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Soil quality — Sampling —

Part 5:
Guidance on the procedure for the investigation of urban and industrial sites with regard to soil contamination

Qualité du sol — Échantillonnage —

Partie 5: Lignes directrices pour la procédure d'investigation des sols pollués en sites urbains et industriels

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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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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.

ISO/IEC 10381-5 was prepared by Technical Committee ISO/TC 190, *Soil quality*, Subcommittee SC 2, *Sampling*.

ISO/IEC 10381 consists of the following parts, under the general title *Soil quality — Sampling*:

— *Part 1: Guidance on the design of sampling programmes*,

— *Part 2: Guidance on sampling techniques*,

— *Part 3: Guidance on safety*,

— *Part 4: Guidance on the procedure for investigation of natural, near-natural and cultivated sites*,

— *Part 5: Guidance on the procedure for the investigation of urban and industrial sites with regard to soil contamination*,

— *Part 6: Guidance on the collection, handling and storage of soil for the assessment of aerobic microbial processes in the laboratory*,

— *Part 7: Guidance on sampling of soil gas*,

— *Part 8: Guidance on sampling of stockpiles.*

Introduction

This part of ISO 10381 is one of a group of standards dealing with various aspects of site investigation and sampling. It should be used in conjunction with the other parts of ISO 10381 (see Foreword).

Whilst serious cases of soil contamination mostly occur at 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 such cases, a combination of the methodologies of ISO 10381-4 and ISO 10381-5 may be appropriate. When the objective of an investigation is related to plant growth, reference should be made to ISO 10381-4.

The general terminology used is in accordance with that established in ISO/TC 190 "Soil quality" and more particularly with the terminology given in ISO 11074.

The investigation of ground water, soil gas and surface water falls outside the scope of (this part of) ISO 10381. For more information on ground water and surface water sampling, see ISO 5667. Information on the sampling of soil gas is provided in ISO 10381-7.

Soil quality — Sampling —

Part 5:
Guidance on the procedure for the investigation of urban and industrial sites with regard to soil contamination

1 Scope

This part of ISO 10381 gives guidance on the procedure for the investigation of urban and industrial sites, where either it is known that soil contamination is present, or the presence of soil contamination is suspected. It is also applicable where there is a need to establish the contamination status of the site, or there is a need to establish the environmental quality of the site for other purposes.

This part of ISO 10381 includes guidance on the 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). However, it only provides guidance on the information required in general. It is emphasized that specific remediation methods may need additional information.

This part of ISO 10381 is also applicable to 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).

Although the sites considered in this document have been defined as urban and industrial sites, the guidance contained in this part of ISO 10381 is equally applicable to any site where the degree and extent of contamination needs to be established.

NOTE 1 Contamination is defined 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 A number of different objectives for soil sampling are listed in Annex A, along with references to the relevant parts of ISO 10381.

NOTE 3 Although the general part of the information for the risk assessment and/or the development of remedial action plans is gathered by applying this part of ISO 10381, this document 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).

NOTE 4 This part of ISO 10381 deals only with the investigation of the ground. It is important to recognize that on old urban and industrial sites, there may be derelict buildings and/or industrial plants awaiting demolition, dismantling or refurbishment. Failure to investigate these buildings before demolition may 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 part of ISO 10381.

NOTE 5 In many situations there is a close relation between the contamination of the soil, ground water, soil gas and — to a lesser extent — surface water.

2 Normative references

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

ISO 11074, *Soil quality — Vocabulary*

3 Terms and definitions

For the purpose of this part of ISO 10381, the terms and definitions of ISO 11074 apply.

4 Objectives

4.1 General

This guidance provides a framework for the various stages and phases that can be taken in the investigation of land. 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 15175, ISO 15176, ISO 15799, and ISO 15800.

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;

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

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

— to 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 may include the following:

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

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

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

d) identify pathways by which particular receptors may 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) enable characterization of contaminated materials to ensure safe and suitable handling and disposal;

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

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

j) 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 the construction of domestic dwellings 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 (expected) contamination within the site boundaries;

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

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

— identify constraints in relation to a proposed development (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.

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 stages 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.

The principal phases are

— preliminary investigation (see 5.2),

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

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

The relationship between these phases is illustrated in Figure 1.

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

Following completion of any of these investigations, a report giving its results should be prepared.

