BRITISH STANDARD

BS ISO 10381-1:2002

Soil quality — Sampling —

Part 1: Guidance on the design of sampling programmes

ICS 13.080.05

British Standards

National foreword

This British Standard reproduces verbatim ISO 10381-1:2002 and implements it as the UK national standard.

The UK participation in its preparation was entrusted to Technical Committee EH/4, Soil quality, which has the responsibility to:

— aid enquirers to understand the text;

— present to the responsible international/European committee any enquiries on the interpretation, or proposals for change, and keep the UK interests informed;

— monitor related international and European developments and promulgate them in the UK.

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Soil quality — Sampling —

Part 1:
Guidance on the design of sampling programmes

Qualité du sol — Échantillonnage —

Partie 1: Lignes directrices pour l'établissement des programmes d'échantillonnage

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.

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 10381-1 was prepared by Technical Committee ISO/TC 190, *Soil quality*, Subcommittee SC 2, *Sampling*.

ISO 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 investigation of soil contamination of urban and industrial sites*

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

Introduction

This part of ISO 10381 is one of a set of International Standards intended to be used in conjunction with each other as appropriate and necessary. ISO 10381 (all parts) deals with sampling procedures for the various purposes of soil investigation.

Soil quality — Sampling —

Part 1:
Guidance on the design of sampling programmes

1 Scope

This part of ISO 10381 sets out the general principles to be applied in the design of sampling programmes for the purpose of characterizing and controlling soil quality and identifying sources and effects of contamination of soil and related material, with emphasis on

— procedures required to locate points from which samples may be taken for examination or at which instruments may be installed for *in situ* measurement including statistical implications,

— procedures for determining how much sample to collect and whether to combine samples,

— methods of collecting samples,

— methods for containing, storing and transporting samples to prevent deterioration/contamination.

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 10381-3, *Soil quality — Sampling — Part 3: Guidance on safety*

ISO 10381-4, *Soil quality — Sampling — Part 4: Guidance on the procedure for investigation of natural, near-natural and cultivated sites*

ISO 10381-5, *Soil quality — Sampling — Part 5: Guidance on investigation of soil contamination of urban and industrial sites*

ISO 10381-6, *Soil quality — Sampling — Part 6: Guidance on the collection, handling and storage of soil for the assessment of aerobic microbial processes in the laboratory*

ISO 11074-2, *Soil quality — Vocabulary — Part 2: Terms and definitions relating to sampling*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 11074-2 apply.

4 Planning the sampling programme

4.1 General

Samples are collected and examined primarily to determine their physical, chemical, biological and radiological properties. This clause outlines the more important factors which should be considered when devising a sampling programme for soil and related material. More detailed information is given in subsequent clauses.

Whenever a volume of soil is to be characterized, it is generally not possible to examine the whole and it is therefore necessary to take samples. The samples collected should be as representative as possible of the whole to be characterized, and all precautions should be taken to ensure that, as far as possible, the samples do not undergo any changes in the interval between sampling and examination. The sampling of multiphase systems, such as soils containing water or other liquids, gases, biological material, radionuclides or other solids not naturally belonging to soil (e.g. waste materials), can present special problems. In addition, examination for some physical soil parameters may require so-called undisturbed soil samples for correct execution of the relevant measurement.

Before any sampling programme is devised, it is important that the objectives be first established since they are the major determining factors, e.g. the position and density of sampling points, time of sampling, sampling procedures, subsequent treatment of samples and analytical requirements. The details of a sampling programme depend on whether the information needed is the average value, the distribution or the variability of given soil parameters.

Some consideration should also be given to the degree of detail and precision required and also to the manner in which the results are to be expressed and presented, for example concentrations of chemical substances, maximum and minimum values, arithmetic means, median values, etc. Additionally, a list of parameters of interest should be compiled and the relevant analytical procedures consulted, since these will usually give guidance on precautions to be observed during sampling and subsequent handling of soil samples.

It may often be necessary to carry out an exploratory sampling and analysis programme before the final objectives can be defined. It is important to take into account all relevant data from previous programmes at the same or similar locations and other information on local conditions. Previous personal experience can also be very valuable. Time and money allocated to the design of a proper sampling programme is usually well justified because it ensures that the required information is obtained efficiently and economically.

It is emphasized that whether soil investigations completely achieve their objectives depends mainly on the design and execution of an appropriate sampling programme.

The main points about which decisions shall be made in the design of a sampling programme are listed below in 4.2 to 4.7. The relevant references are indicated.

4.2 Defining the objective

The following should be considered when defining the objective:

a) delineation of area(s) to be investigated;

b) setting of objectives for the whole investigation;

c) listing of parameters to be determined;

d) listing of other information required to enable interpretation of results;

e) content of sample report;

f) decisions regarding contractual arrangements for sampling;

g) management arrangements;

h) estimation of costs.

4.3 Preliminary information

The following questions may help in the choice of preliminary information:

a) What is already known?

b) What can be made easily available?

c) Who is to be contacted for certain (historical) sources?

d) Are there any legal problems, e.g. entering the site?

e) What should be observed on first visit to the site?

For details see Clause 6 and ISO 10381-4, ISO 10381-5 and ISO 10381-6.

4.4 Strategy

Decisions regarding the following factors are usually involved in a sampling strategy:

a) sampling patterns;

b) sampling points;

c) depth of sampling;

d) type of samples to be obtained;

e) sampling methods to be employed, e.g. borings, drillings, trial pits, etc.

For details see Clause 10 and ISO 10381-4, ISO 10381-5 and ISO 10381-6.

4.5 Sampling

The following procedures are involved in planning the sampling:

a) coordination with personnel responsible for the sample preparation and analysis;

b) choice of suitable sampling tools;

c) choice of suitable storage;

d) choice of suitable preservation measures;

e) choice of suitable labelling and transportation;

f) field tests to be carried out, if specified.

For details see Clauses 7, 8, 10 and ISO 10381-2, ISO 10381-4, ISO 10381-5 and ISO 10381-6.

4.6 Safety

The following safety aspects need to be considered:

a) all necessary safety precautions at the site;

b) informing landowners, construction authorities, local authorities;

c) data protection efforts;

d) requirements for disposal of surplus soil or test material.

For details see Clause 9 and ISO 10381-2, ISO 10381-3, ISO 10381-4, ISO 10381-5 and ISO 10381-6.

4.7 Sampling report

The sampling report should meet the basic content as specified in this part of ISO 10381. Additional information required should be clearly specified by the client and laid down in a written contract. Any later deviation should be justified to avoid deficiencies with regard to evaluation of the investigation and to avoid conflicts between business partners.

For details see Clauses 11, 12, 13 and ISO 10381-4, ISO 10381-5 and ISO 10381-6.

5 Objectives of sampling

5.1 General

5.1.1 Principal objectives

The four principal objectives of sampling of soil may be distinguished as follows:

— sampling for determination of general soil quality;

— sampling for characterization purposes in preparation of soil maps;

— sampling to support legal or regulatory action;

— sampling as part of a hazard or risk assessment.

These four principal objectives are discussed further below.

The utilization of the soil and site is of varying importance depending on the primary objective of an investigation. For example, while consideration of past, present and future site use is particularly relevant to sampling for risk assessment, it is less important to soil mapping where the focus is on description rather than evaluation of a soil. Objectives such as soil quality assessment, land appraisal and soil monitoring take utilization into account to varying degrees.

The results obtained from sampling campaigns to assess soil quality for mapping may indicate a need for further investigation, for example if contamination is detected which indicates a need for identification and assessment of potential hazards and risks.

5.1.2 Sampling for determination of general soil quality

Such sampling is typically carried out at (irregular) time intervals to determine the quality of the soil for a particular purpose e.g. for agriculture. As such, it tends to concentrate on factors such as nutrient status, pH, organic matter content, trace element concentrations and physical factors, which provide a measure of current quality and which are amenable to manipulation. Such sampling is usually carried out within the main rooting zone and also at greater depths but sometimes without exact distinction of horizons or layers.

The guidance given in ISO 10381-4 is particularly relevant.

5.1.3 Sampling for preparation of soil maps

Soil maps may be used in soil description, land appraisal (taxation), and for soil monitoring sites to establish the basic information on the genesis and distribution of naturally occurring or man-made soils, their chemical, mineralogical, biological composition, and their physical properties at selected locations. The preparation of soil maps involves installation of trial pits or core sampling with detailed consideration of soil layers and horizons. Special strategies are required to preserve samples in their original physical and chemical condition. Sampling is nearly always a one-off procedure.

The guidance given in ISO 10381-4 is particularly relevant.

5.1.4 Sampling to support legal or regulatory action

Sampling may be required to establish baseline conditions prior to an activity which might affect the composition or quality of soil, or it may be required following an anthropogenic effect such as the input of an undesirable material which may be from a point or a diffuse source.

Sampling strategies need to be developed on a site-specific basis.

To adequately support legal or regulatory action, particular attention should be paid to all aspects of quality assurance including for example “chain-of-custody procedures”.

The guidance given in ISO 10381-5 is particularly relevant. That in ISO 10381-4 may also be relevant.

5.1.5 Sampling for hazard and risk assessment

When land is contaminated with chemicals and other substances that are potentially harmful to human health and safety or to the environment, it may be necessary to carry out an investigation as a part of a hazard and/or risk assessment, i.e. to determine the nature and extent of contamination, to identify hazards associated with the contamination, to identify potential targets and routes of exposure, and to evaluate the risks relating to current and future use of the site and neighbouring land. A sampling programme for risk assessment (in this context: phase I, phase II, phase III and phase IV investigation) may have to comply with legal or regulatory requirements (see 5.1.3), and careful attention to sample integrity is recommended. Sampling strategies should be developed on a site-specific basis.

The guidance given in ISO 10381-5 is particularly relevant. That in ISO 10381-4 may also be relevant.

5.2 Specific objectives

5.2.1 General

Depending on the principal objective(s), it is usually necessary to determine, for the body of soil or part thereof:

- the nature, concentrations and distribution of naturally occurring substances,
- the nature, concentrations and distribution of contaminants (extraneous substances),
- the physical properties and variations,
- the presence and distribution of biological species of interest.

It is often necessary to take into account changes in the above parameters with time, caused by migration, atmospheric conditions and land/soil use.

