



BSI Standards Publication

Soil quality — Sampling

Part 104: Strategies

National foreword

This British Standard is the UK implementation of ISO 18400-104:2018. Together with BS ISO 18400-101:2017 and BS ISO 18400-107:2017, it supersedes BS ISO 10381-1:2002 which is withdrawn. Together with BS ISO 18400-102:2017, BS ISO 18400-105:2017 and BS ISO 18400-206:2018, it supersedes BS ISO 10381-6:2009 which is withdrawn.

BS ISO 18400-104:2018 is intended to be used in conjunction with BS 10175:2011+A2:2017 and other members of the BS ISO 18400 series of standards as appropriate. Where there are differences in the guidance given in this standard and that in BS 10175:2011+A2:2017, the guidance in this standard takes precedence.

The UK committee notes that this standard covers a wide variety of situations in which investigations including sampling to determine soil quality might be carried out rather than being focused on potentially contaminated sites, as is the case in BS 10175:2011+A2:2017.

The UK participation in its preparation was entrusted to Technical Committee EH/4, Soil quality.

A list of organizations represented on this committee can be obtained on request to its secretary.

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

© The British Standards Institution 2018
Published by BSI Standards Limited 2018

ISBN 978 0 580 87481 9

ICS 13.080.05

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

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 30 November 2018.

Amendments/corrigenda issued since publication

Date	Text affected
------	---------------

**Soil quality — Sampling —
Part 104:
Strategies**

*Qualité du sol — Échantillonnage —
Partie 104: Stratégies*



Reference number
ISO 18400-104:2018(E)

AVA Documents
Document Sharing Hub
© ISO 2018



COPYRIGHT PROTECTED DOCUMENT

© ISO 2018

All rights reserved. Unless otherwise specified, or required in the context of its implementation, no part of this publication may be reproduced or utilized otherwise in any form or by any means, electronic or mechanical, including photocopying, or posting on the internet or an intranet, without prior written permission. Permission can be requested from either ISO at the address below or ISO's member body in the country of the requester.

ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Fax: +41 22 749 09 47
Email: copyright@iso.org
Website: www.iso.org

Published in Switzerland

Contents

Page

Foreword	v
Introduction	vi
1 Scope	1
2 Normative references	1
3 Terms and definitions	1
4 Overall investigation strategy	5
4.1 General	5
4.2 Zoning	7
4.3 Types of investigation	7
4.3.1 General	7
4.3.2 Preliminary investigation	10
4.3.3 Exploratory investigation	11
4.3.4 Detailed investigation	11
4.3.5 Supplementary investigations	11
4.4 Conceptual site model	12
4.5 Preliminary risk assessment	12
5 Sampling strategies — General aspects	13
5.1 Sampling objectives	13
5.2 Scope of the sampling strategy	13
5.3 Designing the sampling strategy	14
5.4 Principal sampling situations	15
5.5 Representative and sufficiently representative samples	16
5.6 Characteristics of the spatial distribution	17
5.7 Statistical aspects	18
5.8 Uncertainty of measurements caused by sampling and analysis	18
5.9 Safety and environmental protection	19
5.10 Barriers to sampling	19
5.11 Timing of investigations	19
6 Sampling strategies — Key aspects and concepts	20
6.1 Statistics and geostatistics	20
6.1.1 General	20
6.1.2 Statistics	20
6.1.3 Geostatistics	20
6.2 Approaches to sampling	22
6.2.1 General	22
6.2.2 Judgemental sampling	22
6.2.3 Systematic sampling	23
6.2.4 Convenience sampling	23
6.3 Average properties	24
6.4 Types of samples	24
6.4.1 General	24
6.4.2 Disturbed and undisturbed samples	24
6.4.3 Spot (single) samples	25
6.4.4 Cluster samples	25
6.4.5 Spatial (composite) samples	25
6.4.6 Selective samples	27
6.5 Number of samples	27
6.5.1 General	27
6.5.2 Number of samples at discrete sampling points	28
6.5.3 Number of cluster samples	28
6.5.4 Number of composite samples	28
6.6 Sample sizes	29

6.6.1	General	29
6.6.2	Practical considerations	30
7	Deciding how many samples to take	32
7.1	General	32
7.2	Basic situations	33
7.3	Determining average concentrations	33
7.3.1	General	33
7.3.2	Using spatial composite samples	34
7.3.3	Using spot samples	35
7.3.4	Determining relation to threshold limit	35
7.4	Finding (hot spots and) areas of interest of a specified minimum size	35
7.5	Sampling for particular purposes	36
7.5.1	Determination of background values	36
7.5.2	Waste classification	36
7.5.3	Supplementary investigations for remediation	36
7.5.4	Validation of remediation and other works	37
8	Sampling strategies for in-ground sampling	38
8.1	Approach to sampling	38
8.2	Sampling patterns	38
8.2.1	General	38
8.2.2	Potentially contaminated sites	39
8.2.3	Hot spot detection, site investigation design and sampling	40
8.3	Types of samples	41
8.4	Sampling depths	42
8.4.1	General	42
8.4.2	Potentially contaminated sites	42
8.4.3	Sampling in relation to the groundwater profile and aquifer	43
8.5	Size of samples	44
8.6	Number of samples	45
8.6.1	General	45
8.6.2	Number of samples at individual sampling points	45
8.6.3	Number of composite samples	45
9	Sampling of above-ground deposits	46
9.1	General	46
9.2	Sampling patterns	46
9.3	Types of sample	46
9.3.1	General	46
9.3.2	Convenience sampling	47
9.4	Sampling depths	47
9.5	Size of samples	47
9.6	Number of samples	47
Annex A (informative) Basic statistical concepts		48
Annex B (informative) Sampling patterns		54
Annex C (informative) Assessment and modification of sampling uncertainty		68
Annex D (informative) Examples of sampling for particular purposes		72
Annex E (informative) Scale of sampling		77
Annex F (informative) Determination of size and number of samples and increments		82
Annex G (informative) Statistical methods for estimating soil parameters		90
Annex H (informative) Geostatistical methods for sampling design and evaluation of soil quality		103
Annex I (informative) Sampling strategies for risk assessment		119
Bibliography		129

Foreword

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

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

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

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

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

The committee responsible for this document is ISO/TC 190, *Soil quality*, Subcommittee SC 2, *Sampling*.

This first edition of ISO 18400-104, together with ISO 18400-101, ISO 18400-102, ISO 18400-105, ISO 18400-107, ISO 18400-202, ISO 18400-203 and ISO 18400-206, cancels and replaces the first editions of ISO 10381-1:2002, ISO 10381-4:2003, ISO 10381-5:2005, ISO 10381-6:2009 and ISO 10381-8:2006, which have been structurally and technically revised.

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

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

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

Introduction

This document is part of a series of sampling standards for soil (the role/position of the individual standards within the total investigation programme is shown in [Figure 1](#)). It provides guidance on the development of site investigation strategies in general (more specific guidance is given in other standards) and of sampling strategies [e.g. what to sample, where to sample (locations and depths) and the types of samples to take] taking into account the need to obtain representative samples and to have regard to relevant statistical principles.

Soils (and other soil materials) are composed of a mixture of mineral particles, organic matter, water, air (soil gas) and living organisms. In the case of some contaminated soils, a non-aqueous liquid phase might also be present. The solid matrix (phase), consists of particles of different size, shape and physical and chemical properties. The aim when carrying out soil sampling is usually to obtain sufficiently representative samples that can be used to characterize the properties of the whole soil entity (e.g. *in situ* soil in the form of a volume or horizon, or surface deposit such as a stockpile) or the portion considered relevant to the objectives of the investigation (e.g. <0,1 mm fraction for exposure assessment via hand-to-mouth activity). The properties of discrete entities such as individual soil particles are not addressed. As the soil as a whole cannot be analysed, soil samples are taken instead. The assumption that the results of these investigations on samples represent the total soil volume of interest is always an approximation, the reliability of which depends on additional information about the soil, the site and use of an appropriate sampling strategy. In other words, the sampling strategy should guarantee that, together with additional information (on-site observations, background information, previous investigation results, etc.), the results for the samples analysed allow a model to be developed of relevant properties of the soil volume of interest to a sufficiently reliable degree, in accordance with the investigation objectives.

Whatever the purpose of the investigation, a sound conceptual site model is required. Every property of a soil or soil material is a result of their dynamic development influenced by natural and human-induced processes such as weathering, leaching, dislocation, contamination, and many others. Without considering this, the results of any investigation of samples cannot be interpreted and evaluated properly. When spatial variability of soil properties (including contamination) is of particular interest, the conceptual site model includes what is known, or believed to be known, about the processes that led to the anticipated spatial distribution of properties.

The sampling strategy, especially when average properties are of interest, is preferably based on statistical methods, as far as practical and appropriate.

Having first defined key elements such as involved parties, objectives, properties of interest, phase of the investigation, background and site information, as well as health and safety aspects, a sampling strategy is developed that can form the basis of a sampling plan in accordance with ISO 18400-101 (the sampling plan covers a number of practical issues as well as the sampling strategy).

The appropriate sampling strategy in any particular case depends on

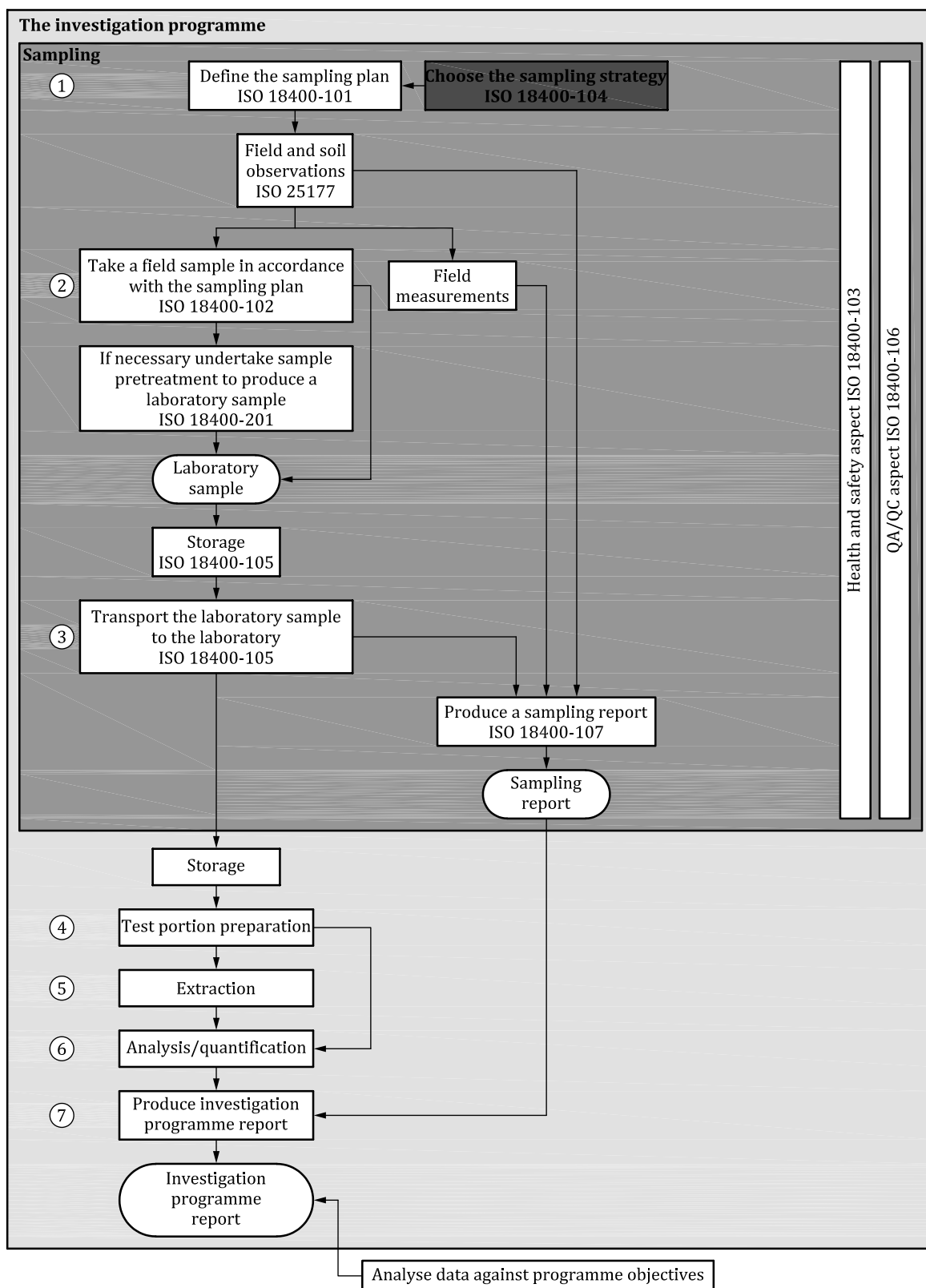
- the objectives of the investigation,
- the special situation and characteristics of the material to be sampled,
- the properties of interest, and
- the required degree of precision and reliability of the results.