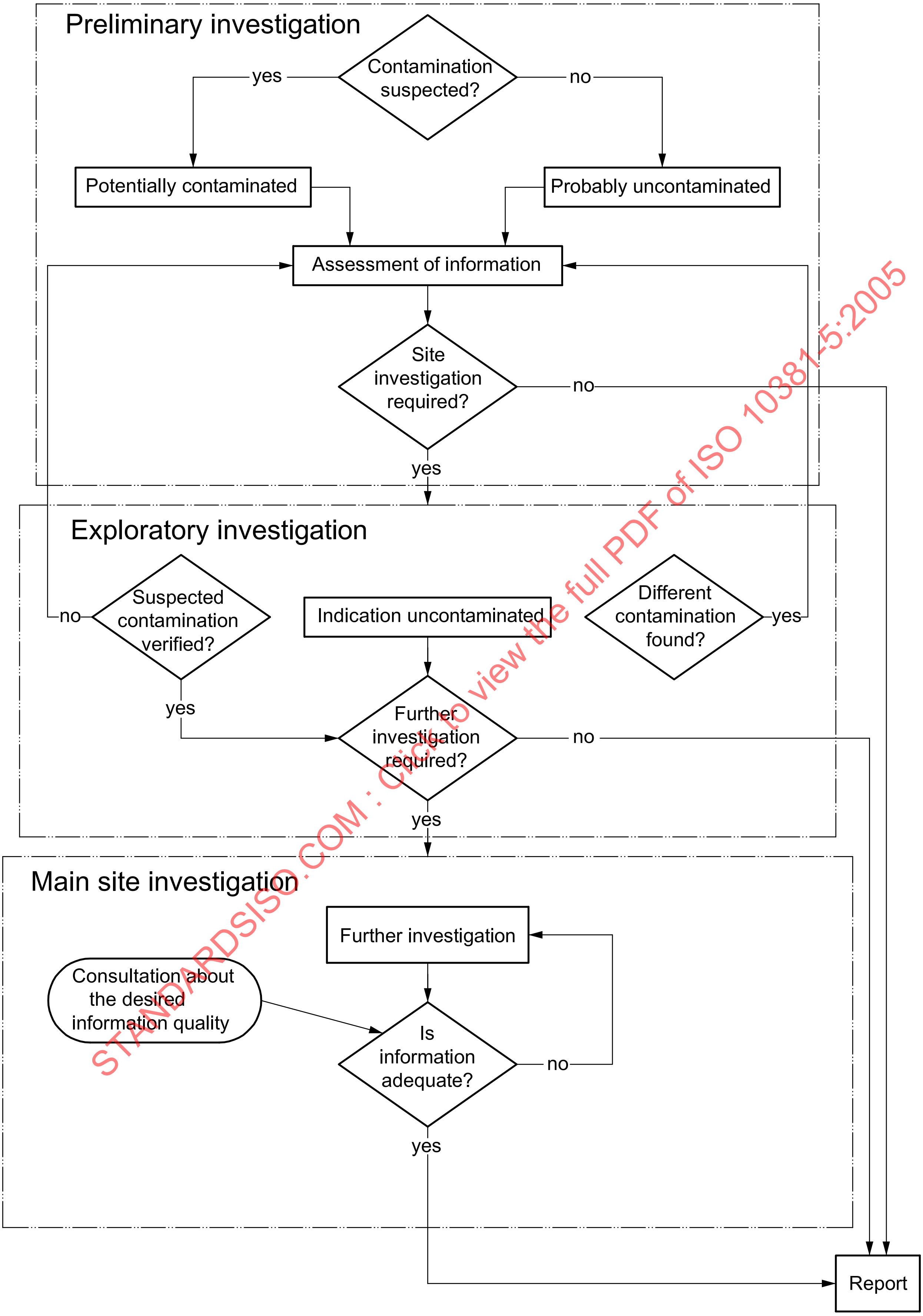

Figure 1 — Flow-chart of phases of site investigation

The strategy for the investigation (whether preliminary, exploratory or main site) 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.

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. 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 model” developed for the site (see 6.5 for the definition of the conceptual model).

When deciding on the strategy, consideration should be given to the applicability and use of onsite analysis and/or in-situ measurement techniques. This part of ISO 10381 does not provide any specific guidance on these topics.

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, pedology, hydrogeology and environmental setting.

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.

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

The preliminary investigation should provide sufficient information

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

— to determine whether there is a need for further action.

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 may 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 an onsite 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 model. It is therefore mainly a qualitative investigation rather than quantitative, typically only a few samples will be analysed.

In some cases where the hypotheses are indicated as being correct, no further investigation may need to be carried out.

However, it may 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 may have already caused or in the future may cause a hazard. In this situation, the information obtained may be inadequate to make decisions with a satisfactory degree of confidence, and it will be necessary to carry out a main 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 main site investigation

The main site investigation serves for the quantitative determination of the amount and spatial distribution of contaminants, their mobile and mobilisable fractions and possibilities of spreading in the environment. This includes possible future development of the contamination situation.

It requires the collection and analysis of soil or fill, surface water, ground water, 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 (sometimes), together with an initial estimate of costs. The analysis of samples can be supported by model calculations and investigation techniques without sampling. Detailed design of protective or remedial works may require further stages of investigation.

The amount and nature of the information required from the main 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 of 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 Introduction

The preliminary investigation serves for gaining knowledge of relevant information, its accuracy and plausibility, and to consider uncertainties and knowledge gaps and their relevance regarding the aim of investigation.

The preliminary investigation consists of:

— a desk study in which information on the history and other relevant aspects of the site is collected and critically reviewed;

— a site reconnaissance (site inspection, walk-over survey);

— development of a conceptual model of the site, in particular

1) formulation of hypotheses on the possible type(s) and amount of contamination,

2) migration pathways (on- and off-site), and spatial and temporal distribution; together with

3) hypotheses regarding other aspects of the site, such as the hydrogeology;

— drawing conclusions with regard to the need for and scope of further investigations;

— identification of any need for immediate actions to protect humans or the environment (e.g. fencing, removal of superficial deposits).