Some detailed objectives are suggested in the subclauses below. The list is not exhaustive.

5.2.2 Sampling for the determination of soil chemical parameters

There are many reasons for chemical investigation of soil and related material and only a few are mentioned here. It is important that each sampling routine be tailored to fit the soil and the situation.

Chemical investigations are carried out

a) to identify immediate hazards to human health and safety and to the environment,

b) to determine the suitability of a soil for an intended use, e.g. agricultural production, residential development,

c) to study the effects of atmospheric pollutants including radioactive fallout on the quality of soil. This may also provide information on water quality and also indicate if problems are likely to arise in near-surface aquifers,

d) to assess the effects of direct inputs to soil; there may be contributions from

   — naturally occurring substances which exceed local background values, e.g. certain mineral phases in metal deposits,

   — (un)expected contamination by application of agrochemicals

   — (un)expected contamination due to industrial processes,

e) to assess the effect of the accumulation and release of substances by soils on other soil horizons or on other environmental compartments, e.g. the transfer of substances from a soil into a plant,

f) to study the effect of waste disposal, including the disposal of sewage sludge on a soil (apart from contributing to the pollution load, such disposals may produce other chemical reactions such as the formation of persistant compounds, metabolites or the evolution of gases, such as methane),

g) to identify and quantify products released by industrial processes and by accident (this is usually done by investigation of suspect sites or contaminated sites),

h) to evaluate soil derived from construction works, with a view to possible or further utilization of such soils (see ISO 15176) or disposal as waste.

Commonly, sampling strategies are employed which require samples to be taken either from identifiable soil horizons, or from specified depths (below ground surface). It is best to avoid mixing the two approaches, particularly when sampling natural strata, as this can make it difficult to compare results. However, a coherent combination of the two approaches can sometimes be useful on old industrial sites where there is variation both in the nature of fill and of the depth of penetration of mobile contaminants into the ground, i.e. there are two independent reasons for changes in soil/fill properties.

Knowledge of the way in which particular chemical substances tend to be distributed between different environmental categories (air, soil, water, sediment and living organisms) is of advantage for the design of some sampling programmes. Similarly, knowledge of the behaviour of those living organisms affected by chemical substances or which affect the availability of substances due to microbiological procedures, is of advantage, too.

5.2.3 Sampling for the determination of soil physical parameters

The sampling of soil for the determination of certain physical properties requires special consideration, since the accuracy and extrapolation of measured data relies on obtaining a sample which retains its *in situ* structural characteristics.

In many circumstances it may be preferable to conduct measurements in the field, since the removal of even an undisturbed sample can change the continuity and characteristics of soil physical properties and lead to erroneous results.

However, certain measurements are not possible in the field. Others require specific field conditions, but the field situation can only be controlled to a very limited extent, e.g. it may be possible to modify the hydrological situation temporarily for measurement purposes by irrigation. The time and expense necessary for field measurements may not be affordable. Laboratory measurements of physical properties are therefore frequently necessary.

Differences and changes in soil structure affect the choice of sample size. Hence, a representative volume or minimum number of replicates shall be determined for each soil type to be studied.

The moisture status of the soil at sampling can influence physical measurements, e.g. hysteresis on rewetting can occur.

Many physical properties have vertical and horizontal components; this should be considered prior to sampling.

Where small undisturbed soil samples are required, manual excavation of cores, clods or soil aggregates can be applied. Sampling equipment should be designed such that minimal physical disturbance is caused to the soil. For larger samples, the use of hydraulic sampling equipment and cutting devices is preferable in order to obtain a sample with minimal disturbance. Care should be taken both in equipment design and manufacture to ensure that internal compression or compaction of the sample does not occur.

Where it is difficult to obtain an undisturbed sample for laboratory measurements, e.g. in stony or iron pan soils then *in situ* measurements may be the most appropriate approach.

5.2.4 Sampling for the assessment of soil biological parameters

Biological soil investigations address a number of different questions related to what is happening to or caused by life forms in and on the soil, including both fauna and flora in the micro and macro ranges. Ecotoxicological questions are usually given first priority, for example tests to verify the effects of chemicals added to the soil on life forms and also the possible effects of life forms in the soil on plants (e.g. high-value crops) and on the environment, especially on human health.

In some cases biological soil test procedures operate with fully artificial soils, but normally the major task of sampling is to choose a reliable soil or site to carry out the tests.

See ISO 10381-6 for information on sampling for the assessment of aerobic microbial processes.

5.3 Sampling of other material in connection with soil investigation

Soil investigation programmes, and particularly those carried out at contaminated sites, may also require samples other than soil to be taken. Reference should be made to International Standards for technical details, or to relevant national standards if no International Standards are available.

International Standards on the sampling of water, sludge and sediment which may be appropriate for use in soil quality investigations are listed in Annex A together with a brief description of their scopes.

6 Special considerations for the sampling of soils

6.1 General

This clause deals with matters which may influence the design of a sampling programme (e.g. pre-existing knowledge of the site) and a number of detailed aspects of the design and implementation (e.g. sampling patterns, sample handling).

Attention is drawn to the requirements for sampling personnel in Clause 7 and to the safety precautions necessary in various situations, briefly mentioned in Clause 8 but more fully described in ISO 10381-3.

6.2 Preliminary survey

6.2.1 General

A preliminary survey should be carried out prior to any sampling programme, although the effort devoted to it depends on the objective of the investigation.

The preliminary survey should always comprise (phase I investigation)

— a desk-top study, and

— a site visit or reconnaissance.

In addition, a limited amount of sampling may be carried out (phase II investigation).

The principal objectives of the preliminary study are to gain knowledge about the present condition of the site, and of past activities on the site and adjacent land which may have affected it, in order to:

— enable the sampling programme(s) to be designed to be both technically effective and cost effective,

— identify measures required to protect the health and safety of the investigating personnel,

— identify measures necessary to protect the environment during the sampling programme.

Other information relevant to the conduct of the sampling programme may also be gathered (e.g. means of access for equipment, locations for site facilities (e.g. laboratories, stores, equipment decontamination), availability of power).

Such preliminary surveys are of particular importance when investigations for risk assessment are to be carried out.

The company and/or the personnel shall ensure they have all necessary permissions to carry out the preliminary survey and to have access to the site during visit or reconnaissance.

6.2.2 Desk-top study

A desk-top study includes collection of relevant information on the site, e.g. references to the location, infrastructure, utilization, historical information.

Possible sources of this information are publications, maps (check the accuracy of any map used), aerial photographs and satellite imagery, e.g. from land surveyor's offices, geological surveys, water management boards, industrial inspection boards, mining boards, mining companies, geotechnical institutions, regional and local city archives, agricultural and forestry authorities and building supervisory boards. Particularly important is information on the physical and chemical properties and the possible spatial distribution of the soil parameter under investigation; special attention shall be paid to geological features such as stratigraphy and hydrogeology.

6.2.3 Visiting the site

A visit of the site should be part of the preliminary survey, preferably in conjunction with the desk-top study, but may be independent. Depending on the local variability of the site and the technical difficulty of the planned investigation, an experienced person should be chosen for this task.

Such a visit gives a first impression about the correlation of existing maps and reality, and provides much additional information in a comparatively short time.

In some cases, it may be necessary to draw a first or additional map at this stage.

Samples are not often taken during preliminary investigations; if they are, it is usually for getting an overview about the kind of soil to choose the right equipment for later activities.

ISO 10381-4, ISO 10381-5 and ISO 10381-6 specify the range of preliminary investigations used within their individual scopes.

6.2.4 Output from preliminary investigation

A report should be prepared summarizing the factual findings of the preliminary investigations, and stating the conclusions (or hypotheses) drawn concerning the anticipated site conditions (e.g. geology, hydrology, possible contamination) which are relevant to the design of the sampling programme.

This should enable the appropriateness of the adopted sampling strategy to be assessed at a later date.

7 Requirements for sampling personnel

7.1 General

The design of the sampling programme needs to take into account the following factors with respect to available personnel:

— their sampling experience relative to the investigation needs;

— their ability to contribute to the design of the sampling programme relative to the investigation need.

7.2 Experience

There are good reasons for a sampler to have detailed knowledge of soil science, but in many regions the soils have little horizon differentiation. Where this is the case, depth-related samples are usually obtained. This approach becomes more difficult to apply when the soil profile is differentiated into distinct horizons, and is essentially unusable where profound differences occur between contiguous horizons; then the profile should be sampled by horizons.

In the latter case, detailed knowledge of for example pedology and to a lesser degree also of geology, hydrogeology, geomorphology and agronomy is essential. In many situations only an experienced scientist may be able to take soil samples properly. When the scientist does not take the sample, then those carrying out the sampling shall be supervised by the scientist or other appropriately qualified and experienced persons.

The sampler should have knowledge of the commonly applied techniques and tools, their advantages and disadvantages. He or she is responsible for the proper use of the tools, which also includes cleaning of the equipment between sampling operations to avoid cross-contamination (see for information ISO 10381-2). The sampler should be consulted regarding choice of sampling equipment. This should enable the appropriateness of the sampling strategy adopted to be assessed at a later date.

Very often soils and soil samples are tested or analysed on-site. Experienced sampling staff should be able to carry out some of these tests. If this it not the case, the design of the sampling programme should include the necessary cooperation between the sampling staff and analytical/scientific staff at the sampling location.

On-site testing facilities may be required

a) for the investigation of physical soil properties (*in situ* methods, e.g. geophysical methods),

b) for the investigation of chemical soil parameters,

c) to provide an indication of the presence of substances or conditions (e.g. toxic vapours, flammable gases, acidic liquids) hazardous to the safety of the investigating personnel.

All necessary on-site programmes should be set up before field work begins.

Staff working on site should have detailed knowledge about necessary safety precautions, particularly when sampling contaminated sites and when applying machine-operated drilling equipment and when digging trial pits (see for information ISO 10381-3).

Personnel employed to sample abandoned industrial sites or otherwise potentially hazardous sites should always have received appropriate training.

7.3 Coordination of sampling and analysis

Sampling depends on teamwork. Responsibilities should be made clear at all stages of the sampling campaign, both in the field and at the office.

The sampler should never have to obtain samples without having an idea what they are intended for.