Many other factors can also influence the design of the sampling strategy including:

- accessibility of the site as well as the sampled material;
- financial, personnel, and technical resources;
- weather conditions;
- the time schedule/frame;

— legal/environmental restrictions.

Following the definition of the sampling approach, the appropriate sampling techniques are selected following the guidance in ISO 18400-102 with regard to health and safety (ISO 18400-103) and various practical considerations. The decisions made regarding sampling techniques form part of the sampling plan.



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

NOTE 2 Figure 1 displays a generic process which can be amended when necessary.

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

Soil quality — Sampling —

Part 104: Strategies

1 Scope

This document gives general guidance on the development of site investigation strategies and detailed guidance on the development of sampling strategies, when collecting information on

- the average properties of soil,
- the variability of soil properties, and
- the spatial distribution of soil properties.

It is applicable to soil samples intended for chemical testing and determination of a variety of other properties (e.g. physical).

Although the main focus of this document is the collection of material (field samples) for transfer to a laboratory for testing, it is also applicable when measurements are made directly in the field.

NOTE 1 This document also provides information on the statistical principles underlying the development of appropriate sampling strategies and statistical methodologies.

NOTE 2 Guidance on other forms of related sampling activities are given in other International Standards [for soil gas (ISO 18400-204) and for biological testing purposes (ISO 18400-206)]. Guidance on sampling groundwater is provided in ISO 5667-11 and ISO 5667-22 and on sampling methods and groundwater measurements in geotechnical investigations in ISO 22475-1.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 11074, *Soil quality — Vocabulary*

ISO 11464, *Soil quality — Pretreatment of samples for physico-chemical analysis*

ISO 18400-201, *Soil quality — Sampling — Part 201: Physical pretreatment in the field*

ISO 18400-202, *Soil quality — Sampling — Part 202: Preliminary investigations*

3 Terms and definitions

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

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

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <http://www.electropedia.org/>

NOTE The hierarchical approach and terms used in this document as well as the relationships between the sampling approaches and sampling patterns employed in this document are shown in [Table Documents](#)

3.1

above-ground sampling

taking samples from material that has been deposited on the ground surface

EXAMPLE Samples are taken from a stockpile (including bulk volumes of excavated soils), deposit of waste or embankment.

3.2

anthropogenic ground

deposits which have accumulated through human activity

3.3

cluster sample

composite sample (3.4) for which the *increments* (3.8) are taken over a small area around a predefined sampling point

Note 1 to entry: Sampled area is typically about 0,5 m² to 1,0 m².

Note 2 to entry: Material sampled is taken from within the same stratum or from material with the same characteristics.

3.4

composite sample

sample made of a number of increments (*cluster sample* (3.3) or *spatial composite sample* (3.22))

3.5

convenience sampling

taking samples based on accessibility, expediency, cost, efficiency, or another reason not directly concerned with sampling parameters

Note 1 to entry: The samples might be taken to a predetermined plan (locations, depths, etc.) or taken from locations and/or depths decided on site.

3.6

fill

anthropogenic ground (3.2) in which the material has been selected, placed and compacted in accordance with an engineering specification

3.7

ground

all materials below the ground surface, including natural materials (soil and rock) and anthropogenic materials

3.8

increment

material forming part of a *composite sample* (3.4) obtained by a single operation of a sampling device

Note 1 to entry: For instance, the filling of a scoop or auger.

3.9

in-ground sampling

taking samples from the ground surface and/or within the ground beneath the surface

3.10

judgemental sampling

targeted sampling

taking samples from particular zones or features of a site taking into account existing knowledge, including what is known about the history and layout of a site or a zone within a site

Note 1 to entry: Judgemental sampling could be required, for example, around underground storage tanks or pipelines where there might have been leaks, above ground storage tanks where there might have been spills, and for areas where raw materials or waste have been stored or deposited.

Note 2 to entry: Sampling locations are usually predetermined based on what is known about the target area but some locations may be selected in the field in response to on-site observations.

3.11

made ground

anthropogenic ground (3.2) comprising material placed without engineering control and/or manufactured by man in some way, such as through crushing or washing, or arising from an industrial process

3.12

macro-aggregate

soil aggregates consisting of micro-aggregates cemented together by organic matter, microbial polysaccharides, fungal hyphae, earthworm excretions and plant roots

Note 1 to entry: Generally, aggregates are >0,25 mm to 5 mm in size.

Note 2 to entry: Macro-aggregates are typically found in undisturbed soils.

3.13

micro-aggregate

soil aggregates consisting of primary particles, plant roots, and humin cemented together

Note 1 to entry: Generally, aggregates are less than 0,25 mm in size.

Note 2 to entry: Micro-aggregates are more typically found in disturbed or cultivated soils. Multiple micro-aggregates can form larger *macro-aggregates* (3.12) through microbial activity, plant root exudates and actions, fungal hyphae, and earthworm casts.

3.14

population

<soil sampling> entirety of a soil volume or mass about which information is to be sought via sampling

EXAMPLE A particular site, an *in situ* volume of soil, a stockpile, a truck load.

3.15

principal sampling situation

one of four sampling situations characterized by a combination of whether information is required on spatial distribution or average properties, with whether *in-ground sampling* (3.9) or *above-ground sampling* (3.1) is required

Note 1 to entry: The concept is illustrated in Table 2.

3.16

probabilistic sampling

taking samples to ensure that each particle or element in the *population* (3.14) has an equal chance of being part of the sample

Note 1 to entry: This means it is easy to obtain a quantifiable level of reliability (or uncertainty) in the estimated mean value and enables estimation of variability of the results for the population being tested.

[SOURCE: ISO 11074:2015, 4.2.10]

3.17

random sampling

simple random sampling

taking samples in locations selected arbitrarily within the area to be investigated

Note 1 to entry: The coordinates of the intended sampling locations are derived using pseudo-random or quasi-random numbers which can be found in tables included in manuals on statistics or generated by computer programs.

3.18

regular sampling

taking samples at the nodes of a regular pattern, such as a square or triangular grid, i.e. the sampling locations are evenly spaced

3.19

sampling pattern

set of predetermined sampling points

3.20

selective sample

sample deliberately chosen or formed based on some specific characteristic(s) of the material to be sampled

EXAMPLE Appearance, odour, particle sizes.

[SOURCE: ISO 11074:2015, 4.2.16, modified]

3.21

site investigation objective

statement regarding the information to be obtained during the investigation

3.22

spatial composite sample

composite sample ([3.4](#)) formed from small incremental point samples taken over an area (such as a field)

Note 1 to entry: The general premise is that the distribution of soil constituents is relatively homogeneous. The *increments* ([3.8](#)) may be located according to a regular grid, random, or other pattern. In agricultural/horticultural land investigations “N”, “S”, “W” and “X” *sampling patterns* ([3.19](#)) are commonly used. Along the outline of such a pattern, a number of samples or increments are taken which are bulked and mixed to provide one (composite) sample for analysis.

3.23

spot sample

sample from a discrete location

Note 1 to entry: Sample can be formed from one or more contiguous portions of material.

Note 2 to entry: Sample may be *disturbed* or *undisturbed*.

3.24

stratified random sampling

dividing the area to be sampled into a number of identical grid cells (strata) and taking samples arbitrarily in each cell

3.25

systematic sampling

taking samples from locations that have been pre-designated according to a geometric or other statistically derived pattern

Note 1 to entry: Systematic sampling can include a random positioning component.

Note 2 to entry: Some systematic sampling patterns are regarded as “*probabilistic*” ([3.16](#)).

Note 3 to entry: This definition is wider than the usual definition found in the literature, where systematic sampling commonly means *regular sampling* ([3.18](#)).

3.26

systematic unaligned sampling

taking samples using a *sampling pattern* (3.19) intermediate between a regular grid and *stratified random sampling* (3.24), where each row (respectively column) of the grid shows a similar pattern of unaligned points

Note 1 to entry: See [Figure B.8](#).

4 Overall investigation strategy

4.1 General

The sampling strategy for soils and soil materials usually forms part of an overall site investigation strategy. This usually comprises a number of phases as described in [4.3](#).

NOTE 1 The soil sampling exercise that is being planned could be only one component of a wider investigation strategy that could also require collection of information relating to, for example, groundwater, geotechnical properties of the ground, archaeology, ecology, and soil gas and that for practical and logistical reasons a degree of integration between investigations into different aspects of the site might be required. How this can be done is outside of the scope of this document.

NOTE 2 Soils (and other soil materials) are composed of a mixture of mineral particles, organic matter, water, air (soil gas) and living organisms. In the case of some contaminated soils, a non-aqueous liquid phase might also be present. The solid matrix (phase), consists of particles of different size, shape and physical and chemical properties. The aim when carrying out soil sampling is usually to obtain sufficiently representative samples that can be used to characterize the properties of the whole soil entity (e.g. *in situ* soil in the form of a volume or horizon, or surface deposit such as a stockpile) or the portion considered relevant to the objectives of the investigation (e.g. <0,1 mm fraction for exposure assessment via hand-to-mouth activity). The properties of discrete entities such as individual soil particles are not addressed.

Sample is generally used in this document to mean the field sample. Sampling, therefore, means the collection of one or more field samples. The field sample usually equates to the laboratory sample [i.e. the material sent to the laboratory (ISO 11074:2015, 4.3.7)], although in some cases, the field sample is subjected to pretreatment in the field according to ISO 18400-201 to produce a sample of smaller size to send to the laboratory. The laboratory sample is usually subject, at least in the case of chemical analysis, to pretreatment in the laboratory (according to ISO 11464) in order to obtain a test sample. Physical and biological testing usually require a different approach and often require use of the whole of the laboratory sample. Information is provided in [6.6](#) and [Clause 7](#) on the amounts of soil required primarily in the context of chemical testing but also for certain physical tests.

Table 1 — Sampling approaches and patterns

Convenience sampling	Judgemental sampling	Samples are taken from pre-designated locations							Spatial composite sampling
		Systematic sampling							
		Linear patterns	Circular patterns	Simple random sampling	Stratified random sampling	Un-aligned sampling	Regular sampling		
Rectangular grid	Non-rectangular grid								

NOTE 3 The terminology used to describe approaches to sampling and sampling patterns, etc. is not always applied consistently. Because of the variability in the use and understanding of terms related to sampling, it is important that those designing or carrying out site investigations explain what they intend to do, or have done, in ways that will be understood by non-experts and avoid reliance on specialist jargon.

The overall site investigation strategy should take into account:

- the client's reasons for requesting the investigation to be undertaken (these should be clearly set out by the client);
- the decisions that need to be made regarding the site or other area to be investigated.

- c) the confidence required for making these decisions (this will determine the level of detail and accuracy of measurements required);
- d) the findings of any investigations already carried out;
- e) known data gaps and uncertainties (e.g. in the conceptual site model, see [4.4](#));
- f) the findings of any risk assessment(s) completed to date.

A preliminary investigation (see [4.3.2](#)) in accordance with ISO 18400-202 should always be carried out before any sampling or other intrusive investigation is carried out.