The objectives of the preliminary investigation should be set out formally before the investigation is started to ensure that the scope (e.g. sources of information searched) is appropriate.

In most cases, it should be possible to make a preliminary assessment of (potential) risks to humans and other receptors.

The information gathered should also enable

a) the design of subsequent stages or phases of intrusive investigation so as to minimize the risks of further spread of contamination or creation of new migration pathways (e.g. boreholes and trial pits), and

b) the adoption of appropriately safe methods of working during intrusive investigation (see ISO 10381-3).

The minimum information that should be collected in the preliminary investigation is set out in 6.2 and 6.3 and the procedures on how the information may be obtained are provided in 6.4. Guidance on reporting the results of the preliminary investigation is provided in 6.6.

6.2 Information on past and present use

The rapid growth of urban areas has resulted both in the absorption of areas which were formerly rural and in the change of use of existing urban land. Contamination within urban areas is therefore frequently the result of some historic industrial process that has occurred on the site, or nearby, and information to be collected for both urban and industrial sites is very similar.

Data gathered on historic and contemporaneous use of a site should, so far as is possible, provide information on the following (subject to any agreed limitations within the objectives):

— any development, building or other activity that has taken place on the site and its immediate surroundings;

— any specific actions that were taken in the past, and (description of the chemical composition of) any materials that were used, in connection with industrial, building or other activities on the site;

— industrial or other activities which have been (or are currently) potential causes of soil contamination (production processes, storage facilities, materials transport facilities (also underground transport), with an indication (as precise as possible) of the location(s);

— details with regard to cables, conduits, areas of soft landscape and areas of hard landscape, areas of made ground and areas of tipped material, effluent treatment, sludge disposal, surface drainage, chemical storage, underground tanks, waste materials, building rubble, etc.;

— information on adjacent land use (present and intended) which could affect the site under investigation.

Information with regard to similar sites elsewhere may be used for comparison.

6.3 Information on geology, pedology, hydrology and hydrogeology

Information should be collected on the geology and pedology of the area and the hydrological and hydrogeological situation as far as available. The scale at which this information should be collected, and the degree of detail that is required, can only be determined in a subjective manner, but should be in line with the defined objectives of the investigation.

The collected information should include:

— anticipated soil profile (natural and anthropogenic);

— the nature of the underlying ground and the depths of the underlying strata;

— the depth of the groundwater and any variation with time;

— horizontal and vertical groundwater flow direction(s), both on a regional and a local scale and variation with time (if possible) (The existence of impermeable strata can be of particular importance where the site is over an aquifer.);

— drainage patterns and the position of surface water courses, even if they are filled in at present and any continuity with groundwater;

— the presence of groundwater springs and wells and other abstraction points and any groundwater and ground gas monitoring installations;

— results of previous soil investigations at the site or its immediate surroundings, like boreholes or other forms of (geotechnical) investigations, in connection with, for example, building activities, and results of any chemical investigations;

— properties of the contamination which may be relevant with respect to the local soil structure or profile (for example, humus in the ground may absorb contaminating organic compounds).

6.4 Methodology

6.4.1 Obtaining information

The information described in 6.2 and 6.3 should be obtained in the following manner:

— detailed maps of good quality should be used as the reference base, for example, regional maps at scale 1:25 000, local maps at scale 1:2 000 to 1:2 500 on which provisions such as utility lines are indicated, historical maps, soil maps, hydrogeological maps;

— examination of maps and databases relating to the geology, pedology, hydrogeology and hydrology of the site and the area.

— examination of aerial photographs (black and white, colour and infra-red);

— examination of archives, of current or previous licenses of owners or users, of current or previous development plans, of information obtainable from offices of land registry (for example, municipalities, provinces, public utility companies) with respect to both the site under consideration and adjacent sites;

— examination of trade and street directories to establish former users of the site and the potential activities;

— consultation with authorities on current use of the site including environmental and operational permits, including discharge consents;

— where possible, and appropriate, interviews should take place with current or former owners and workers, current or former neighbours, neighbouring businesses, environmental groups, groundwater exploration companies, water companies, water quality inspectors etc. (The accuracy of such anecdotal evidence should be treated with caution unless the information can be confirmed by an independent source.);

— a visit to the site to obtain field observations (site reconnaissance). This should be carried out after available historical information and other relevant information has been obtained and collated.

6.4.2 Site visit observations

The result of the site visit should be a report on the existing site conditions with any implications relating to potential cause/spread of contamination including topography, surface drainage, and any “abnormal” situations. A photographic record should be made illustrating the site as a whole and particular features of relevance to the investigation.

The site visit will also be of assistance in formulating a strategy for any subsequent site investigation, which is practical and takes into account site-specific features. During the site visit, as many field observations as possible should be recorded.