Unless there is a mobile field laboratory, analysts are rarely present on the site. In some situations, this has the disadvantage that samples reaching the laboratory may not reflect the original chemical state of the site, especially if the heterogeneity of the material (e.g. embankments, fills) is great. Due to unexpected incidents, decisions must be taken which should not be the responsibility of the sampler alone. The design of the sampling programme should allow for such situations.

Finally, data is evaluated. Relevant observations of the sampler should be considered and what is learned should be described in the sampling report.

8 Safety precautions

Guidance given in ISO 10381-3 should be observed.

9 Samples and sampling points

9.1 General

The selection, location and preparation of the sampling points depend on

— the objectives of the investigation,

— the preliminary information available,

— the on-site conditions.

The nature of samples to be obtained shall be appropriate to the aim of the investigation and shall be specified in the programme before field work begins.

9.2 Sampling patterns

Sampling patterns are based on the probable distribution of soil constituents (in most cases chemical substances) on an area or on a type-of-substance input.

Four major fixed sampling patterns can be identified:

— patterns based on no specific estimate of substance distribution;

— patterns based on local substance distribution and known as a “hot spot”;

— patterns based on distributions along a line;

— patterns based on strip-like distributions.

In addition to these, several other patterns exist (e.g. based on deposition of substances from the air, input due to flooding).

All fixed patterns shall be adjusted to local conditions and are subject to modification.

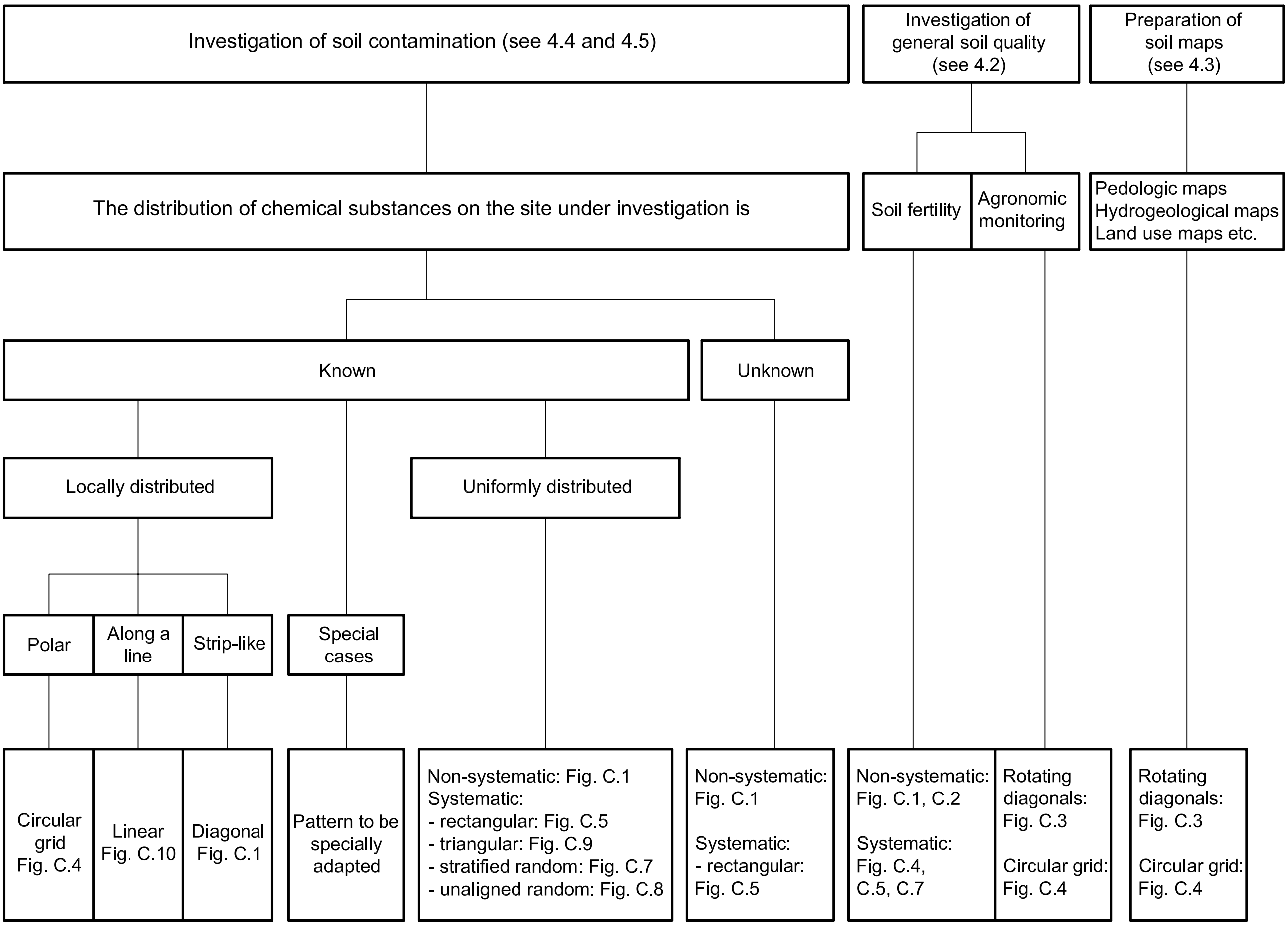
In agricultural sampling, a small number of convenient sampling patterns are established in order to obtain information on e.g. nutrient demand or pesticide residues of rather large areas. Some possible patterns are given in Annex C (Figures C.1, C.2, C.3). For additional information refer to ISO 10381-4. However, it must be emphasized that most grid sampling patterns are not very practical during the growing season, and are rarely applicable.

The investigation of contaminated sites which can have profound health and economic consequences usually requires much more detailed selection and application of sampling patterns, to give calculated, estimated or randomly chosen sampling points on a 1-, 2- or 3-dimensional figure. The choice of pattern should be the result of preliminary investigation of a site, rather than of an *ad hoc* decision taken in the field.

Some investigations are carried out without predetermined pattern plans. This should not be confused with the application of random distribution of sampling points, because a person usually cannot distribute sampling points randomly without preparation, i.e. he must ensure that at every point in the area, despite the position of the other sampling points, a sample will be obtained with equal probability. Where sampling is to be carried out without a predetermined pattern (*ad hoc* sampling), care shall be taken that sampling is carried out by an appropriately experienced investigator. It also should not be confused with the application of sampling plans to verify special hypotheses which, with regard to the problem, are developed and justified by the investigator (judgemental sampling).

Annex C gives examples of a number of commonly applied sampling patterns which meet different statistical requirements (Figures C.7 to C.10 and Figure 1). Experience (and theoretical considerations) shows that in many cases systematic sampling on a regular grid both is practical and allows a sufficiently detailed picture of variations in soil properties to be established. The number of sampling points can be easily increased (e.g. in areas meriting more detailed investigation), the grid is easy to mark out on site, and sampling points are usually easily relocated. Systematic sampling can be supplemented by judgemental sampling when appropriate. ISO 10381-5 provides examples of pattern application for sampling contaminated sites.

For selection of sampling patterns, see Figure 1.



NOTE The modification of patterns depends on:

— special situation on the site, e.g. rapidly changing topography;

— objective/hypothesis;

— applicability and validity of preliminary information.

Figure 1 — Selection of sampling patterns

9.3 Identifying the sampling location

Identification of sampling points is not usually necessary when taking composite samples for agricultural purposes. Where samples are taken at predefined points, their accurate location and identification is important for three principal reasons:

— to enable actual sampling locations to be revisited if necessary;

— to enable accurate plotting of data in relation to site features so that any necessary treatment (e.g. additions of nutrients or removal of contamination) can be properly planned;

— to enable the data to be stored and processed by computers (e.g. for modelling studies, preparation of maps, in geographic information systems).

Moreover, it is recommended that a sketch map be prepared presenting all relevant information on the sampling location. Both maps and photographs should include a scale and a direction marker.

It is important for the interpretation of data, particularly on abandoned industrial sites, etc., to have detailed information on surface levels at sampling locations.

Sampling locations should be determined with an appropriate degree of accuracy. Because it may be necessary to vary the actual location away from the predetermined location because of the presence of obstructions, etc., it may be preferable to do the accurate surveying of sampling locations once the sampling exercise is completed or as it progresses. Surface levels can be determined at the same time.

When investigating abandoned industrial, waste-disposal or other potentially contaminated sites, the horizontal and vertical location of sampling points or probing points should be recorded.

The location of sampling points, etc., should be marked before sampling begins using poles or coloured-spray markers. Coloured sprays should not be used if soil air must be sampled.

9.4 Preparation of the sampling site

Depending on the objective of the investigation, a sampling pattern (see 10.2) is chosen at the design stage and is then applied in the field. The range of patterns can include the setting up of single sampling points of very complex patterns developed using computer-aided statistics. Preparation for sampling, e.g. location of desired sampling points on the ground, can therefore be very time-consuming, whether samples are obtained by boring/drilling techniques or from trial pits.

Preparation of the site can include removal of superficial deposits (e.g. uncontrolled deposition of urban wastes), establishment of safety measures, installation of measurement devices if field tests are carried out together with sampling, marking the exact location of the sampling points. In many cases preparing the site takes longer than the actual sampling procedures.

Both during and on completion of sampling, all necessary measures shall be taken to avoid hazards to the health and safety of anyone entering the site, or to the environment.

9.5 Barriers to sampling

It may not be possible to sample at a planned location due to a variety of reasons (e.g. presence of a tree, large rock, building, buried foundations or services, difficulties of access) and contingency plans for dealing with such situations should be made in advance. The action to take depends on the circumstances. The investigator may ignore the point or follow predetermined rules for choosing a nearby substitute location (e.g. alternative position within 10 % of the grid space, or paired sampling along grid lines either side the obstruction). *Ad hoc* decisions made in the field as they arise can lead to bias. An attempt should be made when marking out the site to identify such obstructions in advance of actual field work.

In all cases when a sampling point has to be relocated, this and the reasons for relocation should be clearly indicated in the sampling report.

Preliminary investigations (phase I and phase II) as described in Clause 6 should provide as much detail as possible about conditions expected to exist on the site, and should therefore guide the design and execution of the sampling programme. However, it cannot totally protect against the danger of misinterpretation of the results of borings, and the selection of sampling points should take this into account.