Once the preliminary investigation has been completed decisions should be made whether:

- a) an exploratory and/or detailed (main) investigation is to be carried out, and in both cases, whether to carry out a single stage of sampling or two or more stages;
- b) to zone the site, e.g. on the basis of past or current land use(s), intended use, or topography (if the site is zoned a separate sampling strategy will be required for each zone), see [4.2](#);
- c) there are safety and environmental issues that could constrain the way that the sampling is carried out, see [5.9](#).

The objectives of the site investigation should be set before the investigation strategy is determined.

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

- information on the pedological state of the site to be sampled;
- information on potential agricultural productivity;
- information on the physical and chemical state of the site to be sampled;
- information on contamination of the ground and groundwater;
- information on natural concentrations of potentially hazardous substances;
- the information needed to form, or further develop, a conceptual site model, including identification of potential pathways and receptors for the purposes of contamination-related risk assessment;
- support for a risk assessment;
- provide data for the design of remedial or protective works;
- provide data for re-use of soil materials (see ISO 15176) or for their disposal as waste.

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

The formulation or refinement of a conceptual site model, see [4.4](#), should always be one of the investigation objectives and the model should be reviewed and revised in response to the results of the site investigation.

NOTE 4 The conceptual site model is to be no more detailed than required by the task in hand.

NOTE 5 Guidance on the investigations of particular types of site and in connection with the assessment for particular purposes is given in a number of other International Standards including: ISO 18400-205, ISO 18400-206, ISO 11504, ISO 15175, ISO 15176, ISO 15799, ISO 15800, ISO 16133, ISO 19258 and ISO 18400-203.

NOTE 6 An investigation (of potentially contaminated sites) are often carried out in one of the following contexts (see ISO 18400-203):

- in support of a proposal to develop or redevelop a site on behalf of the client (who might or might not be the site owner);
- in connection with the potential sale and purchase of a site to enable its value to be estimated, taking into account potential contaminated land liabilities and possible remediation requirements;
- to “benchmark” site conditions (e.g. contamination levels) for future reference;
- to determine whether it falls within a regulatory regime requiring remediation or some other form of response.

4.2 Zoning

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

- near-surface geology (e.g. made ground or natural ground);
- deeper geology;
- topography;
- probable absence or presence of contamination;
- previous, current or planned land uses;
- the nature of probable contaminants [e.g. volatile organic compounds (VOC) or inorganic compounds];
- known differences in soil types;
- observations on plant health;
- intended future use.

Zoning should be reviewed after each phase (and stage) of the investigation.

NOTE A stockpile or other above-ground deposit can be considered to be a single zone requiring separate investigation, or it can be divided into a number of zones, for example to reflect the method of formation (e.g. in layers or by end-tipping), or to reflect difference in appearance or on an arbitrary basis.

4.3 Types of investigation

4.3.1 General

Four principal phases of investigation are described in [4.3.2](#) to [4.3.5](#). The relationship between these phases and other investigation-related activities is shown in [Figures 2](#) to [4](#). The person designing the overall site investigation should decide what phases of investigations are required, whether one or more of the phases should be carried out in stages, and the scope of each phase or stage of investigation.

Typically, investigations should comprise:

- a preliminary investigation (always required), see [4.3.2](#);
- an exploratory investigation (not necessarily required), see [4.3.3](#);
- a detailed investigation (required unless an exploratory investigation indicates otherwise), see [4.3.4](#);
- a supplementary investigation (sometimes required), see [4.3.5](#).

NOTE 4.3.2 to 4.3.5 have been written with particular emphasis on potentially contaminated sites because these are generally more complex to investigate than other sites, for example investigation of an agricultural field to determine the nutrient status would usually be a fairly simple task. However, the principles apply to all sites and are intended to be applied as appropriate in individual cases.

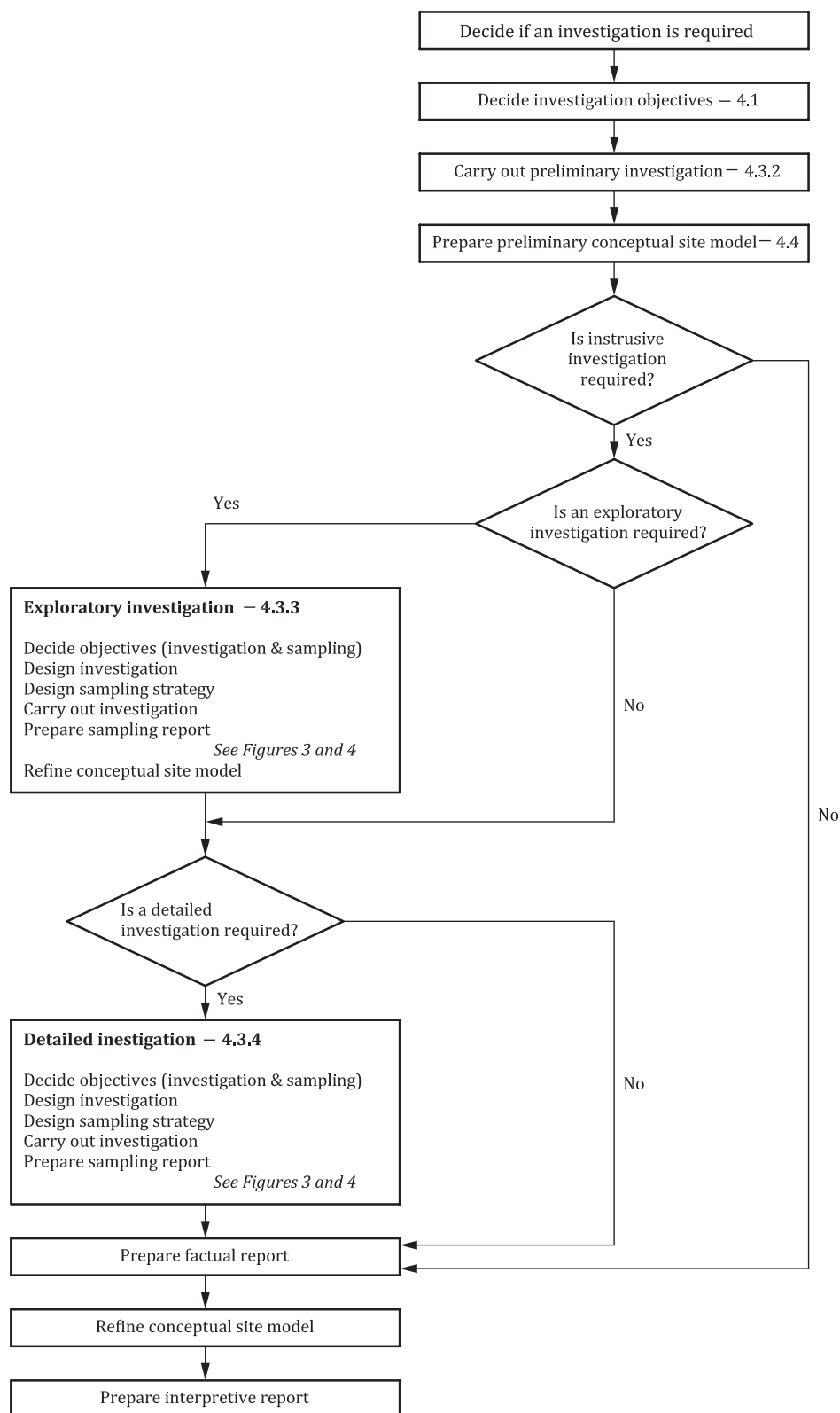


Figure 2 — Site investigation process

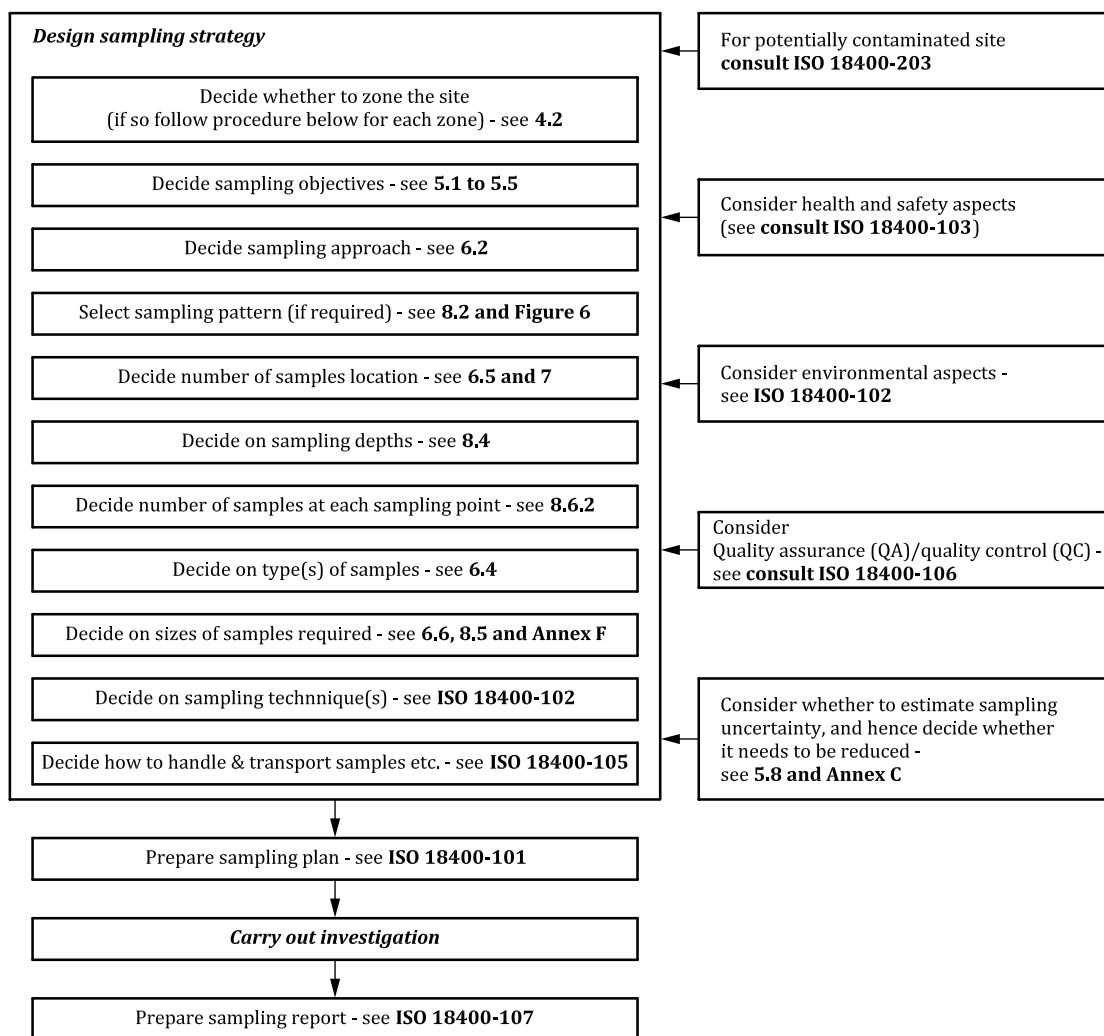


Figure 3 — Intrusive investigation process for potentially contaminated sites or above ground deposit

