.

Whether or not, an additional investigation as part of the exploratory investigation will be worthwhile, will depend on the objectives of the investigation. If, for example, the hypothesis of a “probably uncontaminated site” is rejected, a decision has to be made about whether to review the preliminary investigation, or to carry out a further exploratory investigation.

8.4 Reporting the exploratory investigation

A sampling report in accordance with ISO 18400-107 should be prepared on completion of sampling.

The report of the exploratory investigation (i.e. investigation report) should provide the documentation and information to enable decisions to be made about what further investigation or other action is required. In general, it should include:

— the objective(s) for the exploratory investigation;

— the background to the investigation including reference to the preliminary investigation, the conceptual site model of the site and the hypotheses which were developed as a part of that conceptual site model, including information on the degree of confidence;

— planning and justification of the investigation strategy;

— methodology of the investigation;

— description of the work performed including sampling techniques;

— records of all on-site observations incorporating any variation from the proposed methodology and any anomalies in the site investigation;

— justification of sample selection for analysis and documentation of all relevant details relating to sample preservation, storage, transportation, pre-treatment as well as performance and evaluation of analyses;

— description of analytical results including information on variation and error boundaries;

— evaluation of the results of the investigation, selection of appropriate scales and reference values used for risk assessment and outcome when the results of the investigation are compared with chosen assessment values;

— comparison of the investigation results and the hypotheses and conclusions regarding the validity of the hypotheses;

— an updated conceptual site model (this is very important for the design of subsequent phases or stages of investigation);

— conclusions relating to the contamination status of the site and recommendations for risk assessment if any;

— recommendations for further investigation.

Depending on the objective(s) of the investigation, other aspects might have to be added.

The wording used in the report should supply decision makers and those who ordered the investigation with an appropriate overview and a reliable basis for making decisions. Facts should be clearly distinguishable from interpretations and hypotheses.

8.5 Determination of the need for a detailed site investigation

A detailed site investigation will become necessary if the objectives of the investigation require more detailed information on the amount and spatial distribution of contaminants, on their mobile and immobile fractions, and their possible migration; as well as the possibility of contaminant uptake by humans, animals and plants. This is commonly the case when:

— the hypothesis of a “probably contaminated” site has been found valid and suspicion of danger for human health and the environment is supported;

— when generally a higher level of knowledge about the contamination situation of a site is required to enable decisions to be made with sufficient degree of confidence;

— to enable detailed risk assessment and identification of options for management of identified potential or actual risks.

NOTE The exploratory investigation might identify (actual) risks requiring urgent action (e.g. implementation of remedial or protective measures), that arise with the site in its present condition or potential risks that would only require management if the site were to be redeveloped. In both cases, detailed investigation is likely to be required to enable options to chosen and then implemented.

9 Detailed site investigation

9.1 General

NOTE Clause 9 assumes that an exploratory investigation has been carried out. If this is not the case, then the strategy for the detailed investigation might need to be adjusted from that indicated below in order to encompass the objectives that would otherwise have already been addressed.

The detailed site investigation should be preceded by a preliminary investigation and an exploratory investigation. As a result, there should be a considerable amount of information available when the detailed site investigation is designed including:

— a good indication of the contaminants present;

— an indication of the extent of the contaminated area(s) (in three dimensions);

— an indication of the distribution of the contamination (homogeneous or heterogeneous);

— a knowledge of the soil composition and geology and pedology of the site;

— a knowledge of the local hydrology and hydrogeology.

All the data and information that has been assembled so far should be evaluated regarding completeness and reliability before the detailed site investigation is started.

9.2 Objectives and scope

9.2.1 Objectives

The scope of the detailed site investigation will be highly site-specific so it is not possible to specify the exact requirements of a detailed site investigation. Great care should be exercised in designing the investigation to clearly determine what the exact objectives are and what the consequent requirements are in terms of distribution of sample locations and samples to be collected and analysed.

The detailed site investigation will usually have a number of major objectives:

a) to establish the nature and extent of the contaminated area and the degree of contamination;

b) to provide adequate data to enable assessment of risks for humans and other receptors;

c) provision of information to enable

   1) evaluation of financial and technical options for subsequent development, and

   2) selection and planning of remedial actions.

In addition to the major objectives (a) to (c) listed above the detailed site investigation should be designed to:

— ensure the health and safety of the public and identify safe working practices for on-site personnel;

— determine the requirements for both long and short term monitoring.