Examples of possible misinterpretation include

- very thin soil layers or horizons which are not recognized in a core sample, sometimes due to smearing at tube wall contacts;
- erroneous correlation of horizons at different soil profiles in the same area;
- anomalies in the soil “missed” by borings, e.g. foundations of buildings, spots of waste, barrels, tanks;
- erroneous indication of bed rock upper limit due to encountering lumps of rocks;
- erroneous indication of bed rock upper limit by “hitting” the shoulders of a groove;
- missing the natural sequence of layers/horizons due to near-vertical layering (occurs especially in geological material and in fill and wastes when “end-tipped”).

Certain geophysical methods can give useful information that can help to avoid such misinterpretations. The merits of using such methods will depend on the objectives of the study and a variety of site-specific factors.

9.6 Choice of appropriate equipment to obtain samples

The selection of appropriate sampling equipment depends on the objective of sampling and should be done after consideration by the analyst or scientist responsible for subsequent determination. ISO 10381-2 gives guidance on commonly used equipment for sampling soil and related material.

ISO 10381-4, ISO 10381-5 and ISO 10381-6 give requirements for specific purposes within their individual scopes.

9.7 Depth of sampling

No general recommendation can be given on the depths at which samples should be taken or on the final depths to which trial pits or boring/drilling should extend. This depends on the objectives and might be subject to change during a running programme. The investigation of soil for chemical characteristics can be divided into two general cases:

— the investigation of agricultural and similar near-natural sites, where information is required mostly on the top soil or ploughed horizon or arable zone but often over an extended area.

— the investigation of sites which are known or suspected to be contaminated, where information is required from deeper layers, sometimes to a depth of several tens of metres. The extent of the area is usually rather small compared to agricultural sites.

A mixture of both these cases is found in so-called “permanently monitored soil sites”, which represent larger areas of homogeneous soil development and in most cases are established to monitor environmental effects on the complete profile over a long time-scale (see ISO 16133).

A precise description should be made of all soil horizons or layers encountered during the sampling exercise and included in the report (Clause 11).

If a profile is to be sampled, care should be taken that every horizon/layer of interest is sampled and that different horizons/layers are not mixed. In general, contaminated sites should be sampled horizon by horizon, unless stated otherwise by the client.

Care should be taken in a site investigation to ensure that pathways for migration of contamination are not created, particularly where low-permeability strata may be encountered.

If trial pits are used, it may be appropriate to sample from more than one side.

A depth-related sampling programme is based on a number of conventions, depending on the project. It is not as representative with regard to the soil as a horizon-related sampling programme can be. The mode of sampling from each depth should be carefully specified, e.g. the maximum depth range (usually not more than 0,1 m) and how horizontal variations are to be dealt with.

The total depth reached, the thickness of the horizons/layers penetrated and the depth from which the samples are obtained should be recorded. All data should be recorded as “metres below surface”. The soil depth should be measured from the ground surface, with the thickness of the humus litter layer being recorded separately.

Mountainous regions or hilly areas with pronounced slopes require special consideration. For slopes of 10° and greater, vertical drilling lengths should be extended according to the cosine rule to maintain slope-parallel thicknesses of soil layers constant. The extension factor is 1/cos of slope. Without correction, for example, the error will be 2 % at a slope of 11,5°.

9.8 Timing of investigation

In some circumstances, it may be necessary to restrict sampling to specific periods of the year. For example, if the characteristic or substance to be determined is likely to be affected by seasonal factors or human activities (weather, soil conditioning/fertilization, use of plant-protective agents), this should be taken into account in the design of the sampling programme. This is particularly important where monitoring lasts several months or years, or is continued periodically and therefore requires similar preconditions every time sampling is carried out.

9.9 Sample quantity

At least 500 g of fine soil as sampled should be obtained for chemical analysis. This number applies both to single samples and composite samples, in the latter case after sufficient homogenization. Samples obtained to serve as reference material or to be stored in a soil specimen bank should be larger, usually larger than 2 000 g.

Where the sampling of soil involves the separation of oversized material (i.e. mineral grains, sand, pebble and all other materials) due to very coarse-grained or heterogeneous soil conditions, the material removed shall be weighed or estimated and recorded and described to enable the analytical results to be given with reference to the composition of the original sample. These procedures should be carried out in accordance with ISO 11464.

This part of ISO 10381 does not specify the sample quantities used for determination of soil physical parameters. Details are given in the respective methods. In particular, the determination of particle size distribution may need a very large mass of soil material. The actual mass required depends on the largest grain size to be determined (see ISO 11277).

The quantity of soil sample needed for biological investigations is highly dependent on the aim of the investigation.

9.10 Single samples vs. composite samples

Composite samples are usually required in cases where the average concentration of a substance in a defined horizon/layer is to be determined.

Single samples are required in cases when the distribution of a substance over a defined area or with depth is required.

In most guidelines on sampling for agricultural or similar investigations, it is recommended that composite samples be collected by taking a number of increments (according to ISO 10381-4 at least 25 increments should be obtained) and combining them to form a composite sample. For further information see Clause 11.

When preparing composite samples, regard should be paid to analytical requirements. For example, composite samples should never be used if volatile compounds are to be determined.

9.11 Laboratory preservation, handling and containerization, labelling and transport of soil samples

9.11.1 General considerations

Samples of soils and related materials are liable to change to differing extents as a result of physical, chemical or biological reactions which may take place between the time of sampling and the analysis. This is especially true of soils contaminated with volatile constituents.

The causes of sample variations are numerous and may include:

— changes in certain constituents due to the activities of living organisms in the soil;

— oxidation of certain compounds by atmospheric oxygen;

— changes in the chemical nature of certain substances due to changes of temperature, pressure and hygroscopicity (e.g. loss to the vapour phase);

— modification of the pH, conductivity, carbon dioxide content, etc. by the absorption of carbon dioxide from the air;

— irreversible adsorption on the surface of containers of metals in solution or in a colloidal state, or certain organic compounds;

— polymerization or depolymerization.

The extent of these reactions is a function of the chemical and biological natures of the sample, its temperature, its exposure to light, the nature of the container in which it is placed, the time between sampling and analysis, the conditions (e.g. rest or agitation during transport) to which it is submitted, seasonal conditions, etc.

It must be emphasized, moreover, that these variations are often sufficiently rapid so as to modify the sample considerably within several hours. It is therefore essential in all cases to take the necessary precautions to minimize these reactions, and in the case of many parameters to analyse the sample with a minimum of delay. Any of the procedures described in 10.11.2 to 10.11.6 should be mentioned in the sampling report if applied during sampling.

9.11.2 Preservation

The addition of chemical preservatives or stabilizing agents is not a common practice for soil sampling. This is because a single soil sample is usually used for a large number of different determinations, and moreover has to undergo preparation (drying, milling, etc.) during which unwanted and unquantifiable reactions of the preservatives may occur.

If in special cases it is necessary to preserve samples, a method that does not introduce unacceptable contamination should be chosen.

Broadly, stability of samples can be considered in three classes:

a) samples in which the contaminant(s) is/are stable;

b) samples in which the contaminant(s) is/are unstable but stability can be achieved by a preservation method;

c) samples in which the contaminant(s) is/are unstable and cannot be readily stabilized.

For those contaminants which are unstable, loss or change (chemical or biological) of the contaminant should be minimized by either preserving the contaminant, e.g. freezing or addition of a stabilizing agent, or by arranging for analysis to be undertaken immediately or soon after sampling. The use of liquid nitrogen for immediate deep freezing of soil samples in vapour phase is effective, for which the use of containers made of stainless steel (not chromium- or nickel-plated) is recommended. Some contaminants are not easily stabilized in a manner compatible with subsequent analysis. Volatile solvents fall into this category and some of them may begin to volatilize as soon as the soil is exposed by sampling. A special sampling procedure is needed to minimize such loss.

In spite of numerous investigations which have been carried out in order to recommend methods which enable soil samples to be stored without modification of their composition, it is impossible to give absolute rules which cover all cases and all situations and which do not have exceptions.

In every case, the method of storage shall be compatible with the analytical techniques which will be used and should be discussed with the analytical laboratory.

9.11.3 Use of appropriate containers

9.11.3.1 Choice of container

The choice and the preparation of containers can be of major importance. The most frequently encountered problems are

— adsorption onto the walls of the containers;

— improper cleaning, resulting in contamination of the container prior to sampling;

— contamination of the sample by the material of which the container is made;

— reaction between constituents of the sample and the container.

The purpose of the container is to protect the sample from losses due to adsorption, volatilization or from contamination by foreign substances.

Other factors to be considered in selection of the sample container used to collect and store the sample include:

— resistance to temperature extremes;

— resistance to breakage;

— water and gas tightness;

— ease of reopening;

— size, shape and mass;

— availability;

— potential for cleaning and re-use.

9.11.3.2 Cleaning of the container

Cleaning of the sample container is a very important part of any sampling/analysis programme. Two basic situations can be distinguished:

— cleaning of new containers to remove dust and packing material;

— cleaning of used containers prior to re-use.

The type of cleaner used depends on the container material and on the constituents to be analysed. The selection of acids or other cleaning agents should ensure that no contamination of the container results with regard to the constituents to be analysed, and moreover, that there is no harm to the environment or human health.

Containers already used for investigations of contaminated sites should not be used again, because cleaning containers of soils containing unknown substances may cause health risks.

The determination of organic constituents may require drying or cooling procedures under carefully controlled conditions to avoid microbial contamination. Sterilization is required whenever biological or microbiological determinations are to be carried out.

Special instructions are given in ISO 10381-4, ISO 10381-5 and ISO 10381-6. ISO 10381-2 provides information on the applicability of different container materials in relation to substances to be determined.

9.11.4 Transport and storage

Containers holding samples should be protected and sealed in such a way that the samples do not deteriorate or lose any part of their content during transport. Packaging should protect the containers from possible external contamination, particularly near the opening, and should not itself be a source of contamination.

Most of the analytical procedures used in chemical soil analysis recommend that soil samples be taken to the laboratory immediately after sampling, but in some cases a range of time is given within which the sample should arrive in the laboratory.

Soil samples should be kept cool and dark during transportation and storage.