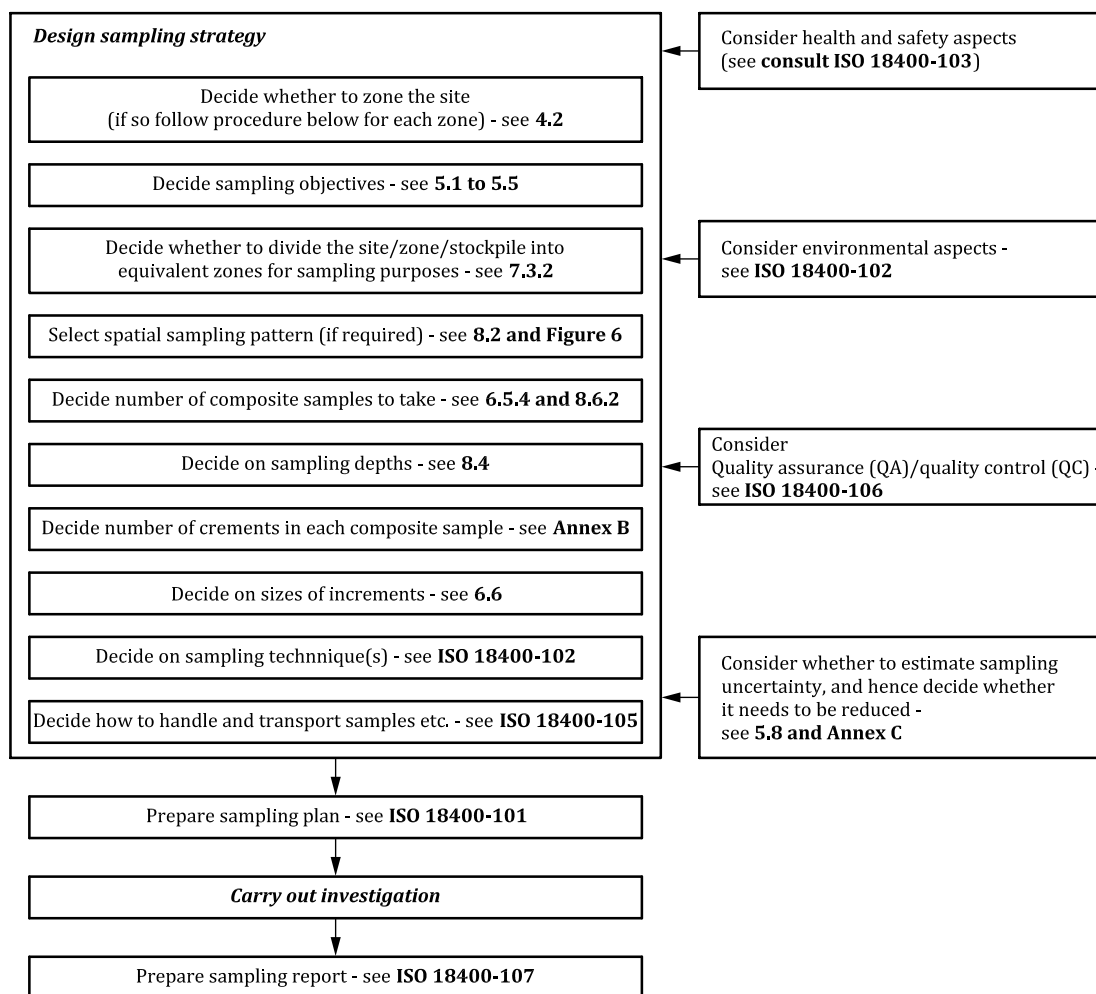


Figure 4 — Intrusive investigation process using spatial composite sampling to determine average properties

4.3.2 Preliminary investigation

The first phase in the overall investigation process should always be a preliminary investigation. This should include reference to historical records and other sources of information, consultation with relevant sources, and a site reconnaissance in accordance with ISO 18400-202.

The overall investigation strategy should provide for a review of the information obtained at the conclusion of the preliminary investigation to determine if the objectives have been achieved (and are still appropriate) and whether there is a need to carry out an exploratory investigation (see 4.3.3) and/or detailed investigation (see 4.3.4).

The output from the preliminary investigation should include an initial conceptual site model (see 4.4) and can include a preliminary risk assessment (see 4.5) based on the information available.

NOTE 1 Detailed guidance on preliminary investigations is provided in ISO 18400-202, including the type of information that could be required in relation to particular types of site, e.g. agricultural and near-natural sites, wooded sites and potentially contaminated sites.

NOTE 2 Preparation of a preliminary risk assessment requires interpretation of the information gathered during the preliminary investigation. Although in the case of a potentially contaminated site, a preliminary risk assessment will usually be an essential prerequisite for the design of further phases of investigation, guidance on how to do this is outside of the scope of this document.

4.3.3 Exploratory investigation

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

- reduce uncertainty in knowledge of the site, including determining the validity or otherwise of contamination-related and other hypotheses developed in the preliminary investigation, thereby enabling the initial conceptual site model to be refined;
- provide information that helps the design of any subsequent detailed investigation.

NOTE 1 Exploratory investigations typically comprise one or more judgmental (targeted) sampling exercises although systematic sampling or composite sampling are also sometimes carried out.

NOTE 2 Detailed guidance on the design and execution of exploratory and detailed investigations of potentially contaminated sites, is provided in ISO 18400-203 and for natural and near-natural sites (e.g. agricultural) in ISO 18400-205.

NOTE 3 In the case of an agricultural site, an exploratory investigation could be used to confirm conclusions from the preliminary investigation about the soil type(s) present or to test a hypothesis, for example, that poor growth of vegetation is due to compaction and/or water logging. With this information available, the investigator can decide whether more detailed investigation is required, or that sufficient information is available to advise the client (e.g. the farmer).

4.3.4 Detailed investigation

The detailed investigation should, as far as is practical, provide all the information necessary to fulfil the objectives of the overall investigation.

In the case of potentially contaminated sites it should include collection of:

- all information necessary to test the validity or otherwise of contamination-related and other hypotheses developed in earlier phases of the overall investigation;
- all information necessary for the assessment of risks to all potential receptors;
- information relevant to the selection, design and costing of remedial or protective works.

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

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

NOTE 3 Detailed investigations of potentially contaminated sites typically comprise a combination of judgmental and systematic sampling exercises.

4.3.5 Supplementary investigations

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

NOTE In the case of potentially contaminated site, a supplementary investigation can be required, for example:

- to provide additional information needed to design and cost remedial works, for example, to delineate volumes of soil requiring remediation, or to carry out specific tests to evaluate the suitability of specific remedial treatment techniques;
- to provide chemical testing information for the classification of wastes;

- to monitor groundwater quality and levels, and/or soil gas conditions, after completion of the detailed investigation to determine any changes in site conditions and to provide additional data to assess risks and aid design of protective measures;
- to monitor groundwater and soil gas conditions during and after construction or remediation to determine whether there have been any adverse changes in site conditions.

4.4 Conceptual site model

A conceptual site model, embracing all information relevant to the objectives of the investigation, should be prepared prior to development of the sampling strategy. It should be presented in narrative, pictorial, tabular, or a combination of forms as appropriate.

The conceptual site model should be first formally formulated during the preliminary investigation (desk study and site reconnaissance) and should inform subsequent investigations, if these are necessary, to meet the objectives of the overall investigation. One of the objectives for the overall investigation should always be reduction of uncertainty in the conceptual site model.

NOTE 1 Although the conceptual site model is usually first formally prepared following a preliminary investigation, it first comes into existence the moment the question is asked whether the site needs to be investigated. At that stage, for example, it might be recognized that the site is agricultural land or is industrial land and the assessor will immediately form an initial picture about what the site might be like and act accordingly.

NOTE 2 The scope of, and level of detail in, the conceptual site model will depend on the objectives of the investigation and requires judgement on the part of the person preparing the model.

NOTE 3 The conceptual site model in the case of a potentially contaminated site is a description and/or representation of the site, incorporating what is known about the ground and groundwater conditions, the actual and potential contamination, the physical conditions and environmental setting, the current and past uses of the site, the receptors and potential pathway linkages between contamination sources and receptors, foreseeable events such as flooding, changes in groundwater level, global warming, extreme weather conditions, the closure of mines, etc.; in fact, all information relevant to the task in hand. Depending upon the objectives of the investigation, it could be relevant to consider new future receptors associated with the construction and completion of a new development, as well as existing receptors. The conceptual site model leads, for example, to the formulation of contamination-related hypotheses (see ISO 18400-203:2018, Annex A) which the investigation process examines through the collection of relevant data.

NOTE 4 An ISO Standard providing general guidance on how to develop an appropriate conceptual site model is planned. Guidance relating to particular objectives or site types is given in the relevant standards.

4.5 Preliminary risk assessment

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

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

NOTE Guidance on carrying out a formal risk assessment is outside the scope of this document (see also ISO 18400-203). Risk assessment covers:

- a) identification of contaminants, pathways and receptors;
- b) estimation of the likelihood, nature and extent of exposure to a hazard, and the risk of adverse effects;
- c) assessment of the likely pollutant linkages and the degree of risk;
- d) evaluation of the need for controlling the identified risk.

Site investigation provides baseline information for stage a) of the process.

5 Sampling strategies — General aspects

5.1 Sampling objectives

The sampling strategy, which forms the basis for the sampling plan (see ISO 18400-101), defines what samples are to be taken and where they are to be taken from. Before the soil sampling strategy is developed:

- a preliminary investigation should be carried out in accordance with ISO 18400-202;
- an initial conceptual site model should be developed, see [4.4](#);
- any safety and environmental issues ([5.9](#)) or other factors ([5.10](#)) that might constrain the way that the sampling is carried out should be identified;
- clear and appropriate objectives set.

Sampling objectives should be developed from the site investigation “objectives” (see [4.1](#)) taking into account which of the principal situations defined in [5.4](#) apply to the site, whether any of the characteristic distribution of properties described in [5.6](#) is believed likely to be present, and any applicable regulations or guidance.

The objectives should include statements regarding what information is required including:

- whether information about spatial distribution of soil properties is required (see [5.6](#));
- whether information about average properties is required (see [6.3](#) and [7.3](#));
- what properties and characteristics are of interest;
- what aspects of variability are of interest;
- what “scale of sampling” is required (see [Annex D](#) and [Annex E](#)).

When intending to determine the average properties, the area, volume or feature for which the average is required should be carefully defined taking into account the purpose of the overall investigation. When the results of the investigation become available, the appropriateness of calculating an average for the previously defined entity should be carefully reviewed.

NOTE 1 It might, for example, be decided that the objective is to determine the average value of a property in the surface soil in a field. However, the investigation can show that there are two distinct soil types present and it is, therefore, more appropriate to calculate separate averages for the two soil types (this is of course not possible if only composite samples covering the whole field have been taken, see [6.4.5](#) and [7.3](#)).

NOTE 2 There might be occasions when determination of other population parameters might be required.

There may be several reasons why information is required especially on a potentially contaminated site where it may be necessary, for example, to obtain analytical and other data to aid assessment of risks to human health and the environment, to assess materials for waste disposal and to comply with requirements in relation to the health and safety of construction workers. It is likely to be more economical if single samples, or at least a set of samples, can be taken to serve all purposes in a single operation. However, care should be taken not to compromise achievement of the different objectives for sampling.

5.2 Scope of the sampling strategy

The sampling objectives usually determine which type of sampling strategy is adequate and how reliable the sampling should be. When there is only an indirect relation between sampling objectives and sampling strategy, the programme manager has to define the quality and type of sampling explicitly.

Depending on the sampling objectives, the sampling strategy should define specific operational elements that will subsequently form the basis of the sampling plan (see ISO 18400-101) including:

- the soil to be sampled (the population), [this might, for example, be the site, a zone, horizon or above-ground deposit (e.g. stockpile)];
- whether the whole of the soil is to be sampled or whether there are particular fractions (e.g. based on size or appearance) that are relevant for the objectives of the investigation including whether selective sampling is required (see [6.4.6](#));
- the components to be determined and/or tests to be carried out on the samples;
- the statistical parameters to be determined (e.g. mean concentration, degree of heterogeneity, percentile);
- likely measurement uncertainty arising from different sampling approaches, see [5.8](#);
- the type of sampling (e.g. judgemental, systematic or composite, see [6.2.2](#) and [6.2.3](#));
- type(s) of sample to be taken, see [6.4](#);
- the density of sampling (e.g. distances between sampling points);
- sampling locations including sampling pattern;
- depth of sampling;
- size of sample(s), see [6.6](#);
- number of samples to be taken at each sampling point or over each area in the case of composite sampling, see [6.5](#) and [Clause 7](#);
- definition of the desired level of uncertainty (i.e. bias and precision, see [A.5.2](#), [A.5.3](#)) and confidence required (see also [Annex C](#));
- phasing and staging of the investigation (see [Clause 4](#)).