Typical observations to be made during a site visit are

— current usage and state of the site;

— site access and ease of movement onsite, and conditions which may prohibit sampling at specific locations (e.g. buildings or other structures),

— conditions at boundaries to the site and surrounding land usage;

— proximity of sensitive developments and habitats;

— potential site risks (e.g. overhead power cables, live services and voids);

— hazardous materials;

— evidence of changes in site levels (both increases and decreases);

— indications of pollution (e.g. vegetation stress or lack of plant growth);

— visual evidence of contamination on or entering or emitting from the site or the presence of odours;

— condition of any surface waters;

— evidence of water abstraction points;

— existence of any ground water or soil gas monitoring wells.

Safety shall be an important consideration during the site reconnaissance and those carrying it out should be aware of possible physical risks as well as contamination or biological risks. Old buildings, etc. may be structurally unsound and shall only be entered after taking expert advice (for further guidance on safety, see ISO 10381-3).

6.5 Development of the conceptual model

6.5.1 Overall conceptual model

The conceptual model is a representation and/or description of the site incorporating all that is known about the site (e.g. contamination, geology, pedology, environmental setting) and, where appropriate, indicating pathways by which current and future receptors might be affected by contamination currently or in the future. An important aspect of the conceptual model is the formulation of contamination-related hypotheses.

The development of a conceptual 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 stages of investigation. It also aids decisions on how remediation (if required) might be achieved and other works carried out.

6.5.2 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.

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.

Hypotheses relating to individual substances should be developed (see 6.5.4) that can then be incorporated into a conceptual 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 models for individual zones can be combined into a conceptual model for the site as a whole. This site-wide conceptual model is used to design the sampling strategy to be employed in the next stage of investigation.

However, before deciding on the sampling strategy, it is first 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 categorized as “probably uncontaminated” or as “probably contaminated”.

6.5.3 Hypothesis of a “probably uncontaminated” site or zone

If, based on the results of the preliminary investigation, there is no reason to suspect that polluting 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 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 in national or regional legislation.

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

The results of the exploratory site investigation may 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”, normally a relatively wide range of contaminants will 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 chance that unexpected contamination is found.

6.5.4 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 type of contaminants, its 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.

When formulating the hypotheses relating to different parts of the site (zones) will provide the best assessment and the combination of hypotheses in this manner should enable an optimum investigation strategy to be designed.

6.5.5 Hypotheses relating to spatial distribution of contamination

6.5.5.1 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.

6.5.5.2 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 1 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.

The hypotheses concerning the nature of the distribution are very important, since these will affect the subsequent sampling strategy.

Thus where a homogeneous distribution is hypothesised,

— the sampling strategy may adopt a wider spacing between sample locations since it is anticipated that the contamination should be similar at all locations (This sampling strategy would of course reduce the likelihood of identifying hotspots).

— Additionally, for homogeneous contamination, the use of composite samples can be cost effective as the costs for analysis can be diminished while the analytical results are representing a relatively large area (see also 7.4.6).

However, if heterogeneous distribution is hypothesised,

— the sampling strategy will need to specify distances between sample locations which should enable the expected variations in contaminant concentrations to be identified, and

— may also include some judgmental sampling where the heterogeneity is attributable to “known” locations of point source contamination.

It should be noted that the definition of contamination as “homogeneous” or “heterogeneous” basically in plane depends on the scale that is used to investigate the contamination.

EXAMPLE 2 A contamination that is considered to have contaminated a site of 100 m by 100 m homogeneously, will be recognized as homogeneous, as long as the investigation does not exceed the limits of the location. However, when looking at the soil quality on a 1 000 m by 1000 m scale, the same contamination will be identified as a “hot spot” and is to be considered as heterogeneous

Homogeneous and heterogeneous are therefore only qualitative concepts.

In practice, the distribution of contaminating substances is likely to be a combination of distribution patterns and the sampling plans should be defined to accommodate the individual types of distribution.

Since hypotheses about spatial distribution should be postulated for each individual substance (or group of substances), the final sampling plan should take into account of the different sampling patterns required for the different contaminants present on the site.

6.6 Reporting the preliminary investigation and the conceptual model

The preliminary investigation should be reported in such a way that the initial formulation of the conceptual model and individual hypotheses will stand out as a clearly recognizable, identifiable, section of the report.

The report of the preliminary investigation should contain the following:

a) information collected on past and present uses of the site together with details on geology, pedology and hydrogeology;

   1) All aspects mentioned in 6.2 and 6.3 should be discussed, and details should be provided of all the sources that have been consulted.

   2) Indications should also be given about where there are possible gaps in the information that has been obtained, and any other constraints or limitations of the survey;

b) a record of where a source of information has been accessed, but no specific information was available;

c) a record of anecdotal evidence which has been obtained, together with

   1) the name of the person interviewed, and

   2) the date of the interview.

   3) (The relationship of the interviewee with the site should be recorded, as this can be useful for assessing the reliability of the information);

d) a full discussion and a full description of the development of the conceptual model of the site, including

   1) the hypotheses which have been formulated,

   2) the conclusions relating to the presence or absence (and the type and nature) of the contamination, and

   3) the spatial distribution, and details of delineation into zones for which the different hypotheses have been formulated;

e) in the case of a "probably uncontaminated" site, the arguments supporting this conclusion should be included;

f) in the case of a "probably contaminated" site, the following elements should all be discussed where relevant:

   1) the nature of the source(s) of contamination and the manner in which the contaminants were introduced into the soil,

   2) a list of possible contaminants (and if applicable their chemical specification),

   3) the spatial distribution that is anticipated and the expected distribution and location of the contamination in the soil, surface and ground water, and soil gas;

g) conclusions and recommendations on the need and form of further actions – specifically the need for a site investigation – that are considered appropriate taking into account the objectives.