Cooling or freezing procedures can be applied to samples to increase the time period available for transport and storage. A cooling temperature of 4 °C ± 2 °C has been found suitable for many applications. But cooling and freezing procedures should only be used in consultation with the analytical laboratory. Freezing especially requires detailed control of the freezing and thawing process in order to return the sample to its initial equilibrium after thawing.

Light-sensitive soil constituents require storage in darkness or, at least, in light-absorbent containers.

Vibration or other damage to undisturbed samples should be avoided in order to maintain the original structure during transport.

Disturbed samples, and especially non-cohesive very dry soils, tend to separate into different particle fractions during transportation. In such cases, the soil material should be re-homogenized before further pretreatment and analysis.

Any national regulations regarding the packaging and transport of hazardous materials should be observed.

9.11.5 Labelling

Once a sample is obtained it should be clearly and unmistakably marked. Normally, a containerized sample should have a label having all the required information on it. This can be done, for example, by either using adhesive labels, writing the information directly on the container, or putting the label inside the container with the sample. If placed inside the container, the label must not be affected by the sample since this may cause loss of the information. When traces of organic compounds are to be determined, labels shall not be placed inside the container. Labels should be short and simple, to avoid mistakes arising in transcribing numbers.

It is recommended that at least the sample number should be placed on both the container and the lid to avoid undesired mix-up of containers and lids. The sample number should not be placed only on the lid.

It is essential that labels and inscriptions are stable to surrounding environmental conditions. Considering the area of sampling, the kind of soil material and the required storage and transport conditions, labels and inscriptions should be resistant to heat and cold, solar radiation, abrasion, water and chemical reaction. Cleaning of dirty labels shall not lead to loss of information or contamination of the sample.

Some commercially available adhesive labels and marker pens contain organic solvents. Whereas absorption of these organics by soil particles is likely to be insignificant, this may however lead to contamination of soil air samples.

Before samples are dispatched and on receipt in the laboratory, a check should be made that sample numbers on the container and on the lid can be correlated with the respective sampling report.

9.11.6 Disposal of surplus soil material

Surplus soil arising directly from sampling operations in the field (drilling, trial pits) or pretreatment and analytical procedures in the laboratory or resulting from clearing stored material, and especially in the case of contamination or expected contamination, should be disposed of so as to avoid risks for human health and the environment and in accordance with relevant national legislation.

For additional information, see ISO 10381-3.

10 Sampling report

10.1 General

A detailed sampling programme should specify all the information that is required for each sample before the sampling starts. A *pro forma* is a convenient way of doing this. The sampling report should be available to staff working on the project at any stage of pretreatment, analysis and evaluation.

Chain-of-custody forms are particularly important when samples are required for legal purposes.

Chain-of-custody traces the possession of the sample from its origin through to data analysis. Such samples should not be left unattended for any reason, to avoid the possibility of breaking the chain-of-custody.

The following describes the minimum information required for a sampling report independent of the aim of investigation. Depending on the objectives, this list may be extended.

The field information should be presented in a neat and legible form, because data sheets are not always retyped, but are submitted to the client and/or filed in their original form.

10.2 Title data

A sample identification should unambiguously identify a sample and its origin. The identification can be either numbers or letters or both. In cases where the data obtained from a sample is meant for long-term storage in data banks, it is recommended that the same sample number be used throughout the whole sampling, analytical and evaluation procedure. Therefore, it is advantageous to include x- and y-coordinates of the location of sample origin [e.g. conventional cartesian systems or universal transverse mercator (UTM)] in the sample number for quick reference (see also 10.3).

Changing sample numbers during the various steps of investigation presents a risk of false transfer of data and the possibility of complicating the identification of the location of sample origin

The statement of the date of sampling is very important. It is recommended that dates be entered in the following order:

year: month: day [hour: minute: second], e.g. 02-12-31 or 2002-12-31 (exception: e.g. 31 December 2002).

10.3 Site data

The information about the sampling site attached to each sample should be reduced to a minimum. That should be left to the site description which should be part of the report on the whole investigation.

The site data shall consist of the coordinates of the site (see also 10.1) and keywords regarding the utilization at the time of sampling. It is recommended that ISO 11259 be followed or that any other key publication used be specified.

10.4 Sampling procedure

Details of the sampling procedure should be entered for the benefit of analysts/interpreters, because they may affect the results. It should be clearly stated whether the sample was obtained from a trial pit, natural exposure, or by boring/drilling (given by inner diameter of tube, in millimetres).

The kind of sampling should be described by designating the depth of sampling measured from a specified level according to the requirement of the investigation, and specifying in detail:

- the upper and lower limits of the horizon sampled, in metres;
- the upper and lower limits of the depth of sampling within a horizon;
- whether a single sample or a composite sample is obtained; and the number of increments and area for which the value to be measured should be representative;

- whether the sample is obtained in a horizontal or vertical direction in relation to the position of the horizon;
- the tools used to obtain the sample, i.e. core-cutting cylinder (including material, diameter and height, in millimetres, or volume, in cubic centimetres), or sampling frame (including material, dimensions, in millimetres, or area, in square millimetres). Also, the number of parallel samples constituting a composite sample should be stated, if relevant;
- whether the sample is related to volume or to mass.

10.5 Transportation and storage

The material of the container should be indicated, e.g. glass, stainless steel, polyethene, other plastics material, etc.

The transport conditions should be given, indicating whether the sample was cooled or frozen or transported uncooled. In addition, the period of transportation should be reported (hours/days).

10.6 Sample, profile and site description

Detailed descriptions of soils, profiles and sites are time-consuming. Therefore it should be made clear whether they should be made for every individual sample or for a number of samples. This strongly depends on the local variability of soil, the density of sampling points, and the scale of the sampling pattern. For example, in soil mapping it is a standard procedure to consider these aspects particularly when soils are described in detail.

10.7 Sample and profile description

There are several ways to describe a sample either as an individual sample or as part of a profile. If such a description is required, this should be stated clearly in the definition of the objectives. For the description, documents conforming to ISO 11259 preferably should be used.

Sample and profile descriptions for soils include aspects such as soil type, soil group, rock type, thickness of layers and horizons, colour, odour, humus content (estimated), carbonate content (estimated), iron and sesquioxide contents (estimated), moisture, density, soil texture (which may be required for varying investigation needs).

The description of artificial soils, man-made or man-affected, requires field experience in mapping urban areas.

10.8 Site description

In some cases a very detailed description of the site is required, which includes climate, weather conditions, surface relief, landscape, erosion features, exposure, slope, groundwater regime, improvement measures, vegetation, present and historical land use in the surroundings, sources of contamination, and others if specified by the customer.

11 Quality control, quality assurance and operation and testing of laboratories

Because of the various reasons for and objectives of sampling, there can be no single set of quality control and quality assurance procedures to be followed by all organizations offering sampling services under all circumstances. It is, consequently, more difficult to set out principles for proficiency testing than it is for soil analysis procedures. However, it is strongly recommended that, as far as practicable, the guidelines in ISO 9000 should be followed. Organizations offering analytical services should follow requirements in ISO 17025, EN 45002, EN 45003, EN 45011 and EN 45012.

Annex A
(informative)

Sources of additional information

A.1 Sampling of water

The International Standards listed here contain details which may be used in the framework of this part of ISO 10381.

ISO 5667-2 provides guidance on water sampling techniques with special mention of suitable equipment for obtaining and containing samples including life forms.

ISO 5667-3 provides guidance on methods of preservation and handling of water samples and includes a table containing different preservation agents in relation to the parameter to be studied.

ISO 5667-4 provides guidance on techniques for obtaining water samples from lakes, excluding sampling for microbiological examination.

ISO 5667-6 provides guidance for taking water samples from rivers and streams but does not apply to estuarine or coastal waters and is of limited applicability to the sampling of canals and other inland waters with restricted flow regimes. Also taking of sediment and biological samples are not the subject of this part of ISO 5667.

ISO 5667-8 provides guidance on sampling techniques to collect wet deposition, i.e. water precipitated from the atmosphere as rain and snow/ice. This excludes (for technical reason) fog, mist, dew and cloud waters. This part of ISO 5667 may be of use to obtain relevant information during preliminary investigation and for site description.

ISO 5667-9 provides guidance on techniques for taking water samples from marine waters, such as tidal waters (estuaries, tidal inlets), coastal region and the open sea. It does not apply to the collection of samples for biological and microbiological examination or to the collection of sediments.

ISO 5667-10 provides guidance on the sampling of wastewaters. This may be of interest in cases where waste water pipelines imply a possible hazard to soil and groundwater in case of exfiltration.

ISO 5667-11 provides guidance on sampling for the general quality surveillance of groundwaters but not on the day-to-day operational control of groundwater extractions.

A.2 Sampling of sludge and sediment

ISO 5667-12 provides guidance and is applicable to the sampling of sedimentary materials from inland rivers and streams, lakes and similar standing bodies and estuarine and harbour areas, i.e. underwater sediments, including information on suitable equipment, techniques and preservation measures. Industrial and sewage works and sludges together with open ocean sediments are specifically excluded, although some of the techniques may apply part of ISO 10381.

ISO 5667-13 provides guidance on sampling of sludges, e.g. sewage sludges, including information on suitable equipment, techniques and preservation measures.

A.3 Sampling of material from stockpiles, waste dumps, covered waste deposits and similar accumulations

Although these situations are comparably frequent in the investigation of soil at contaminated sites, no international harmonized guideline currently exists which addresses the related problems. With regard to present definitions, waste deposits etc. are also considered as soils or soil-like material in the light of soil protection. At present this part of ISO 10381 does not apply directly to the sampling of these materials, but another part of this International Standard is in preparation (ISO 10381-8).

At present, users of this part of ISO 10381 should refer to national standards and guidelines, if available[1)].

A.4 Sampling of soil gas

Currently an International Standard giving guidance on the sampling of soil gas is under development (ISO 10381-7).