It is important to recognize that there could be a variety of constraints on the works that can be carried out that should be taken into account when transposing the ideal sampling strategy into a sampling plan. For example, access, ground stability, the safety of those doing the work and the general public, and potential impacts on the environment while the works are in progress or at a later date (see [5.9](#) and [5.10](#)).

NOTE Decisions on how the samples are to be obtained usually form part of the development of the sampling plan. However, the person developing the sampling strategy might wish to include preferences regarding the techniques to be used. Guidance on the techniques that can be used to obtain samples and their application is provided in ISO 18400-102.

5.3 Designing the sampling strategy

The designer of the soil sampling exercise should have an understanding of how the information that is to be gathered is to be used including any statistical analyses that are likely to be employed (see [5.6](#)), of the factors that can contribute to sampling errors and uncertainty (see [5.7](#)) and what would constitute a sufficiently representative sample in the context of the investigation (see [5.5](#)).

The sampling strategy should take into account:

- the objectives of the investigation;
- the possibility of zoning the site (see [4.2](#));
- the conceptual site model developed to date (see [4.4](#));
- site-specific factors, (for example, the site size and topography, physical obstructions);

- the location of buried services, etc.;
- the need to avoid creating routes for migration of either gas or (contaminated) groundwater;
- protection of health and safety and the environment (see 5.9 and ISO 18400-103);
- temporal effects and the significance of such effects on the results of the investigation;
- locations and extent of any proposed buildings and infrastructure;
- off-site considerations;
- how data and other information used to inform risk assessment are to be analysed and presented so as to aid understanding of the data.

5.4 Principal sampling situations

The sampling strategy and the statistical methods to be used should take into account which of the following two sampling situations is applicable to the site or zone that is to be sampled:

- a) sampling is required at the ground surface and/or in the ground beneath the surface, i.e. in-ground sampling;
- b) sampling is required of materials that have been deposited on the ground surface, i.e. above-ground sampling.

NOTE 1 Ground is used here to mean all materials below the ground surface, including natural materials and anthropogenic materials (i.e. materials resulting from human activity). The ground surface might be formed by natural *in situ* materials or anthropogenic deposits in the form of (engineered) fill or “made ground”.

For each of these sampling situations, decisions should also be made whether information is required about:

- spatial distribution of soil properties;
- average properties.

Thus, there are four principal sampling situations that might be encountered as shown in Table 2.

Table 2 — Principal sampling situations

	In-ground sampling	Above-ground sampling
Spatial distribution	I In-ground sampling to determine spatial distribution of properties	III Above-ground sampling to determine spatial distribution of properties
Average properties	II In-ground sampling to determine average properties	IV Above-ground sampling to determine average properties

NOTE “Spatial distribution” is used here with a general, geographical meaning: the arrangement or pattern of areas where a soil property has large values (e.g. exceeds a threshold), or the arrangement or pattern of contaminated areas (see also 5.6).

Whatever the principal sampling situation, a decision should be made about how to address the variability of soil properties, taking into account the guidance in 5.6 about scale, etc. and 5.8 about sampling uncertainty.

When in-ground sampling is to be carried out, it is almost always possible to form exploratory holes in the surface in order to investigate the ground beneath. Obviously, not all sites are flat and the ground could be sloping, uneven, or in places of low bearing capacity; and access to all parts of the site might be difficult for a variety of reasons. Nevertheless, it is possible to envisage placing a two-dimensional pattern across the site and then sampling at varying depths at each sampling location. The extent

intervals for sampling will typically be much less than the spacing between the nodes of the sampling pattern (see [B.1.3](#) and [B.12](#)).

In contrast, the starting point for sampling a stockpile or other above-ground deposit is to assume that the main interest is in average properties and that an equant three-dimensional sampling pattern is required. In practice, this will often be difficult to achieve for a variety of reasons (see [Clause 9](#)) and a pragmatic approach to sampling based on the expert judgment will often be required (see [B.12](#)). One of the major difficulties is that stockpiles and similar deposits are usually unconsolidated and thus unstable.

Engineered deposits such as rail and road embankments present other problems. Although there could be a level surface, this will often be occupied by a road or railway limiting access except when absolutely essential. Sampling on the sloping sides is then likely to be required. This presents considerable practical and safety issues, will often require the use of specialist and expensive equipment, and thus also require expert judgement about how and where to sample.

Some natural deposits (e.g. landslips, recent deposits of volcanic ash, scree slopes) can have similar characteristics to anthropogenic deposits in that they are generally unconsolidated and unstable, and are often underlain by sloping ground, e.g. landslips. The investigator will have to decide how best to approach such ground taking into account the information that is being sought and the paramount need for safety.

NOTE 2 Type a) sampling situations where in-ground sampling of soil materials is to be carried out include, for example, agricultural or silvicultural soils, potentially contaminated sites and landfilled materials (see Note 4).

NOTE 3 Type b) sampling situations include, for example, embankments, waste dumps, and stockpiles of such materials as wastes, processed soils, manufactured soils and excavated materials.

NOTE 4 In industrial and other urban sites, the soil is seldom the original undisturbed soil: the soil might have been “disturbed” during building and other works, buildings might have been demolished and the waste spread around, the soil surface might have been smoothed with a bulldozer. Consequently, the soil material can be very heterogeneous. A dump from a mine or from steel works will usually have been formed over a number of years (sometimes decades) with a variable composition of the waste (some are now mined as true ore bodies). In both cases, the present soil results from these transformations and its properties can be studied as depending on the *x, y, z* coordinates. In contrast, a truck load or a temporary stockpile of loose material deposited on the surface of an otherwise level site has to be approached in a different way.

NOTE 5 Investigations to determine spatial distribution of properties can also provide information on average properties (see [6.3](#) and [Clause 7](#)).

5.5 Representative and sufficiently representative samples

Soils (and other soil materials) are composed of a mixture of mineral particles, organic matter, water, air (soil gas) and living organisms (see Note 2 in [4.1](#)). As the soil as a whole cannot be analysed, soil samples are taken and investigated as representative of the whole soil. The assumption that the results of these investigations on samples represent the total soil volume of interest is always an approximation, the reliability of which depends on additional information about the soil, the site and use of an appropriate sampling strategy. In other words, the sampling strategy should guarantee that, together with additional information (on site observations, background information, previous investigation results, etc.), the results for the samples analysed allow estimation of relevant properties of the total soil volume under investigation (or that part of interest) to a sufficiently reliable degree, in accordance with the sampling objectives.

Whatever the purpose of the investigation, a sound conceptual site model should be developed, which when spatial variability of soil properties (including contamination) is of particular interest, should include what is known, or believed to be, the processes that led to the anticipated spatial distribution of properties. The sampling strategy, especially when average properties are of interest, should be based on statistical methods, as far as practical and appropriate.

5.6 Characteristics of the spatial distribution

Soil materials are inherently variable in composition. A key element of sampling programme design is an understanding of the main components of variability in the soil being sampled (the population).

Two distinctive types of variability can be distinguished:

- at very small scale, that of soil particles, i.e. fundamental variability;
- at large scales, i.e. spatial variability.

NOTE 1 Scale is an important concept, as heterogeneity is a scale-dependent characteristic: soil properties show less heterogeneity with large-scale measurements than with small-scale measurements. Two scales of sampling are usually considered: the scale of the sample and the scale of the assessment. These rarely coincide. A discussion about the scale of sampling is provided in [Annex E](#).

NOTE 2 One cause of spatial variability can be temporal variability in the nature and composition of the soil or soil materials making up the soil volume (population that is to be sampled). Examples of when this might be the case include:

- when materials have been deposited in stockpiles over a period of time;
- when materials have been deposited on the ground surface by spreading or end tipping over a period of time;
- when there have been a number of flooding events;
- when there have been a number of land slips or similar events.

When temporal effects are expected based on the process wherein the stockpile or other deposit was formed, these effects should be accounted for in the assumptions on the spatial variability.

NOTE 3 Fundamental variability and spatial variability are discussed in detail in [Annex A](#).

NOTE 4 Spatial variability usually occurs at all scales from that of sample increments to that of large volumes or even the whole site of interest.

NOTE 5 How a substance or particular material is distributed within a soil is of particular importance. For example:

- a contaminant (e.g. cadmium) might be concentrated in the finer fractions of a soil which form a reasonably constant portion of the soil. In this case, the analytical result obtained will be similar whether just a few hundred grams are taken to form a sample or whether many kilograms are taken, i.e. it is comparatively easy to obtain a representative sample; or
- the contaminant might be concentrated in slag particles, of say about 10 mm diameter distributed unevenly through the soil. In this case, if the laboratory sample is too small, it might not include any of the slag particles, or unless it is realized in advance that cadmium might be present in this way, the >10 mm might be rejected as “stones” and of “no interest” by the laboratory unless instructed otherwise thus leading to a misleading analytical result. In this case, a particle size analysis and separate analysis of fractions might be the best approach. However, for meaningful results, it would be necessary to take large samples (how large would depend on the number of particles/m³); or
- the substance of concern might be present as discrete particles or fragments of material distributed unevenly through the soil, e.g. lead shot in areas where game birds are regularly hunted; fragments of asbestos-containing materials; asbestos fibres; or pieces of copper wire; plant roots.

In the third example there is usually no spatial relationship between the occurrence of one particle/fragment and another (e.g. there is no concentration gradient between them) although if it is known how they arrived in the soil it might sometimes be possible to predict areas where particles/fragments are more likely to be present.

Analogous to the third example is when there is combustible carbon present in a soil. Whether this is evenly distributed, or present in discrete lumps (e.g. fragments of coals or wood) the calorific value might be the same. However, the ignitability, combustibility and ability to sustain smouldering could be very different.

It is important to take into account that the substance of concern might:

- occur predominantly in solution in the pore water and that, consequently, care should be taken to capture and retain the water during sampling;
- be present as, or occur in, a non-aqueous phase;
- be concentrated in plant roots having been taken-up or adsorbed from the soil.

The anticipated variability at varying scales should be considered when developing the conceptual site model (see [4.4](#)) and the subsequent investigation should include among its objectives an aim to “disclose” this variability. Achieving this aim requires that samples are taken from sufficient sampling locations selected by application of an appropriate sampling pattern(s), taking enough samples at each location (see [6.5](#)) and taking samples of sufficient size (see also [6.6](#), [Annex B](#) and [Annex F](#)).

5.7 Statistical aspects

An understanding of certain basic statistical principles and concepts is essential for the design of sampling strategies and to the processing, presentation, analysis and assessment of the results of sampling exercises (see [6.1](#), [Annex A](#) and [Annex H](#) which describe basic statistical principles and concepts and their application in soil sampling programmes). Of particular importance is an understanding of such concepts as fundamental variability (see [A.3.3](#)) and spatial variability (see [A.3.4](#)).

5.8 Uncertainty of measurements caused by sampling and analysis

Overall uncertainties in the measurement results obtained during site investigations originate from a combination of measurement uncertainties arising from the laboratory procedures and those that arise from sampling and sample preparation prior to analysis or testing. The uncertainties arising from laboratory analytical procedures can be estimated and controlled, for example, by using a laboratory running appropriate quality assurance and quality control procedures (see ISO 18400-106).

The uncertainties associated with sampling tend to be much larger than those arising from analysis and testing and are more difficult to control and estimate. Depending on the heterogeneity of the site and the nature of the contamination or other property of interest, changing a sampling position by only 100 mm or so could in some cases have a marked effect on the result.

There are methods that can be applied when trial pitting, for example, that can be used to estimate sampling uncertainties (see [Annex C](#)). While it is an initial priority to have a sufficient number of sampling locations, it is also important to have an estimate of the sampling uncertainty, for example to decide whether cluster sampling might be employed in the detailed investigation, to reduce this uncertainty.