9.2.2 Major aspects to be considered in setting the scope and determining the objectives

There are five major aspects which require consideration in setting the scope of the investigation and determining the objectives:

— contamination;

— present and future usage;

— hydrological setting (surface and groundwater regime);

— geological setting and geotechnical properties;

— present and future pathways and receptors.

9.3 Investigation design

Investigations of soil gas (see ISO 18400-204) and groundwater (see ISO 5667-11) can support the detailed site investigation for soil contamination. However, it is important to note that the results from these investigations do not allow direct estimation of the presence or degree of soil contamination but can help the design and execution of the soil investigation, e.g. by identifying areas requiring investigation.

Satisfying the objectives of the detailed site investigation requires:

— determining the nature and extent of the contamination on the site (this includes migration of contamination on the site and into its surroundings as well as the movement of contaminants over a period of time – note that migration will take place through groundwater and soil gas, for which the sampling is specified in ISO 5667-11 and ISO 18400-204 respectively);

— identifying risks posed by the contamination to humans, animals, plants and the environment, etc.;

— determining the presence of non-natural deposits and underground structures on the site [for example, physically unstable material, combustible material (coal deposits), deep foundations, storage tanks];

— identifying, characterizing and assessing potential receptors and pathways;

— providing sufficient information to be able to assess the need for remedial action;

— determination of the need for short- and longer-term monitoring and maintenance;

— identifying and planning for immediate health and environmental protection.

Although the detailed site investigation might be an extensive investigation, still only a very small fraction of the actual soil volume will be sampled and analysed. The properties of the contamination on the site are estimated from the investigated samples. The resulting uncertainties have to be considered and should be minimized by the investigation design as far as necessary (see ISO 18400-104:2018, 5.8 and Annex C). This on the other hand means: if the contamination status can be estimated with sufficient accuracy, there is no need for sampling or any further investigation. If a hypothesis has been found valid with a previously demanded degree of confidence, it should not be questioned again.

The detailed investigation, including the sampling and analytical strategies, should be designed and supervised by an experienced contaminated site investigator.

9.4 Sampling strategy

9.4.1 General

As a result of the detailed site investigation, the conceptual site model should be improved up to the point where it is sufficiently accurate for the objectives of the investigation and the decisions that are to be taken. The amount of sampling needed in the detailed site investigation will therefore depend on the objectives, as well as on the type of contamination present. If, for example, the contaminants have migrated away from the point of intrusion into the soil and the migratory pathways and processes are reasonably known, the conceptual site model can be improved rather quickly. On the other hand, when the contamination is characterized by irregularly contaminated soil material, more sampling will be necessary to obtain the same level of accuracy of the conceptual site model.

9.4.2 Sampling locations

The sampling pattern (horizontally and vertically) of the preceding exploratory investigation (see Clause 8), as well as stages of the detailed site investigation, should be taken into account (see 7.4).

Increasing the density of a sampling pattern stepwise (in the area or on profiles) taking into account the results of the preceding stages can often be more effective than beginning with a denser pattern.

Sampling should be intensified in those parts of the site where there are the most important needs for information or major uncertainties.

9.4.3 Depth of sampling

The depth of sampling during the preceding exploratory investigation (see Clause 8) should be taken into account together with those employed in any earlier stages of the detailed site investigation (see 7.4.5).

9.4.4 Selecting parameters for testing and analysis

The exploratory investigation should have identified the contaminants of particular interest, so generally no additional contaminants have to be investigated during the subsequent detailed site investigation unless only group parameters have been determined and it is deemed necessary that information on individual compounds is now required.

To quantify the extent and mobility of the contamination, it could be necessary to determine, for example:

— specific contaminants (e.g. when only group parameters such as "total PAHs" have been analysed previously or when petroleum hydrocarbons have been determined but not secondary hydrocarbon components such as ETBE (ethyl tertiary butyl ether), MTBE (methyl tertiary butyl ether) and organic lead);

— products of decay and chemical reactions;

— the chemical form(s) of the contaminants.

To determine the distribution of the contamination, it could be sufficient to trace only selected contaminants or possibly group parameters.

If significant correlation has been found between contaminants, the concentration of one of them might be calculated from the concentration of the other with sufficient degree of confidence.

If the single value measured has a lesser importance during the detailed site investigation than during the exploratory investigation, in special cases, a less precise and hence cheaper or faster method of determination can be used. The results of this method should be checked from time to time using more sophisticated analysis.