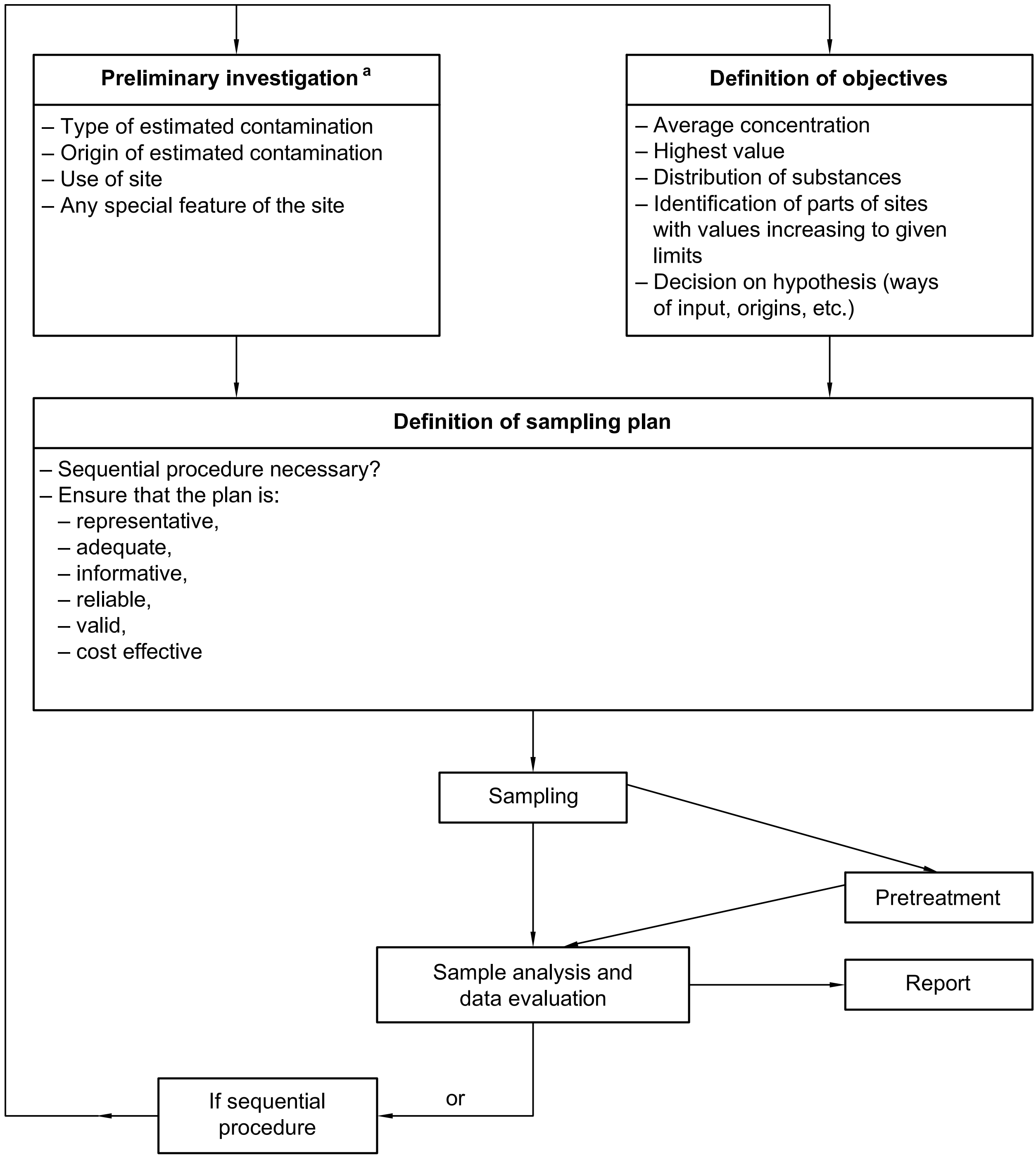
A.5 Sampling of dry and wet depositions

No International Standard is currently under development on this topic. Several national standards and guidelines exist which should be considered, if necessary.

1) At the time of publication of this part of ISO 10381, guidelines were in preparation by CEN/TC 292, *Characterization of waste*, including procedures for the sampling of waste. Further information can be obtained from national standardization bodies, from CEN/CS, Brussels, or from ISO/CS, Geneva.

Annex B
(informative)

Determination of a sampling plan



a Typically only relevant for investigation of contamination.

Annex C
(informative)

Examples of different sampling patterns used in soil sampling programmes

C.1 General

Most natural properties of the soil vary continuously in space and, as a consequence, the values at sites that are close together are more similar than those further apart. They depend upon one another in a statistical sense. This property is known as spatial dependence, and its implications for sampling are covered by methods of geostatistics, i.e. spatial statistics.

Viewed mathematically, the value of a soil property at any place is a function of its position. The only practicable approach is to regard such a property as a random variable and to treat its variation in space statistically. Such properties are known as regionalized variables. The application of regionalized variable theory by developing variograms is a common tool in geostatistics.

Another geostatistical approach is multi-stage or nested sampling and analysis, which also can be linked with a regionalized variable theory.

The applicability of geostatistical methods does not depend on the observed values at those sites, but on the configuration of the sampling points in relation to the area or block (if three dimensions are considered) to be estimated. A general criterion for the usefulness of a sampling pattern should be decreasing of the relatively largest part of the total area which is not being sampled. In terms of statistically efficient sampling, a regular equilateral triangular grid provides the best selection of sampling points. For a grid with one node per unit area, next sampling points are 1,074 6 units of distance apart, and no other point is more than 0,620 4 units of distance away from a sampling point. For practical purposes, sampling patterns are based on rectangular grids.

For a grid with one node per unit area, the distance between sampling points is 0,707 1 units of distance, i.e. the greater ease of use of the square grid is offset by the slightly greater area of unsampled site.

C.2 Non-systematic patterns (irregular sampling)

Widely used in agricultural/horticultural land investigation are the “N”, “S”, “W” and “X” patterns of sampling (Figure C.1). The general premise is that the distribution of soil constituents is relatively homogeneous. The patterns used are simplifications of the stratified random sampling method (C.6). Along the outline of such a pattern, a number of samples are taken and then may be bulked and mixed to provide one sample for analysis. The distribution of sampling points is likely to be inadequate to provide location of point pollution, and in any event high contaminant levels will be lost in mixing of these samples. Thus in the majority of contaminated land investigations these patterns are unlikely to be useful, because they obscure high levels of point contamination.

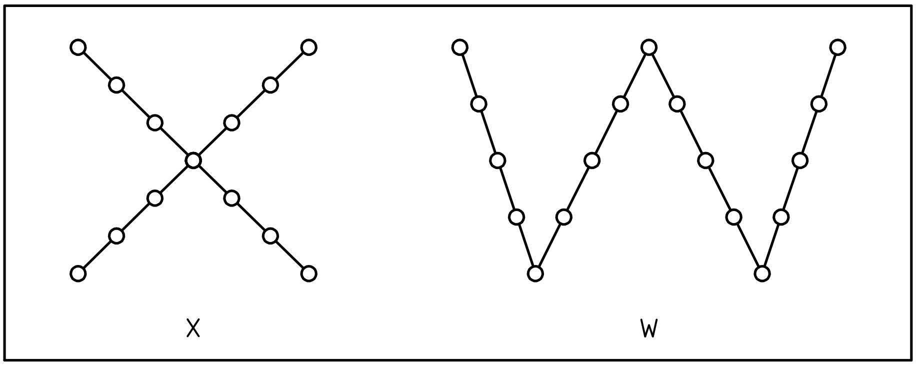


Figure C.1 — Non-systematic patterns

Wherever there are likely to be differences in soil type or conditions, crop growth, plant species, previous cultivation etc., the site should be subdivided according to these differences and a separate sample taken from each area.

Sampling along a single diagonal of a field or a unit is only recommended in case of strip-like distribution of contaminants on agricultural areas due to application of fertilizers. Applying a diagonal for sampling avoids, by simple and effective means, systematic bias which would arise with strip-parallel sampling. However, a greater number of diagonals is to be preferred. Two diagonals (X-shape) introduce a serious bias to the central area of the field (Figure C.1). This should be considered in the evaluation of the results of the determinations.

Application of diagonal patterns should be based on the following:

— estimation of uniform distribution of substances;

— useful only for uniformly developed areas. Deviating parts of the area should be sampled separately;

— application of more than one diagonal is recommended (e.g. parallel or X-shape);

— distance of sampling points is equal for each diagonal, i.e. shorter diagonals have fewer sampling points;

— selection of sampling point is independent of local characteristics. Points are fixed by pacing preferably.

Traversing the area in a zig-zag manner similar to that shown in Figure C.2 is another way of applying a non-systematic pattern.

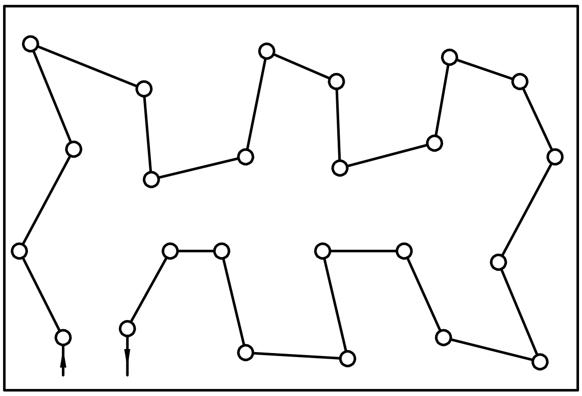


Figure C.2 — Zig-zag traverse sampling pattern

A general exception of the "biased diagonals pattern" was developed for permanently monitored areas to obtain information about long-term changes within selected sites due to human influence. The aim is to make available samples from an area representative of the surrounding environment for a defined number of examinations to be carried out over a period of some years.

The following procedure is recommended (see Figure C.3).

a) Select a representative area of approximately 1 000 m^2.

b) Divide this area into four squares, each of 250 m^2.

c) Within each square, draw two diagonals along each of which nine samples are obtained (Figure C.3).

d) Take samples according to the specified requirements.

e) Prepare composite samples 1, 2, and 3 by

— mixing single samples of positions 1, 4, 7, 10, 13, and 16 to give composite sample 1,

— mixing single samples of positions 2, 5, 8, 11, 14, and 17 to give composite sample 2,

— mixing single samples of positions 3, 6, 9, 12, 15, and 18 to give composite sample 3.

f) Rotational sampling of the area may be conducted by

— taking samples in the intersections of the sampling points (positions 1 to 18 in Figure C.3),

— rotating the diagonals clockwise around the centre of the square in steps of 22,5° so that, all in all, four series of sampling can be carried out at undisturbed positions.