The report should follow a formalized structure (see also 9.6) and it is suggested that the contents should include:

— Table of contents;

— Summary;

— Introduction;

— Objectives;

- Details of the research (including sources of information which may be given in an appendix for convenience);
- Details of the site (including gathered information and the results of the site visit);
- Discussion and formulation of hypothesis;
- Conclusions;
- Recommendations;
- Appendices (containing as much of the documentary evidence, etc. as is practicable).

7 Design of intrusive investigations

7.1 Introduction

This clause provides guidance applicable to the design of all types of intrusive investigations (e.g. exploratory and main investigations). Subsequent sections provide guidance relating to specific types of investigation. Guidance is provided on overall design, sampling soils, compositing of 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 10381-3 should be consulted for further information on the possible risks and precautions to control those risks.

ISO 10381-1 and ISO 10381-2 should be consulted for information on specific aspects of sampling techniques including sampling patterns, methods of collecting samples including boreholes, probe holes and trial pits, and sample preservation. It should be noted that other – non-intrusive – investigation techniques can contribute significantly to the understanding of the spatial distribution of the contamination.

It is advisable to ensure from the start of the field work that sufficient samples will be collected. It will often 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 may not be possible to preserve the samples for later analysis.

Instead of taking samples, it might be advantageous to use on-site and/or in-situ methods for testing and analysis.

If at any time during the investigation it becomes evident that the implemented strategy has not been optimal, the strategy should be altered immediately (for example, ground water table differs markedly from the expected depth). In some cases it may 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.

Descriptions of ground strata should be drawn up in the field immediately after a sampling location has been completed if this has not been done during formation. Taking photographs with sampling location identification boards 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 main 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 onsite, to vary locations and sample additional locations in the light of the onsite observations.

The hypotheses postulated may indicate some area(s) of potential contamination where preliminary information will be of assistance in designing the more detailed main site investigation.

EXAMPLE For example, preliminary information on the potential extent of spillage of chlorinated solvents may be of assistance.

The design of the exploratory site investigation can take such aspects into consideration, and so provide information to enable the main (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 may be applied to different areas of a site (zones), and hence different sampling strategies may be applied within the investigation process.

7.3.2 Design of site works

7.3.2.1 Planning

The designer of the site works shall 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, grain fraction, water, gas);

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

— requirements for sample containers;

— requirements for on-site and off-site testing;

— analyses 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 to prevent migration of contamination during and after completion of the investigation;

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

- requirements for quality assurance;
- 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;
- location of suitable areas for offices, decontamination unit, welfare and sample storage;
- health and safety - (Reference should be made to ISO 10381-1, ISO 10381-2 and ISO 10381-3 which cover in detail the risks to investigators and the environment which could result from a site investigation. The necessary precautions and actions shall be designed into the site investigation methodology.);
- communications and accident and emergency plans and communications with the emergency services;
- actions to protect the environment, for example, dust suppression and control and prevention of migration of contamination;
- disposal of (possibly) contaminated ground water, 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;
- 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 may be different.

7.4 Sampling patterns and spacing for sampling soils

7.4.1 General

The sampling strategy requires consideration of the pattern to be used, the depths at which samples will be collected and the types and sizes of samples to be collected. Consideration of sampling patterns is given in ISO 10381-1. Statistical considerations may also be applied to sampling patterns, particularly the distance between sampling points.

Sample locations may 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 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. 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 may be considered 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, but always with such a minimum number of samples that an indication of the spatial variability within the zone is obtained.

NOTE This will commonly require about six samples.

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 shall be borne in mind that contamination rarely exists with sharply defined boundaries and increasing concentrations may be used as indicators of contamination, even though the areas of highest concentration have not been sampled.

Sampling grids typically vary between 30-m centres for an exploratory investigation down to 15-m centres for a main site investigation. Greater density of sampling grid may be considered appropriate where very heterogeneous contamination is hypothesised, for example, on a former gasworks site where in localized areas 10-m centres may be considered to be necessary. A high-density sampling grid may 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).

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. Alternatively an area of contamination may have been detected in the exploratory site investigation, and further delineation is required as one of the objectives of the main site investigation.

Sampling locations may 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 may be related to a regular pattern which is being used for other areas of the site, or as an alternative to sampling at adhoc locations, the sampling locations may be placed along radii from the suspected source or point of high concentration. Where a plume is being targeted, sampling locations should be selected according to the hypothesis relating to the location and nature of the contamination. The ultimate in judgmental sampling is likely to occur in the exploratory site investigation, when specific locations of visually contaminated material or suspected contamination are encountered and sampled to confirm suspicions prior to more detailed investigation in the main site investigation.