9.5 Evaluation of the detailed site investigation

The evaluation of the results of the detailed site investigation does not differ much from that described in 8.4 for the exploratory investigation (see also ISO 18400-104). The increasingly detailed conceptual site model of the contamination, based on progressively expanding knowledge, is the basis for the judgements about the overall contamination situation.

Complete knowledge of the contamination can, in practice, never be achieved, even with a very dense sampling pattern. Assessment of the extent of soil contamination involves interpolation between sampling locations. The degree of confidence of this estimation will depend on the density of the sampling pattern but most of all on the type and heterogeneity of the distribution of the contamination and the degree to which this was considered during interpolation.

For risk assessment of soil contamination, the spatial and temporal distribution of contaminants should be known sufficiently well. This often implies a compromise between wishful reliability and (financially) feasible investigation programmes. The resulting uncertainties should always be documented and quantified as far as possible. Improvements of the contamination hypotheses using, for example, numerical model calculations can minimize the uncertainties if sufficient data have been gathered.

NOTE Statistical and geostatistical tools facilitate an exploratory analysis of the data, notably the detection of trends and anomalies, or the existence of subpopulations with different behaviours. This is especially useful when many contaminants are considered and when data of different types and origins are taken into account. In areas displaying homogeneous spatial variations, geostatistics can provide global or local estimates of the contaminant concentrations. A measurement of the precision of the estimates is given, which enables the derivation of confidence intervals and a sound interpretation of the results. Geostatistics can also predict probabilities of exceedance of a concentration threshold, aid estimation of volumes of soils to be decontaminated, aid design of further surveys, etc.

Geostatistics has some requirements about the data. The most important one is that the sampling shall not be solely focused on areas supposed to be of high contamination. Preferential sampling in such areas is useful but shall be supplemented by a systematic sampling survey. In areas where it is applied, geostatistics requires sufficient number of data which depends on spatial variability and on the objectives of the study; 50 data are usually considered as a minimum and 100 data as desirable, even if a spatial exploratory analysis can be of interest with less data. Geostatistics also requires sufficient expertise in the personnel undertaking the geostatistical interpretation.

Further information about statistical and geostatistical methods is provided in ISO 18400-104, notably ISO 18400-104:2018, 6.1 and Annexes A, H and I.

9.6 Reporting

A sampling report in accordance with ISO 18400-107 should be prepared on completion of sampling.

The report of the detailed site investigation (investigation report) mostly will form the basis for the final risk assessment. Based on the information provided in the report, it will be decided whether remedial action is necessary or not.

The report generally should include:

— the objective of the detailed site investigation;

— the state of knowledge about the site previous to the beginning of the detailed site investigation, and presentation of the contamination hypotheses formulated using the results of the preliminary investigation and verified by the exploratory investigation, including statements concerning the reliability of the hypotheses;

— the planning and justification of the strategy and design of the investigation (if necessary in consecutive stages);

— a description of the methodologies used for the investigation;

— a description of the works performed and sampling techniques used;

— the documentation of the results of all field observations (including any differences and irregularities during the practical application of the proposed methodology);

— the justification of the sample selection for analysis and documentation of all relevant details relating to sample preservation, storage, transportation, pre-treatment as well as performance and evaluation of analyses;

— a description of the analytical results including information on variation and error boundaries and limitations of the analytical methods used;

— an evaluation of the results of the investigation, selection of appropriate scales and reference values used for risk assessment and the outcome of comparing values;

— a description of the progressive refinement of the hypotheses during the investigation and statements concerning the validity and degree of confidence of the final hypotheses;

— a “plain language” summary of the contamination status of the site and risk assessment;

— a review of uncertainties and limitations of the investigation;

— recommendations for future measures including when appropriate prioritization on the basis of, for example, urgency and/or the magnitude of the risks.

The wording used in the report should supply decision makers and those who ordered the investigation with an appropriate overview and a reliable basis for making decisions. Facts should be clearly distinguishable from interpretations and hypotheses.

The production of separate factual and interpretative reports (two separate volumes) might be advantageous but cannot be recommended in general. Evaluation and interpretation of the results should be done involving the investigator who planned and performed the investigation to avoid information losses.

NOTE 1 The identified risks might only become manifest when a site is redeveloped for another purpose so although the risks would then be high there is no need for urgent action. On the other hand, something might be identified relating to the site in its present condition requiring urgent, even immediate action.

NOTE 2 The costs of the recommended corrective measures will always be an important consideration, but as this will often raise questions of client confidentiality and could initially be very uncertain, these will often be best dealt with in a separate report.