An area selected and sampled according to the above-mentioned scheme serves for eight sampling series. After the final series, the area may be considered unsuitable for further sampling. Extension or reduction of the dimensions of the test area may require changes in the total number of samples and therefore also affect composite samples.

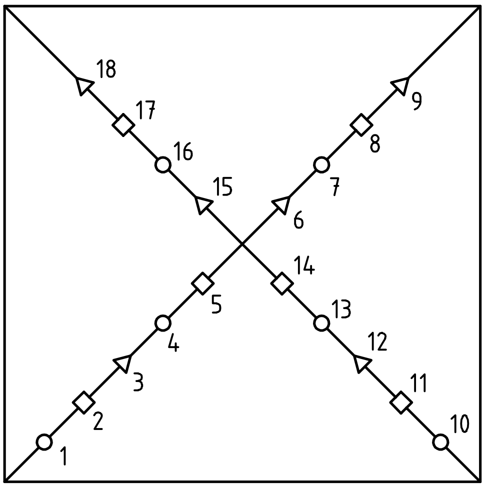


Figure C.3 — Pattern of rotating diagonals for permanently monitored areas

C.3 Circular grids

Circular grids are useful for delineating localized contamination areas such as storage tanks but also to indicate influences around a regional emitting source, e.g. precipitation from industrial plants. Sampling is carried out at the section of concentric circles (the radii of which depend upon the suspected area of contamination) and the lines of the main eight points of the compass (Figure C.4).

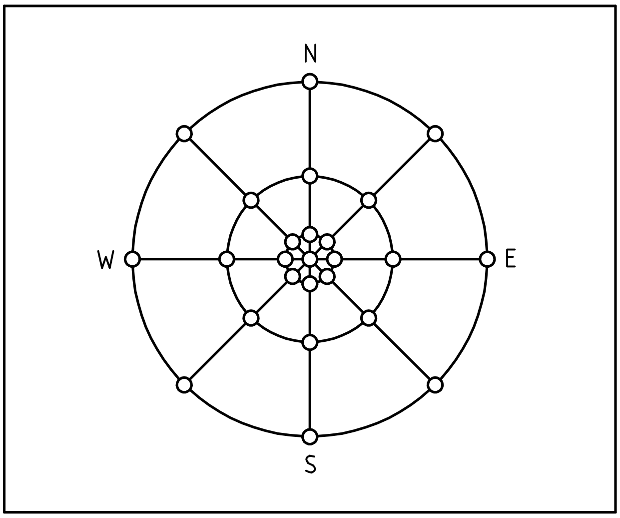


Figure C.4 — Circular grid

Sampling based on circular grids may provide various information:

— information on substance concentrations in the grid centre (maximum values);

— information on distribution of contamination (dimensions of particular area with increased contamination);

— shape of distribution of contamination.

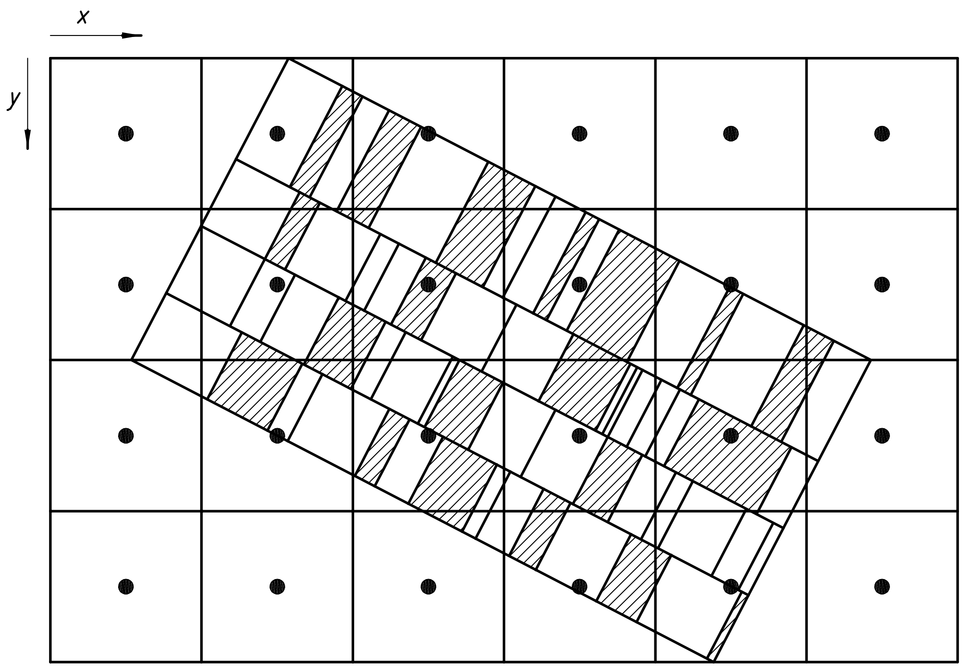
Disadvantages of circular grids are:

- star-shaped (radial) location of sampling points is practicable but not optimal. Rotation of concentric circles of 22,5 ° leads to a higher quality of the pattern;
- relationship of sampling point densities of the (usually) eight samples close to the centre and those (usually) eight samples at a greater distance might not be optimal in every case. If, for example, borders of distribution of a contaminated area are sought, fewer central points should be sampled and more samples at the margins of the grid;
- circular grids might imply a uniform extension of contamination in all directions. This is usually not the case. Preferred directions, e.g. due to main wind direction in case of airborne contaminants, should be considered in modifications of the circular grid, e.g. an increased number of sampling points in critical directions, extending the distance of sampling from the centre in critical directions.
- circular grids generally are not applicable for taking composite samples, because the values measured give information neither on the average nor on the maximum concentration of the area sampled.

C.4 Systematic sampling (regular grids)

In many cases a regular grid is selected for soil sampling (Figure C.5). Because there is a direct relationship between optimal distance between sampling points and the (estimated) dimension of the contamination, spacing between sampling points should not exceed the greatest (estimated) extent of the contamination.

Grid dimensions depend on how much detail is required. The assigned spacing will differ according to the objective of the sampling, e.g. to collect samples of average degree of contamination, to locate isolated sources of contamination or to establish the extent of contaminated zones (horizontal and vertical). The latter is of particular importance in cases where a contaminated area is already located and a follow-up sampling programme becomes necessary.



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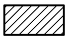
 contamination

Figure C.5 — Regular distribution of sampling points on a regular grid

Although more frequently used for the investigation of soil contamination, regular grids are also suitable for soil fertility investigations, etc.

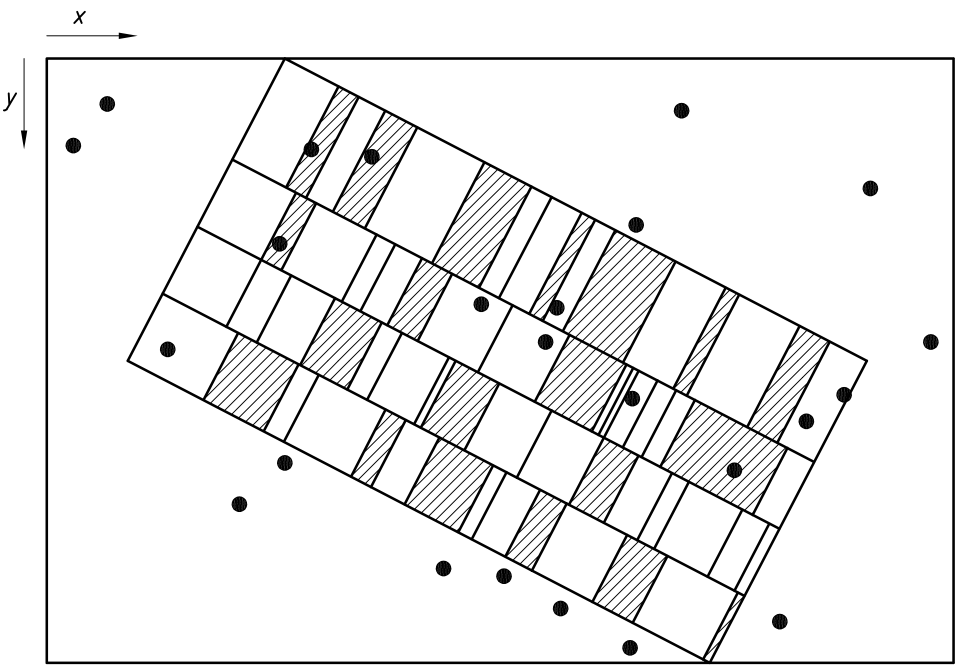
An advantage of a regular grid is that it may be set up easily and grid dimensions may be readily varied.

Interpolation between sampling points and return to the grid and carrying a more intensive sampling in localized areas to further delineate point sources of contamination is easy.

It is also possible to fix the sampling points at the intersections of the grid lines.

C.5 Random sampling

In cases of presumed irregular occurrences of contaminated zones, random sampling may be applied. Sampling points within the area are selected by using random numbers which may be found in tables included in manuals on statistics or which may be generated by computer programs. This technique has the disadvantage of irregular coverage and makes interpolation between sampling points difficult (Figure C.6). In general, random sampling can also be applied for soil fertility investigations etc. In practice, random sampling (in its purest form) is rarely used in soil surveys.