7.4.3 Regular sampling

Site investigations (both exploratory and main) should usually be carried out using systematic sampling so that the sampling locations are distributed throughout the site (or zone) according to a regular pattern. However, non-systematic sampling (in particular judgemental sampling) patterns may be acceptable where there are good reasons for such use (for example, where it is important to check potential preferential pathways for migration), or to complement a systematic sampling pattern.

The reasons for selecting a systematic sampling pattern are:

a) sampling locations on a systematic pattern are simpler to establish in the field;

b) identification of areas of contamination and design of further investigations is much easier to carry out using the systematic pattern.

Reliability of interpolation will depend substantially on variations in soil characteristics. In well stratified sediments, vertical variations in concentration may be much greater than horizontal variations.

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

The sampling pattern used, and the number of the sample locations, will vary and be dependent on the hypotheses formulated and the phase of the investigation.

— In an exploratory site investigation, fewer samples will be collected from fewer locations than in main site investigation. For exploratory site investigation, sampling locations should be selected with the aim of confirming the hypotheses and establishing the areas which will require greater attention in the main site investigation.

— In contrast, the main site investigation will be a detailed investigation to establish a comprehensive picture of the contamination status of all parts of the site. The number of samples collected and the spacing between sample locations should be related to the objectives and degree of confidence required in the resultant assessment of contamination and associated risk assessment and need for remedial works.

7.4.4 Detection of hotspots

7.4.4.1 Hotspot definition

The "efficiency" of a sampling pattern is often expressed in terms of the confidence there is in whether a "hotspot" of a given size will, or will not, be identified. However, the concept and definition of the hotspots should also be carefully considered during the design stage of the investigation, and particularly so for the main site investigation.

A hotspot can be defined as

— an area of contamination in an otherwise uncontaminated area;

— an area of much greater contamination in a site that is generally contaminated.

7.4.4.2 Hotspot size

The size of a hotspot is not a fixed parameter and depends on

a) the source and nature of the contaminative process (for example, a hotspot due to buried drums of contamination will present a different sampling problem than that for identifying a hotspot due to a leakage from a storage tank), and

b) the definition of what concentration of a particular contaminant is judged to be noteworthy when assessing the results of the investigation.

The size of a hotspot or area to be detected will be related to the consideration of the maximum area that will not pose unacceptable health risks, if it is not detected in the site investigation and subsequent assessment of results. In this respect, it is important to bear in mind the area of contamination which could be of concern where the evaluation of human health risks is involved.

EXAMPLE In the case of a housing development, this could require the identification of contaminated area the size of a small garden, or even part of a small garden. This could be only 50 m^2 (or just 0,5 % of a 1 hectare site).

7.4.4.3 Hotspot detection, site investigation design and sampling

In practice, the probability of detecting a hotspot can be improved by the careful design of the exploratory site investigation and subsequent main site investigation.

Greater density of sampling will usually be appropriate in areas of suspected contamination with less intense sampling in areas not suspected of contamination, in accordance with the hypotheses relating to different areas of the site.

NOTE Under some circumstances there can be greater monetary value in demonstrating, with a high degree of confidence, that a particular part of the site is “uncontaminated”. This will usually require a high sampling density.

If the contamination is expected to occur in known localized hotspots, each suspect location should be subject to investigation.

— In the exploratory investigation, one sample location shall be placed at the assumed centre of the hotspot. For contaminations that can be observed in the field, this one sample might be sufficient. If contaminations are not observable in the field, and when some information on the extent of the contamination is already required in the exploratory investigation, another four sample locations should be placed at the expected perimeter of the contamination. Samples should be taken from each location and all relevant depths. If hotspots are found (by chance) during the exploratory investigation, these hotspots shall be investigated with a similar approach.

— In the main site investigation, the number of additional sample locations depends on the extent of the contamination and the desired confidence of the delineation.

7.4.5 Depth of sampling and the strata to be sampled

7.4.5.1 Factors to take into account for sampling at depth

The sampling strategies described above apply only to a single contaminant in a single plane. The distributions of different contaminants on a site may 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 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 may 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 usage of the site.

Where a site has been identified as potentially contaminated, ideally those horizons of the soil strata which are expected to be contaminated should be sampled (sampling will be concentrated on suspect areas in accordance with the hypothesis). In some situations, where the site is underlain by an impermeable strata at fairly shallow depth, it will be possible to identify specific depths which should be sampled. However, it is often very difficult, prior to any intrusive investigation, to have a clear indication of where contamination may exist.

Individual samples should be taken over a limited depth range (say 0,1 m to 0,5 m) to be representative for no more than 1,0 m of the soil profile, taking into account the hypotheses. They should usually be restricted to a specific stratum. Samples should be taken to represent any strata of particular interest (e.g. appearance) that are encountered. Where samples are not restricted to a single stratum, the reasons should be stated in the report of the investigation.

At all sampling locations, samples should be taken through the full depth of interest in accordance with the hypotheses. Where contamination is indicated at greater depth than anticipated prior to the site investigation, sampling should be carried out to whatever greater depth seems appropriate and is practicable.

Taking samples of natural strata is always beneficial: if uncontaminated, these will indicate the natural background chemical conditions which are essential to the evaluation of risks and decisions on target remediation values.