Annex A
(informative)

Contamination hypotheses

A.1 General

NOTE Following the preliminary investigation and preparation of a preliminary conceptual site model, consideration is given to the development of contamination-related hypotheses. These form the basis for the subsequent design of subsequent phases of investigation including soil sampling exercises.

A.2 Hypothesis of a "probably uncontaminated" site or zone

If, based on the results of the preliminary investigation, there is no reason to suspect that contaminating activities have ever taken place on the site, and there is no information which indicates the possibility of migration of contaminating substances into or onto the site, the hypothesis formulated will be that the site should be categorized as a "probably uncontaminated" site.

It is very difficult to provide definitive evidence that a site is uncontaminated and free from any possible contamination. It will therefore often be necessary to carry out an exploratory site investigation after the preliminary investigation has been completed. This exploratory investigation should follow the guidelines set out below and in Clause 8.

The question whether a site can be considered as being uncontaminated will depend on:

— the levels of potentially contaminating substances;

— the contamination pathways that are included;

— the concentration levels of these components that are usually encountered; and

— target levels for these components set.

NOTE For urban and industrial sites, a mild degree of anthropogenic contamination is often present due to atmospheric deposition.

The results of the exploratory site investigation might show agreement with the hypothesis "uncontaminated", but will seldom provide undeniable proof of the absence of contamination. In an exploratory site investigation of a "probably uncontaminated site", a relatively wide range of contaminants will normally be determined in a limited number of samples. This implies that the extent of the investigation should be agreed upon between the involved parties prior to the actual investigation. The extent of the investigation will, after all, determine the probability that unexpected contamination is found.

A.3 Hypothesis of a "probably contaminated" site

If, on the basis of the preliminary investigation, there is good reason to expect that contaminating activities did take place on the site at some time, the hypothesis will be that the site is "probably contaminated".

In this case, different hypotheses should define in detail the expected contaminants, their expected spatial distribution throughout the site, possible migration pathways and potential effects on ground and surface water.

In formulating the hypotheses, the following factors should be taken into account:

— the chemical and physical nature of the contaminants (if necessary, several individual hypotheses);

— the nature of the source and the manner in which the contamination has entered the soil (diffuse or spot contamination);

— where in the soil or groundwater, the contamination is expected to be located, on the basis of the anticipated migration processes (in both a horizontal and vertical direction), depending on the nature of the contaminants;

— the potential presence of preferential pathways;

— physical characteristics of the contaminants and the possibility of change or decay (including biodegradation) with passage through the ground and solubility in water, interaction with clay and other soil components;

— sorption and complexing processes;

— interaction of contaminants with organic matter in the soil;

— possibility of residues in zones through which the contaminant has migrated;

— migration of landfill gases and volatile compounds;

— the soil structure and stratification (for example, highly pervious sandy soil or peat or highly impervious clay, cracks from shrinking or macropores and biological activities in the soil);

— the period of time during which the contamination has been in the existence;

— the depth of the groundwater table.

Formulating hypotheses relating to different parts of the site (zones) and then combining them in the overall conceptual site model will provide the best assessment and should enable an optimum investigation strategy for the site as a whole to be designed.

A.4 Hypotheses relating to spatial distribution of contamination

A.4.1 Types of spatial distribution of contamination

For the purposes of designing the sampling strategy, four basic types of spatial distribution of contamination can be identified:

— no contamination present or contamination is present with a homogeneous distribution;

— contamination present with a heterogeneous distribution with point sources of contamination of known location;

— contamination present with a heterogeneous distribution with point sources of contamination of unknown location;

— contamination present with heterogeneous distribution but no point sources of contamination.

A.4.2 Heterogeneous versus homogeneous distribution

The definition of heterogeneous or homogeneous is only really relevant in individual strata in the horizontal plane, since in the smaller vertical direction distribution is almost always described as heterogeneous. The nature of the contaminant, the nature of the ground and the length of time the contamination has existed will all affect the type of distribution.

EXAMPLE A plume of contamination in the early stages will be considered to be a heterogeneous contamination, but after time with the spread of the plume, the main area can be considered to be a homogeneously distributed contamination.

Annex B
(informative)

Methods of non-intrusive investigation

Table B.1 — 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 hydrocarbons.	Poor signal penetration in conductive ground. Only suitable for relatively even ground. Can suffer signal interference through reinforced concrete and from adjacent foundations.
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 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.

Table B.1 *(continued)*

Methods	Applications and advantages	Disadvantages
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 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.
Infrared 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.
Infrared 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; remotely controlled drones and model aircraft; 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. Use of helicopters is expensive.

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