Uncertainties also arise because the process of sample preparation is not always well-controlled and varies between laboratories despite the existence of relevant International Standards intended to guide the process. For example, there can be differences in the size of material separated as “stones”, the methods of grinding and subsampling, and the fineness of the analytical sample.

Further uncertainties can arise from mistakes when samples are taken in the field (see [5.10](#)). These should be controlled by establishing standard working practices (see ISO 18400-106 and References [\[26\]](#) and [\[27\]](#)).

Because of these inherent measurement uncertainties, it is important not to treat laboratory measurements as “true” values, or to place undue reliance on single analytical results, and also that assessors employ their experience and professional judgement when interpreting data.

5.9 Safety and environmental protection

Sampling strategies should take into account the need to protect the health and safety of those carrying out the work and of the general public, and the need to avoid causing adverse environmental impacts during the works or at a later date (e.g. contamination of groundwater).

NOTE Guidance on the safety aspects of site investigation are provided in ISO 18400-103. Guidance on the selection of sampling techniques and their application taking into account health and safety and protection of the environment is provided in ISO 18400-102.

5.10 Barriers to sampling

It is not always possible to sample at a planned location (e.g. on a regular grid pattern) due to a variety of reasons (e.g. presence of a tree, large rock, building, buried foundations or services, difficulties of access). Contingency plans for dealing with such situations should be made in advance. The action to take depends on the circumstances. The investigator might 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 of 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.

Similarly, when judgemental sampling is being employed, site constraints might limit where samples can be taken from so that an element of “convenience” is often inevitable when selecting sampling locations. For example, safety zones around underground storage tanks will limit where holes can be drilled on a vehicle fuelling station so that the locations that have to be used might not be those that would give the highest probability of detecting a leak. However, the locations where drilling is to take place can still be pre-selected so this is not “true convenience sampling”.

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 (see ISO 18400-107).

Preliminary investigations as described in 4.3.2 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 intrusive investigations, 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 intrusive investigations, 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 (see ISO 18400-203:2018, Annex B).

5.11 Timing of investigations

In some circumstances, it could 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 or presence of nesting birds).

NOTE 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.

6 Sampling strategies — Key aspects and concepts

6.1 Statistics and geostatistics

6.1.1 General

NOTE [Clause 6](#) is primarily informative but there are some recommendations within some of the clauses (e.g. in [6.6](#)). It is included in the main text of this document because an understanding of certain key concepts is essential for the application of the guidance provided in [Clauses 7](#) to [9](#).

Statistical and geostatistical methods are used to characterize parameters of the variables of interest (e.g. contaminant concentrations) and the uncertainties in these parameters from the sample data. If the uncertainties are too large, these methods are also used to design further sampling in order to achieve objectives for parameters such as the concentration in a grid cell. This can also be done at an early sampling stage by reference to similar situations.

Both the spatial variability in concentration, and the measurement uncertainty of concentration caused by sampling and analysis, can be quantified as standard deviation (or its square, variance). The total variance can be sub-divided to identify its source (e.g. within- or between-sample) (see [Annex C](#)).

Neither statistical nor geostatistical methods can be used in the case of judgemental sampling (e.g. data specially located in areas assumed as likely to yield high contaminant concentrations) except in the context mentioned in [6.1.3](#) when judgemental sampling is used in combination with a regular pattern.

6.1.2 Statistics

Statistics of independent random variables offer techniques for estimating parameters of a statistical distribution and confidence intervals: mean value, standard deviation, probability not to exceed a given threshold, etc.

The approach is valid when the medium is so heterogeneous that there is no spatial structure. Another way to get independent samples is to use a random sampling pattern. This is, however, not a reason for doing so, because a stratified random pattern, as well as a regular grid, leads to more precise estimates.

NOTE Detailed information on statistical concepts is provided in [Annex A](#) and on their application in [Annex G](#).

6.1.3 Geostatistics

A preliminary to the application of geostatistics is the characterization of spatial and/or temporal variability with the variogram and other spatial exploratory analysis tools.

NOTE 1 Values at locations that are close together are more similar than those further apart. They depend upon one another in a statistical sense. This property, known as spatial dependence, is the basis for geostatistics or spatial statistics. In this approach, the similarity or dissimilarity of the values taken by the variable of interest at two different sample points is statistically represented by a function of their distance, the variogram.

A geostatistical approach can be used in most situations not covered by statistical formulae, if:

- the scale of interest does not coincide with the sample scale (e.g. the interest lies in properties of large cells whereas only spot samples are available);
- the concern is in local properties rather than global properties (e.g. the average value of a property in a given cell, or the probability that this average property exceeds a given limit);

- the sampling pattern is random or regular;

and also:

- when sampling points are (within certain limits) unevenly distributed provided that sampling is not systematically focused on specific areas such as locations where high concentrations are expected;

EXAMPLE 1 Declustering techniques enable the use of a combination of a regular pattern and of judgemental samples in areas where large concentrations are likely.

- auxiliary information is to be incorporated.

EXAMPLE 2 A qualitative property, or a secondary property linked with the property of interest and known at any location.

Although application of geostatistics is proven when certain criteria are met, it can be unhelpful if they are not. For example:

- the objectives of the site investigation should require spatial resolved estimates of concentration; if the requirement is simply for the estimation of the mean concentration of a site, the application of geostatistics is unlikely to be worth the extra cost;
- the site should be suitable in terms of size and complexity; if the site is small there could be issues with justifying the large numbers of sample required ($n > 100$ is desirable even if a spatial exploratory data analysis can be of interest with much less data), and if it is known to be made up of several areas of different materials, there might well not be broad trends of geochemical variation that will fit sufficiently well to a single variogram model. It will be necessary to study each area separately, with the risk that some of them do not have enough samples for a sound geostatistical approach.

The sampling strategy also has to be suitable, not only in ensuring the required total number of samples, but also in ensuring that their coverage of the site is even enough to not leave gaps where the interpolation of concentration values is highly uncertain. Probably the most important requirement is for sufficient expertise in the personnel undertaking the designing of the sampling plan and the subsequent geostatistical interpretation.

Many software packages purport to provide geostatistical interpretation of measurements made from site investigations, but in inexperienced hands, they can produce apparently convincing output that could have little basis in reality. These comments more generally apply to all interpolation methods and models aiming at predicting concentration estimates at unsampled locations. Whatever the characterization approach chosen to support remediation decisions, expertise in sampling design and experience in site characterization is obviously fundamental to their proper application.

NOTE 2 See [Annex H](#) for a detailed discussion of geostatistical methods for sampling design and evaluation of soil quality.

A series of geostatistical methods, named “kriging”, enable the calculation of optimal estimates (in a statistical sense) and of the property of interest at unsampled locations or over grid cells. It also provides confidence intervals. An alternative to kriging, called “conditional simulations”, is to generate fields that mimic the variations of detail of the real variable; they are used as substitutes for the unknown reality to evaluate, for example, contaminated volumes, pollutant mass, or the uncertainty of the cost of remediation. These methods offer the possibility of anticipating the gain in precision that will be obtained with supplementary samples, and thus to optimize the design of further sampling plans.

6.2 Approaches to sampling

6.2.1 General

There are two principal approaches to the determination of spatial distributions:

- judgemental sampling is based on already available information (prior knowledge) and expert judgement – although this can provide valuable results at reasonable efforts, these results cannot be considered as representative in a statistical sense;
- systematic sampling is based on statistical considerations and requires a predefined sampling pattern before starting the field work (a variety of sampling patterns is available depending upon the situation to be explored).

Sound practice is often to combine the two approaches.

NOTE The approaches to sampling described in [6.2.2](#) to [6.2.4](#) and their relationship to one another are illustrated in [Table 1](#).

6.2.2 Judgemental sampling

“Judgemental sampling”, sometimes called “targeted sampling” or “preferential sampling”, is where samples are collected taking into account what is known about the history and layout of a site or a zone within a site. It is the best approach for situations wherein a characteristic (e.g. concentration) of a constituent is to be determined at a specified location (e.g. a small area where spillage has occurred, for the delineation of the area or volume of soil affected). Other examples where judgemental sampling might be required include around underground storage tanks or pipelines where there might have been leaks, above ground storage tanks where there might have been spills, areas where raw materials or wastes have been stored and known deposits of wastes in the ground.

Judgemental sampling can be supplemented by systematic sampling (see [6.2.3](#)) in order to confirm that there are no other areas of contamination. This is particularly important for old industrial sites and other potentially contaminated sites whose history is not precisely known.

Within the sub-area of a site to be subjected to judgemental sampling it is still possible, and often sensible, to adopt a localized sampling pattern to ensure that the area in question is examined in its entirety and as far as possible the extent of the affected area or volume can be delineated.

The use of judgemental sampling in situations where the average characteristic is to be determined will nearly always result in samples being taken from a sub-population, which is substantially more restrictive than the whole population. But within that sub-population it is feasible that the sampling could be “systematic”, see [6.2.3](#). This means that provided that the sampling is indeed systematic for that sub-population, the results will still be representative for the part of the population sampled (within which the conditions for systematic sampling are met), though it still runs the risk of exhibiting a larger uncertainty for the whole population.

Judgemental sampling should not be confused with “convenience sampling” or “*ad hoc* sampling” which is undertaken on the basis of accessibility, expediency, cost, efficiency, or for other reasons not directly concerned with sampling parameters (see [6.2.4](#)). There is no way of assessing the uncertainty in any subsequent data that results from the sampling steps.

The uncertainty resulting from judgemental sampling is highly dependent on the quality of the background information, on which any expert judgement and ultimately the sampling plan, is based. This will be especially sensitive for new sampling scenarios where there is an absence of suitable information or validation results.

Over reliance on “prior knowledge” can lead to unjustified assumptions being made that parts of a site are not contaminated and need not therefore be sampled at high spatial density, hence the need often to combine systematic sampling with judgemental sampling and/or to target areas assumed to be uncontaminated.

6.2.3 Systematic sampling

Systematic sampling as defined in this document involves taking samples from predetermined random locations (random sampling) or non-random locations determined by use of sampling patterns.

Some systematic sampling patterns are regarded as “probabilistic”, i.e. they ensure that each particle or element in the population (e.g. *in situ* volume of soil or stockpile) has an equal chance of being part of the sample. This means it is easy to obtain a quantifiable level of reliability (or uncertainty in the estimated mean value and enables estimation of variability) of the results for the population being tested. However, non-probabilistic sampling patterns can also yield this information if the appropriate statistical methods are applied to the results.

The principle types of systematic sampling are:

- simple random;
- stratified random;
- regular sampling; and
- unaligned sampling.

Simple random sampling involves selecting locations randomly in the domain of interest (e.g. a field or other site) and independently of one another.

Stratified random sampling involves selection of each sampling point randomly within the cells of a regular sampling pattern.

Regular (systematic) sampling involves taking samples at the nodes of a regular pattern, such as a square, triangular or hexagonal grid.

Systematic unaligned sampling involves taking samples off-set in both a systematic and random way from the nodes of a regular grid (this improves the chances of locating an elongated area of atypical properties).

When a regular grid is employed the initial location from which the nodes of the grid are derived is selected at random.

Systematic sampling can be performed stepwise: if the results exhibit too high an uncertainty, it is possible to take additional random samples or to refine the grid, which will result in an improved measure of uncertainty, at an additional testing cost.

Systematic sampling can be supplemented by judgemental sampling at locations where high concentrations are suspected.

For the same sampling effort (i.e. a given number of samples), simple random sampling is always less efficient than stratified random sampling, which is itself usually less efficient than regular sampling [efficiency measured in terms of estimation variance of the concentration, and at locating a hot spot (see [8.2.3](#) and [Annex I](#))].

In terms of statistically efficient sampling, a regular equilateral triangular grid provides the best selection of sampling points. For a square grid with one node per unit area, the distance of a point to the nearest sampling point never exceeds 0,707 units of distance, i.e. the greater ease of use of the square grid is offset by the slightly greater area of un-sampled site

NOTE Further guidance on sampling patterns and their application is provided in [8.2](#) and [9.2](#) and [Annex B](#) and [Annex I](#).