7.4.5.2 Sampling depth in relation to intended use of the site

Sampling depths should reflect what is known about intentions for the use of the site (i.e. the receptors which may be at risk) and the probable pathways by which contaminants may enter the environment.

EXAMPLE 1 On most housing developments, excavation to at least 1,5 m is likely to be required to install services and strip foundations. Deeper excavations may be required for the installation of sewers.

EXAMPLE 2 On commercial developments, excavation to considerable depths may be required to construct several floors of basements. Thus, the construction work force may encounter contaminated materials at these depths and materials from these depths may be brought to the surface and either become spread about (if there is inadequate control) or have to be taken off-site for treatment or disposal.

NOTE ISO 10381-8 provides a guidance for the investigation of stockpiles of excavated soil from these types of sites.

The sampling plan should also take into account whether there is a likelihood that the surface level of the site is to be lowered, which will thus expose deeper layers of the site.

In many sites, a correlation between contamination in the topsoil and the subsoil will be found. Often a correlation will also exist between contamination in the subsoil and contamination in the ground water.

7.4.5.3 Sampling in relation to the ground water profile and aquifer

Frequently contamination migrates into ground water in such a way that it is preferentially concentrated in, or along, the upper layers of the ground water profile. Therefore, it is prudent to collect soil samples from these depths.

However, this depends highly on the density of the contaminant; contaminants like chlorinated hydrocarbons [Dense Non Aqueous Phase Liquids (DNAPL's)] show just the opposite behaviour and can be found in high concentrations at the base of the aquifer.

7.4.6 Sample quantity and use of composite samples

7.4.6.1 Sample quantity

Information on the quantity of material to be collected for soil samples is given in ISO 10381-1.

7.4.6.2 Production of composite samples

Composite samples may be produced in the field by combining two or more increments. Alternatively, individual samples can be combined in the laboratory.

NOTE In both cases, a good pre-treatment (i.e. mixing) is essential to obtain a representative analytical sample.

7.4.6.3 When the use of composite samples may be considered

Depending on the nature of the investigation, the defined sampling strategy and the objectives of the investigation, the use of composite soil samples may be considered. In some situations the use of composite samples may result in dilution or loss of components, and hence the risk of not detecting contamination. However composite samples may enhance the representiveness of the samples and may be considered in a number of specific situations.

More specifically the use of composite samples may be considered where

— there is homogeneous distribution;

— there is heterogeneous distribution over a small distance, but over a large distance the distribution is homogeneous;

— the components are non-volatile or semi-volatile.

The use of composite samples may be of assistance in situations where there may be a large degree of variation of composition over a short-scale, but where on a larger-scale the distribution may be considered to be homogeneous, for example, where ash or slag is mixed with soil. In this instance, composite samples may give much more representative analytical results.

7.4.6.4 When composite samples may not be appropriate

Composite samples are not appropriate in all cases and the type of contaminant will determine to a large degree the possibility of forming composite samples. Composite samples cannot be made without significant loss of volatile compounds. Where semi-volatile compounds are present, composite soil samples may be prepared in the laboratory. The pre-treatment of the composite samples is of vital importance to ensure that representative results are obtained.

Whilst the combination of a number of individual samples into a "composite sample" for analysis may increase the chance that a general contamination will be detected, it is also possible that the mixing process will dilute a hotspot concentration to below detection and hence give a false indication in relation to contamination of the site. Any values used to judge the presence of contamination should be revised downwards to allow for this dilution effect.

7.4.6.5 Which samples should be combined

Whether the samples are combined in the field or in the laboratory, only adjacent samples from within the same soil stratum should be combined. Combining samples that come from different soil layers would result in a loss of information, and only combining neighbouring samples will also ensure that any large-scale spatial variation in concentrations in the plane of the soil layers will be detected.

7.5 Analytical and testing strategies

7.5.1 General

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

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

In deciding on the components to be analysed, there are two distinctive approaches:

— a component specific approach; and

— a broad spectrum approach.

Both approaches might be used in either the exploratory investigation or the main 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* might be the best choice if you also want to know more about the treatment potential of that contaminated soil, or indeed, if general information about the soil quality is required.

7.5.2.2 Selecting parameters for testing and analysis

Contaminants such as heavy metals (Cd, Cr, Cu, Hg, Ni, Pb, Zn), arsenic, mineral hydrocarbons, EOX and PAH have proven useful and cover a wide range of urban and industrial soil contaminations. Therefore, they are normally sufficient when testing the hypothesis of a “probably uncontaminated” site, and are also recommended for unspecific suspect of contamination. Regional specialities and national recommendations are to be regarded.

Determination of the proportion of organic material (humus) and the proportion of fine-grain size fraction may be considered necessary in connection with the determination of reference or threshold values which are accepted to be applicable at the site. (These could, for example, include local background values.)

7.5.2.3 Using separate or composite samples

Combining of samples (if permissible), after pre-treatment in accordance with ISO 11464 and ISO 14507, 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 model of the site will determine what is the most appropriate strategy for analysis.

If composite samples are used, the original samples should be stored separately. This will ensure that, if necessary, they may 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. pre-treatment)].