Key

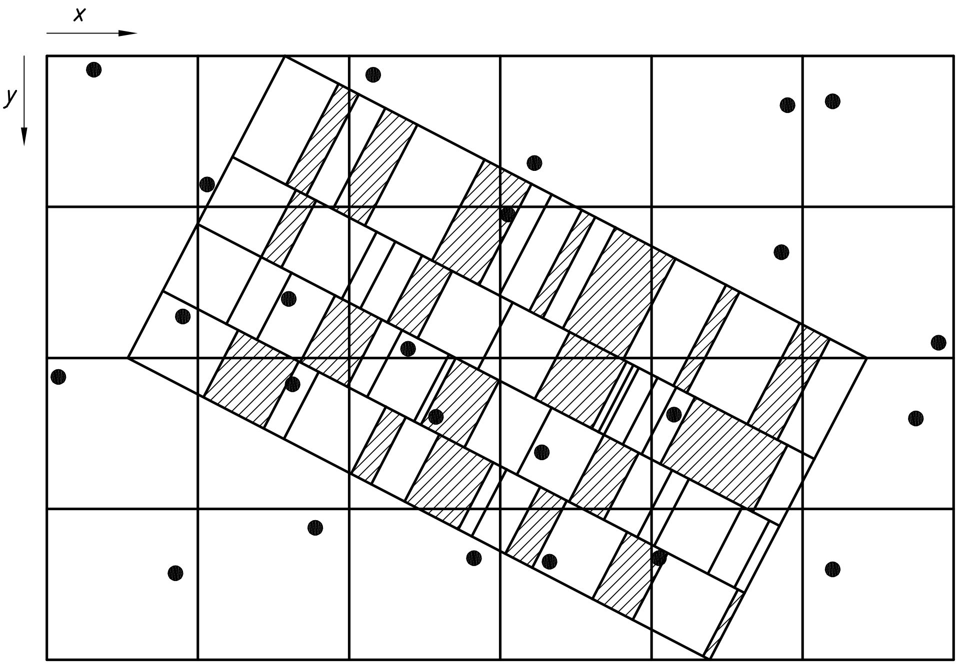
contamination

Figure C.6 — Random sampling without grid

C.6 Stratified random sampling

This method avoids some of the disadvantages of random sampling. The site is divided into a number of grid cells, and a given number of randomly distributed sampling points is chosen in each cell (Figure C.7). In general, stratified random sampling can also be applied for soil fertility investigations, etc. The method has disadvantages in terms of interpolation between the sampling points.

Further sampling of the site to identify local areas of contamination based on the original sampling locations is difficult.



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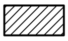
 contamination

Figure C.7 — Stratified random sampling

C.7 Unaligned random sampling

The term "unaligned" means "irregular" in the sense of "not in a line".

The method is similar to stratified random sampling, but in this case, only one of two coordinates is chosen at random.

The procedure is as follows.

EXAMPLE Given a grid with 24 cells (squares), arranged in 4 lines and 6 columns (Figure C.8).

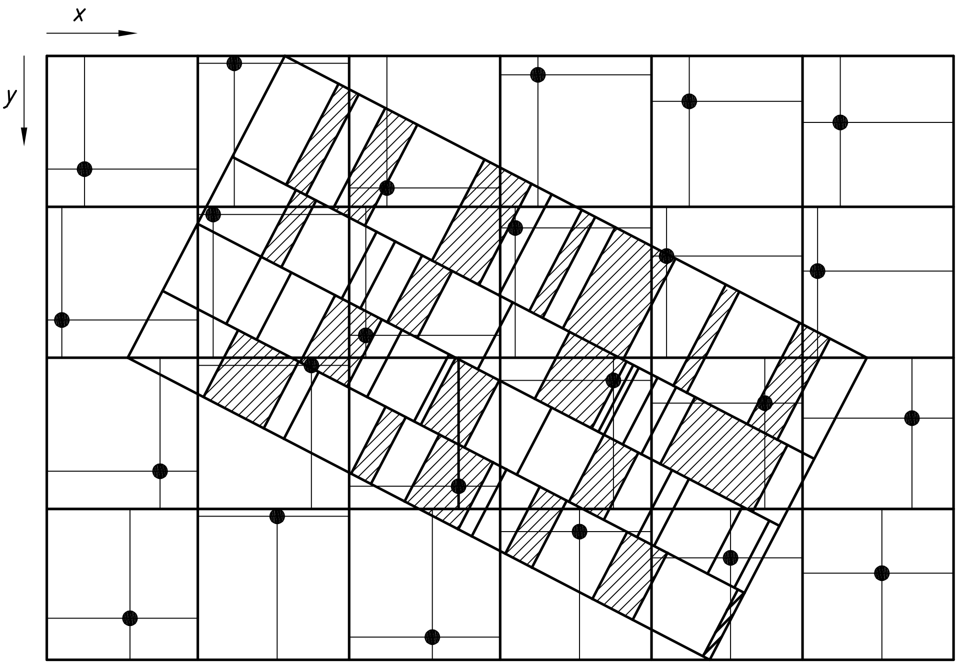
a) For the first cell (line 1, column 1) x- and y-coordinates are chosen at random.

b) For cells 2, 3, 4, 5, and 6 only the y-coordinates are chosen at random.

c) For cells 7, 13, and 19 only the x-coordinates are chosen at random.

d) All sampling points are now located on the grid. For all sampling points in the columns, the y-coordinates of cells 2, 3, 4, 5, and 6 are valid and for all sampling points in the lines the x-coordinates of cells 7, 13, and 19 are valid.

The method has disadvantages in terms of interpolation between the sampling points. Further sampling of the site to identify local areas of contamination is difficult based on the original sampling locations.



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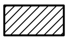 contamination

Figure C.8 — Unaligned random sampling on a regular grid

C.8 Systematic sampling on a non-rectangular grid

In case of an equilateral triangular grid (Figure C.9), each grid point is neighboured by three grid points at the unique distance d_x No other adjacent points exist. The free, unsampled distance between the related adjacent points has a radius of

$$r = \frac{d_x}{3} \cdot \sqrt{3}$$

The circular area (A) not being sampled therefore is

$$A = \pi \cdot r^2 = \pi \cdot \frac{d_x^2}{3}$$

EXAMPLE Take an area of 10 m ×10 m; using 99 sampling points arranged in 11 rows with 9 sampling points each (distance between rows = 1,11 m) the area not being sampled is 1,29 m^2. This unsampled area is thus smaller than for example a rectangular grid of the same size and using 100 sampling points arranged at a distance of 1 m one from another, where the area not being sampled is 1,57 m^2.

Any circular contamination with $r > 0{,}64$ is certain to be detected. Thus, just by changing the pattern (and with one sample less) the size of the unsampled circular area decreases to approximately 18 %.

Application at the site: sampling points are fixed at a distance of d_x in parallel rows spaced at a distance

$$d_y = \frac{d_x}{2} \cdot \sqrt{3}$$

i.e. approximately 0,87 d_x. The sampling points on the parallel rows are staggered by $d_x/2$.

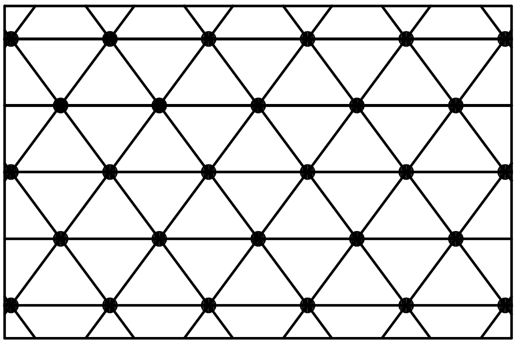

Figure C.9 — Triangular grid

C.9 Sampling along a linear source

In case of contamination following a line, e.g. caused by leaking pipelines, sampling points can be arranged in the covering soil directly above the pipeline or, if not practicable for certain reasons, close to the pipeline. If the distribution of contaminants caused by a line-like structure is also of interest, it is recommended to take samples at a distance x one from another above the line and further samples at increasing distances (e.g. $2x$) parallel to the line (see Figure C.10).

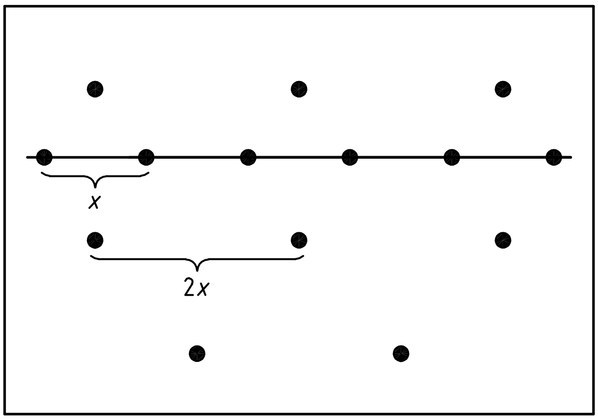

Figure C.10 — Sampling along a linear source

Bibliography

[1] ISO 5667-2, *Water quality — Sampling — Part 2: Guidance on sampling techniques*

[2] ISO 5667-3, *Water quality — Sampling — Part 3: Guidance on the preservation and handling of samples*

[3] ISO 5667-4, *Water quality — Sampling — Part 4: Guidance on sampling from lakes, natural and man-made*

[4] ISO 5667-6, *Water quality — Sampling — Part 6: Guidance on sampling of rivers and streams*

[5] ISO 5667-8, *Water quality — Sampling — Part 8: Guidance on the sampling of wet deposition*

[6] ISO 5667-9, *Water quality — Sampling — Part 9: Guidance on sampling from marine waters*

[7] ISO 5667-10, *Water quality — Sampling — Part 10: Guidance on sampling of waste waters*

[8] ISO 5667-11, *Water quality — Sampling — Part 11: Guidance on sampling of groundwaters*

[9] ISO 5667-12, *Water quality — Sampling — Part 12: Guidance on sampling bottom sediments*

[10] ISO 5667-13, *Water quality — Sampling — Part 13: Guidance on sampling of sludges from sewage and water-treatment works*

[11] ISO 9000, *Quality management systems — Fundamentals and vocabulary*

[12] ISO 10381-2, *Soil quality — Sampling — Part 2: Guidance on sampling techniques*

[13] ISO 10381-7, *Soil quality — Sampling — Part 7: Guidance on the investigation and sampling of soil gas*

[14] ISO 10381-8, *Soil quality — Sampling — Part 8: Guidance on the sampling of stockpiles*

[15] ISO 11259, *Soil quality — Simplified soil description*

[16] ISO 11277, *Soil quality — Determination of particle size distribution in mineral soil material — Method by sieving and sedimentation*

[17] ISO 11464, *Soil quality — Pretreatment of samples for physico-chemical analyses*

[18] ISO 15176, *Soil quality — Characterization of excavated soil and other soil materials intended for re-use*

[19] ISO 16133, *Soil quality — Guidance on the establishment and maintenance of monitoring programmes*

[20] ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories*

[21] EN 45002, *General criteria for the assessment of testing laboratories*

[22] EN 45003, *Calibration and testing laboratory accreditation system — General requirements for operation and recognition*

[23] EN 45011, *General requirements for bodies operating product certification systems* (ISO/IEC Guide 65:1996)

[24] EN 45012, *General requirements for bodies operating assessment and certification/registration of quality systems* (ISO/IEC Guide 62:1996)

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