6.2.4 Convenience sampling

Some investigations are carried out without predetermined sampling locations. There could, for example, be circumstances in which the application of either of the above two approaches is not possible

because, for example, access around a site is severely limited, so that samples can only be taken in limited areas which might not be those that are actually of most interest on the basis of the site history. For example, on a vehicle dismantling site, the areas of interest could be beneath stockpiled vehicles or there might be growing crops in a field that limit access during the season when the work is being carried out (see [5.11](#)). In such situations, only *convenience* sampling can be carried out. This should not be confused with the application of random distribution of sampling points, because persons usually cannot distribute sampling points randomly without preparation, i.e. they cannot ensure that at every point in the area, despite the position of the other sampling points, a sample will be obtained with equal probability.

When sampling is to be carried out without a predetermined plan, care should be taken that sampling is carried out by an appropriately experienced investigator.

6.3 Average properties

Average properties can be derived using composite samples or by averaging the results of investigations to determine spatial distributions. In both cases, it is essential to carefully define the area/zone/volume that is to be sampled and to understand what is being sampled. This can be particularly important when comparisons are to be made with published assessment criteria requiring consideration of, for example, upper and lower confidence limits (see [7.3.4](#)).

When composite sampling is employed, taking a number of independent samples and averaging the results can reduce uncertainty in the estimated mean value and enable estimation of variability.

If average concentrations and variability parameters are to be derived from sampling used to determine spatial distributions, it is essential to define very carefully the volume of soil for which the average is being calculated. While an average is always a valid parameter, its practical and theoretical usefulness will be limited if, for example it includes different soil types, sampling horizons, or zones with different contamination histories.

NOTE Further guidance on determination of average properties and associated variability is provided in [7.3](#), [A.5.4](#), and [Annexes E, F and H](#).

6.4 Types of samples

6.4.1 General

NOTE This subclause is mainly informative. Guidance on the choice of sample type(s) for particular applications is provided in [8.2](#) and [9.2](#).

6.4.2 Disturbed and undisturbed samples

Two basic types of samples are collected for the purposes of investigating soil and ground conditions:

- disturbed samples (ISO 11074:2015, 4.4.8), and
- undisturbed samples (ISO 11074:2015, 4.4.31).

Disturbed samples are suitable for most purposes, except for some physical measurements, analysis for volatile substances, and microbiological examinations for which undisturbed samples could be required. Disturbed samples may be taken as single spot samples ([6.4.3](#)), cluster samples ([6.4.4](#)) or as spatial composite samples ([6.4.5](#)) where this is appropriate for the objectives of the investigation.

Undisturbed samples are inherently spot samples, i.e. taken from a specific material at a specific location and depth, although the initial undisturbed field sample might sometimes be taken over a depth range or be of extended lateral extent (e.g. when a core is taken for later examination and subsampling in the laboratory).

6.4.3 Spot (single) samples

Spot samples are taken as a single increment or formed from a limited number of increments of material that lies in direct contact. If there is a space left un-sampled between the increments, the result will be a cluster sample (6.4.4), which is not a true spot sample.

Spot samples are required in cases when information about the distribution of a substance or other property over a defined area or with depth is required. They are essential for estimating the degree of heterogeneity of a population or to detect limits of anomalies. Information resulting from spot (single) samples will be quite precise in general. To characterize a population, a large number of spot samples might be necessary.

Judgemental sampling around known or suspected sources of contamination, hot spots, or other anomalous areas, also requires single samples.

6.4.4 Cluster samples

Cluster samples made up of a small number of increments are appropriate when sampling top-soils for contamination (a number of small samples are taken over a defined area such as 1 m²) or when using machines for excavating ground to obtain samples. In these latter circumstances, the samples should be formed by taking portions from locations within the bucket of excavated material. The use of cluster samples can reduce sampling uncertainties. This type of composite sampling is particularly appropriate when using trial pits, when surface samples (e.g. at depths of 0,0 m to 0,15 m) are being taken and when carrying out validation sampling of imported topsoil.

6.4.5 Spatial (composite) samples

6.4.5.1 Characteristics

Depending on the nature of the investigation, the defined sampling strategy and the objectives of the investigation, the use of spatial composite samples may be considered. In some situations the use of composite samples could result in dilution or loss of components, and hence the risk of not detecting contamination. However, composite samples can enhance the representativeness of the samples and may be considered in a number of specific situations. Composite samples may be produced in the field by combining increments from not identical locations or spot samples or subsamples of spot samples (in general the larger the number of increments, the more reliable the average result will be in case of more homogeneously distributed properties). Alternatively, individual samples can be combined and thoroughly mixed in the laboratory.

Spatial composite samples are typically obtained by collecting a number of equally spaced increments of the same size, following a prescribed pattern, over a sampling area. These samples are bulked together to form the composite sample. This sample represents the mean quality of the area sampled. Composite sampling is often used where a sample is required to evaluate soil quality for agricultural purposes or for waste characterization of a stockpile. They can sometimes be used when investigating contaminated sites but only under very carefully defined conditions (see 6.4.5.3, Note 2).

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.

Composite samples deliver, per se, averaged information with no information on variability, or sampling uncertainty (unless the composite sampling is replicated).

The use of composite samples could be of assistance in situations where there could be a large degree of variation of composition over a short-scale, but where on a larger-scale the distribution might be

considered to be homogeneous, for example, where ash or slag is mixed with soil. In this instance, composite samples might give much more representative analytical results.

Whether the composite samples are formed in the field or in the laboratory, only increments from within the same soil stratum should be combined.

NOTE 1 Combining samples/increments that come from different soil layers would result in a loss of information, and only combining neighbouring samples/increments will also ensure that any large-scale spatial variation in concentrations in the plane of the soil layers will be detected.

NOTE 2 There are various forms of composite sampling, mainly characterized by the size of the area from which the incremental samples that make up the composite are taken. This could vary, for example, between a few square metres and thousands of square metres. Cluster samples (see 6.4.4) are taken over a very small area (e.g. 1 m²) and are used as an alternative to spot samples.

6.4.5.2 Advantages, disadvantages, limitations

Composite samples are often used to reduce the number of analyses required.

Information resulting from composite samples can neither reflect extreme values nor local variations or gradients. If the number of increments is too high, anomalies can become obscured.

6.4.5.3 Recommendations for application

Composite samples are typically used to characterize a population in total. But care should be taken if the results are intended to be considered representative. The increments also should be taken representatively according to a uniform approach and combined proportionally. Convenience or judgemental subsamples will not result in a representative composite sample.

Composite samples are not appropriate in all cases and the property of interest 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 appropriate pre-treatment of the composite samples (e.g. thorough mixing) is of vital importance to ensure that representative results are obtained.

While the combination of a number of individual samples into a “composite sample” for analysis can increase the chance that widespread contamination will be detected, it is also possible that the mixing process will dilute a hot spot 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.

Care should also be taken to avoid the combination of increments from different populations, subpopulations or soil strata.

NOTE 1 If, when taking an incremental sample out of a sampling device (e.g. a probe or an auger), this is done conveniently by selecting the loose material, the results could be heavily biased and will not be representative.

NOTE 2 Views differ as to whether spatial composite samples are suitable for the investigation of contaminated sites. In some countries, contaminated sites are usually only investigated using spot samples or cluster samples. However, in other jurisdictions (e.g. the Netherlands, see Reference [28] and in some circumstances in the USA, see Reference [29]), a form of composite sampling is either required by regulations or advised in formal guidance, especially when contamination levels are being compared with guideline values.

NOTE 3 Composite sampling can be unsuitable for the investigation of potentially contaminated land because of the:

- difficulty of comparing resultant data with guideline concentrations that relate to spot samples;
- possibility of disguising isolated locations of high concentration by mixing with samples of lower concentration;
- possibility of loss of volatile compounds during the compositing processes;

- difficulty of achieving an adequately mixed and representative sample;
- difficulty undertaking statistical analysis of composited data.

NOTE 4 Examples of the application of composite samples for sampling stockpiles for a number of different purposes is provided in [Annexes E](#) and [F](#). The principles outlined are also applicable to *in situ* volumes of soil.

NOTE 5 The ability to form reliable composite samples depends upon the soil type, for example, it might not be possible to form composite samples from a clayey soil.

6.4.6 Selective samples

Selective samples are prepared by selecting materials on the basis of particle sizes, colour or some other readily discernible property. Two methods for selective subsampling, which can be applied in the field or laboratory, are described in ISO 18400-201:

- sieving (this should not be carried out when VOCs requiring analysis are present);
- hand picking.

Both methods can be applied, independent of whether the interest is in the fraction with the smaller or the larger particles. Hand picking can also be applied when other distinctive features of the material are a basis for the selection (e.g. colour, type of material).

Sieving is preferred when the mass ratio between the fraction with the larger particles and the fraction with the smaller particles of interest is small but is only possible when the material is suitably dry.

NOTE 1 With a small mass ratio between the two fractions, the amount of work for handpicking will be larger and the probability of missing particles will be higher.

NOTE 2 Selective subsampling per definition will result in a highly biased subsample and can only be allowed when indeed such a subsample is sought. This can for example be the case when there is an expected significant difference between the larger and smaller particles or elements in the sampled material, or, when apart from soil material, there are also bricks or other man-made materials present in the sampled material, that it has been decided need not be analysed or need to be analysed separately.

6.5 Number of samples

6.5.1 General

NOTE See also [Clause 7](#), [8.6](#) and [9.6](#).

The total number of samples required in any sampling exercise will depend on a number of factors. In the case of an in-ground investigation in which spot or cluster samples are to be taken it will depend on the number of sampling locations (see below); the depths from which samples are taken at each location ([8.4](#), [9.4](#)); and whether one or more sample is taken from each sampling point ([6.5.2](#)).

When composite sampling is to be carried out, the total number of samples will depend on the number of zones into which the site is divided ([7.3.2](#)) and whether one or more sample is taken from each zone.

The number of sampling locations required when systematic sampling is employed will depend on sampling pattern used and the spacing between sampling locations (sampling density). As described in [Clause 7](#) there are variety of factors governing the density of sampling required (e.g. a need to find a hot-spot of a particular size if it exists) and the total number of samples required to enable a statistically sound estimate, for example, of average properties (see also [6.3](#)). Whether geostatistics are to be used will also have an influence (see [5.7](#) and [Annex H](#)).

[Clause 7](#) also provides guidance on a number of situations when sampling is required for particular purposes [e.g. classification of materials for disposal as waste ([7.5.2](#))].

When judgemental sampling is employed, the number of sampling locations required will, by definition, be a matter of expert judgement but important factors include:

- the number and size of features to be targeted,
- the need (or otherwise trying) to delineate a feature (as noted in [6.6.2](#), this can be aided by using a localized sampling pattern),
- the need to have information on non-target areas.

NOTE Illustrative examples of the numbers of samples required under particular circumstances can be found in [Annexes D, E, H and I](#).

6.5.2 Number of samples at discrete sampling points

It might be necessary to take more than one sample from a discrete sampling point to:

- aid estimation of measurement uncertainty, and its sources (see [5.8](#) and [Annex C](#));
- provide samples of more than one type to satisfy testing requirements (e.g. disturbed and undisturbed samples);
- provide samples of different size for test purposes;
- provide samples for different analytical and test regimes as required by the laboratories (see Note 1);
- provide duplicate samples for quality assurance purposes (see ISO 18400-106).

The practicality of providing near-equivalent samples will be constrained by the technique used to obtain them (see ISO 18400-102), the particle sizes (maximum and distribution), and the nature of the soil (e.g. clayey, granular, organic-rich).

NOTE 1 Often, laboratories carrying out the chemical analyses will require more than one sample from a location with those for different tests being of an appropriate size and placed in an appropriate container (e.g. plastic tub, glass jar, vial) rather than a single large sample that can be sub-divided or subsampled in the laboratory.

NOTE 2 There are obvious practical difficulties obtaining several equivalent samples, for example, when the material to be sampled is in the form of a 50 mm diameter core.

NOTE 3 Duplicate samples can be taken a small distance apart to show the effect of small-scale heterogeneity (see [Annex C](#)).