7.5.2.4 Storage and transport of samples

Guidance on storage and transport of samples is given in ISO 10381-2.

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 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.

The exploratory investigation will usually give limited information only. However, depending on the objective(s) for the specific case, the information obtained may 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; and

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

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

8.1.2 Steps to be incorporated

The exploratory investigation shall incorporate the following steps:

— design of an investigation strategy;

— 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 for the exploratory investigation are

a) the hypotheses;

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

c) any indicated risks to human health or the environment.

These aspects determine the

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

— depth of sampling and sampling techniques to be used;

— sampling patterns;

— number of samples to be taken;

— possible use of composite samples;

— number of samples to be analysed;

— potential contaminants to be determined.

During an exploratory investigation relatively few sample locations will be investigated, compared with the main 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 utilised in the subsequent assessment deriving from the main site investigation.

In the exploratory investigation particularly, it will 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 with oil may not be necessary at this stage. But in utilising visual assessment, it must be remembered that not all contamination can be identified in this manner.

It is advisable to use an experienced contaminated site investigator in designing the exploratory investigation, including sampling strategy and the number of samples to be collected and analysed, and in supervising the performance of the investigation to test the hypotheses.

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.

The assessment of contaminations usually is done considering the relevant pathways. For economical reasons, spacing and depth of sampling, even at the exploratory investigation, should be chosen so that the results can be used for risk assessment during later investigation steps.

National regulations shall be obeyed.

The investigation of potential soil contamination should be carried out in close connection to the investigation of the other matrices in which the contamination might be present, specifically

— ground water (see ISO 5667);

— surface water (see ISO 5667);

— soil gas (see ISO 10381-7).

8.2.2 Sampling locations

Two basic approaches can be used in the exploratory investigation, judgemental sampling and systematic sampling (see 7.4).

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. Specific recommendations for sample spacing cannot be given. Note that a dependency of sample spacing on the overall size of the site is – in most cases – not justifiable. The sample spacing should be defined based on the desired probability of finding a contaminated area with a predefined size. The definition of both the probability of finding (or missing) such a contaminated area as well as the size of it, is a policy decision. Therefore national regulations shall be regarded.

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 strategies should be combined.

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

8.2.3 Depth of sampling

Like sampling patterns, the depth of sampling depends on the hypotheses and on the scope of the investigation (see 7.4.5).

National 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 always should be analysed. Thus if samples of the same strata from a number of different locations appear similar, only a representative number may be submitted for analysis.

Sufficient samples should be analysed to test the hypotheses. Delineation of contaminant distribution is not objective of an exploratory investigation.

8.2.5 Selecting parameters for testing and analysis

For testing the hypothesis of a “probably uncontaminated” site, a limited number of components such as heavy metals (Cd, Cr, Cu, Hg, Ni, Pb, Zn), As, mineral hydrocarbons, EOX and PAH will usually be sufficient. Regional specialities and national recommendations are to be regarded.

NOTE A similar approach is usually appropriate for the initial investigation of suspected areas where the contaminating substances are unknown.

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 defined investigation (both in contaminants as well as in sampling pattern) in order to obtain additionally information on the general quality of the site. In general, the selection of the contaminants is directly related to the objective(s) of the investigation and the defined hypothesis.

If a reference value for a group parameter 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 main site investigation instead of an additional stage in the exploratory investigation.

8.3 Interpretation 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 during the preliminary investigation. The testing procedure is carried out in the same way that was made 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, it is usual to apply threshold values (usually contained in legislation or guidance from authorities) to determine whether a site should be considered contaminated or not. If threshold values are not available, local background values may also be used, or if applicable in conjunction with threshold values.

8.3.2 Risk assessment

If the site is contaminated, a subsequent risk assessment may be necessary to establish the seriousness of the contamination. A risk assessment may be carried out if the quality and quantity of the data is 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 may be possible to carry out a screening risk assessment.

8.3.3 Consider 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 Obtain 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 Check 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

The hypothesis of a “probably uncontaminated’’ site shall 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 must 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 must 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 shall be accepted.

Because of the limited objectives of the exploratory investigation, its usefulness to test the hypothesis regarding the spatial distribution of the contamination of a “probably contaminated’’ site is limited. Nevertheless, the hypothesis has to be adapted when possible, and improved with increasing knowledge.

8.3.7 Examples indicating if the hypothesis should be revised or rejected

The following examples indicate when it may 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 don't show concentrations of contaminants in excess of the threshold/background value, it shall be concluded that the anticipated point sources either were not localized or do not exist.

b) If a “probably contaminated’’ site, with heterogeneous distribution where the location of pockets of contamination is unknown, was hypothesised, and in order to locate the contamination in the exploratory investigation, a systematic sampling pattern was applied over the entire site, it must be expected that a greater number of samples did not meet 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 may 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, a correction of the works performed or further investigations can become 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 main site investigation can be planned on this basis.

— If a new/modified hypothesis cannot be verified sufficiently, further investigation shall 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

The report of the exploratory investigation aims at a documentation and a presentation of information relevant for decision. 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 model of the site and the hypotheses which were developed as a part of that conceptual model, including information on the degree of confidence;