6.5.3 Number of cluster samples

It can be desirable to take more than one cluster sample from a proportion (e.g. 10 %) of the sampling points within an investigation, in order to estimate the uncertainty in the measurement results (see [Annex C](#)).

6.5.4 Number of composite samples

It can be desirable to take more than one composite sample from the area, zone or above-ground deposit under investigation in order to reduce uncertainty in the analytical and other results and/or to split the area, zone or deposit to be investigated into a number of sub-zones (see [Annexes C](#) and [G](#)). The latter will aid identification of any variation of average properties across the area, zone or deposit that might need further more detailed investigation.

NOTE 1 See also [Clause 7](#).

NOTE 2 Examples of the application of composite sampling including the choice of the number of samples to take are provided in [Annexes E](#) and [G](#).

6.6 Sample sizes

6.6.1 General

A number of factors govern the size of the samples sent to off-site laboratories including:

- a) the range of pedological, chemical, physical and or biological examinations and tests that are to be carried out;
- b) the specific requirements of the laboratory/laboratories carrying out the examinations and tests; and
- c) the need for samples to be sufficiently representative (i.e. acceptable level of sampling uncertainty), taking into account the particle size distribution and the concentration distribution of the material to be sampled.

NOTE 1 More samples than required for the testing suite envisaged are usually taken, in case additional analysis or tests are decided on, in response to site observations and initial results.

Points a) and b) will usually be defined by following an established procedure and/or discussion with the laboratory/laboratories.

Point c) requires that

- 1) the sampling equipment enables the largest particles to be included in the samples or increments, and
- 2) the sample size is large enough for fundamental variability to be acceptably small.

The degree to which it is necessary to take account of the increment and sample size will very much depend on the type of material sampled.

The relationship between particle size distribution and the size of sample or increment required to obtain reliable analytical results is amenable to theoretical determination for a granular material in which the properties of interest are inherent within the particles. The guidance provided in [Annex F](#) is applicable when the property of concern is associated only with the dry particulate matter in the material being sampled. It is not applicable if the substance of interest is present as a non-aqueous phase or is dissolved in the non-aqueous phase. It is also not applicable when dealing with an inherently complex material such as soil which might contain solid particles of several types, water, biota, contaminants adhering to particles and even non-aqueous phase liquids.

In these more complex cases, the person designing the sampling exercise should, in consultation with the laboratory undertaking the planned testing, make a judgement about the minimum sample size required (see [6.6.2](#)). Note, however, that such a specification will usually be based on assumptions about the character of the material to be sampled. The sampler should adjust the sample size to take account of observations in the field (or the results of an earlier Exploratory Investigation, including information about excessive sampling uncertainty).

In general:

- the smaller the sample taken, the more difficult it will be to ensure that the sample is sufficiently representative;
- when the sample to be sent to the laboratory is composed of a number of increments (i.e. is a composite sample), each increment should be of sufficient size to be representative of the material at the particular location from which it was taken;
- where the sample is of coarse-grained material, for example, gravels, a larger sample is required (see Note 1 to [6.6.2](#) for grain size definitions);
- when the contaminant or characteristic of interest is present only in a small proportion of the particles, a larger sample is required;

- the greater the range of particle sizes, the more difficult it can be to obtain a sufficiently representative sample, because of the tendency for segregation of different particle sizes during sampling and subsequent handling;
- if a larger volume is taken as a spot sample which then is homogenized and reduced in volume the investigation result will achieve a more average character — there is a transition to cluster sampling from the informational point of view.

While it is important that the sample taken from the ground is sufficiently representative, it is also important that the fraction of the sample actually analysed or tested is that which is of concern in relation to the objective of the investigation. For example, in human health risk assessment it will be the finest fractions that are of concern as only these are likely to be ingested, inhaled, or adhere to the skin. Segregation of the fractions of interest is best done in the laboratory but a degree of selectivity in the field can sometimes be appropriate (i.e. a “selective sample” might be taken by design). Some sampling techniques can only provide samples of restricted size and/or are not good at capturing larger particle sizes. Notwithstanding the desirability for samples sent to the laboratory to be truly representative, the persons designing and carrying out investigations, might need to decide that the samples that can be practically obtained are “fit for purpose” or at least “good enough” in the context of the investigation and/or that any deficiencies in the quality of the sample will not compromise the decisions that will in due course have to be made (e.g. sampling uncertainty is at a level that is “fit for purpose”, see Reference [30]).

Even when a theoretical determination of minimum increment and sample size is available, it does not consider all components of sampling uncertainty (e.g. the uncertainty due to pretreatment in the field or in the laboratory, and the analytical uncertainty). In any case sample duplicates should be taken to enable estimation of the total sampling uncertainty resulting from the increment and sample sizes actually used and in order to decide whether they are fit-for-purpose for the detailed investigation (see [Annex C](#)).

NOTE 2 Liquids: The minimum increment and sample size have no specific relevance to the sampling plan design for liquids as the potential differences are at a molecular scale when compared to the size of the samples. The sample size is, in practice, governed by the quantity of material required by the laboratory for analysis, whereas the increment size is determined largely by the dimensions of the sampling equipment.

NOTE 3 Powders and sludges: Powders and sludges are basically particulate materials with a (very) small particle size; sludges also contain a substantial amount of liquid.

6.6.2 Practical considerations

The minimum sample size required in any particular case might be:

- the theoretical minimum to encompass expected variability at the scale of interest (see [6.6.1](#) and [Annex F](#)); or
- as dictated by other considerations (see [6.6.1](#) and below), whichever is the greater.

A minimum sample size of 500 g to 1 000 g will often be required (this applies both to single samples and composite samples, in the latter case after sufficient homogenization). The sampler should adjust the sample size to take account of observations in the field (or the results of an earlier Exploratory Investigation, including information about excessive sampling uncertainty). When spatial composite (or cluster) samples are to be prepared:

- the minimum increment should be of sufficient size to yield the required minimum sample size when the increments are combined; if this is not the case, either the size of the individual increments should be increased or the number of increments increased (or a combination of the two);
- the individual increments or samples to be combined should be of equal size (± 25 %, mass fraction);
- the number of increments in each composite sample should be specified in the sampling plan; in most cases, the number of increments should be the same for all composite samples within the sampling programme — this simplifies statistical analysis.

For practical reasons, the minimum size for an increment taken in the field should be 200 g.

The sampling equipment being used, and the depth of layers of materials of different character, will influence the size of sample that can be taken. For example if a 50 mm core is taken, and the layer of interest is only 100 mm thick, all that material is likely to be required to form a sample, the mass of which might be less than otherwise considered desirable. This can be considered acceptable if this situation is not common. Otherwise cores with a larger diameter should be used.

Often the size of sampling equipment is such that more soil material is obtained than needed. Sample pretreatment is then required “in the field” in order to reduce the amount of material to be transported to the laboratory, while keeping it sufficiently representative. Guidance on pretreatment in the field is provided in ISO 18400-201.

In addition to the above, the following should be taken into account when deciding on the practical sample size(s) required:

- **Volume versus mass:** the minimum sample size, potentially, can be defined as a volume or as a mass. However, as the volume per mass ratio can vary significantly, a volume-based minimum sample size is more variable than a mass-based minimum sample size, and thus the latter should be used as a basis.
- **Boulders and other large material:** some soils (partly) contain (very) large boulders and other large material (see Note and [Table 3](#) for named size classifications). If these were considered as part of the sample, this would result in extremely large samples, both in the field and for the material to be transferred to the laboratory. However, often only the smaller soil fraction is of interest, and therefore, these larger materials can be neglected both during sampling and sample pretreatment. Whenever such a situation is encountered, the sampling plan should clearly define the material that is to be sampled. It should be noted, to what extent boulders and other large materials contribute to the total volume of the material to be sampled.
- **Small particle sizes:** for small particle sizes, the minimum size of the sample can be very small, which is particularly relevant for subsampling in the laboratory in order to obtain the analytical sample.
- **Laboratory samples:** for practical reasons, the maximum size of the samples to be sent to the laboratory should not be larger than approximately 20 kg to 30 kg. When larger samples are needed, because of the large particle size, the particle size should be reduced following the procedures described in ISO 18400-201 and ISO 11464 as appropriate. As particle size reduction is (in principle) only allowed under laboratory conditions, for these situations either a mobile laboratory or on-site laboratory is needed.
- **Integrity of sampling:** sample division into a number of representative subsamples can only be carried out in the field when the integrity of the sample and subsamples can be ensured. To ensure this effectively a sheltered area is necessary in most situations. Without adequate shelter, weather conditions like wind and rain can pose a serious threat to the quality of the samples (see ISO 18400-201).
- **Compounds to be analysed/tested:** the compounds to be analysed in the (sub)sample(s), or the test to be carried out, will in some cases affect the possibilities or methods of subsampling [e.g. a requirement to determine volatile organic compounds (VOCs) precludes oven drying, size reduction and sample splitting — subsamples are taken from the “as received” sample].
- **Laboratory provided containers:** analytical laboratories often provide the containers they want to use. For example: 400 ml to 600 ml plastic tubs for material to be dried and pretreated in the laboratory prior to analysis, for example for heavy metals, etc.: 250 ml glass jars for materials on which semi-volatile organic compounds (SVOCs) are to be determined without drying or other pretreatment and 70 ml glass jars for materials on which volatile organic compounds (VOCs) are to be determined without drying or other pretreatment. The assumption is that the material in each container is representative of the same portion of material in the field which is only likely to be true within limits. For example, the diameter of a 70 ml glass jar is only about 40 mm so that it is probable that coarser material will unavoidably be excluded from the sample. The mass of fine dried

sand that can be held by a 70 ml glass is about 100 g (i.e. a bulk density of about 1,4 g/ml) which is less than the 500 g minimum recommended above.

NOTE ISO 14688-1 establishes the basic principles for the identification and classification of soils on the basis of those material and mass characteristics most commonly used for soils for engineering purposes. ISO 14688-1 is applicable to natural soils *in situ*, similar man-made materials *in situ* and soils redeposited by man. Named particle groups are defined in [Table 3](#).

Table 3 — Defined particle size ranges

Name	Size mm	Name	Size mm
Large boulder	>630	Coarse sand	0,63 – 2,0
Boulder	200 – 630	Medium sand	0,2 – 0,63
Cobble	63 – 200	Fine sand	0,063 – 0,2
Coarse gravel	20 – 63	Coarse silt	0,02 – 0,063
Medium gravel	6,3 – 20	Medium silt	0,006 3 – 0,02
Fine gravel	2,0 – 6,3	Fine silt	0,002 – 0,006 3

7 Deciding how many samples to take

7.1 General

The number of samples that should be taken in any particular situation, whether these are to be spot samples, cluster samples or spatial composite samples should take into account:

- the purpose of the sampling exercise;
- the sampling objectives;
- prior knowledge or assumptions about the heterogeneity of the population (e.g. volume of soil) to be sampled; and
- the confidence required in the results and conclusions to be drawn from the results.

In all cases:

- the volume(s) of soil of interest (the “population” or “sub-populations” in statistical terms) should be carefully defined;
- any prior knowledge should be taken into account.

NOTE Attention is given to any specific requirements, such as how to decide if a prescribed limit is exceeded or has not been reached.

It is rare that site investigations are carried out without any knowledge about the site in question, indeed the purpose of the preliminary investigation ([4.3.2](#)) is to acquire information that can be used to develop a preliminary conceptual site model ([4.4](#)) and the sampling plan.

Available information is used to aid decisions about what, where and how to sample, and what substances and properties should be measured. By staging investigations, knowledge about what is, or is not present (and often variability), can be established to inform the design of subsequent stages of investigation and to improve the efficiency of the overall investigation (e.g. by reducing the total number of investigation points required or to enhance the value of information gained from each sampling point).

It can sometimes be possible to adopt a Bayesian approach to the design of a sampling plan. However, this should only be done with care and on the basis of expert advice (see [B.1.2](#)).

7.2 Basic situations

There are three basic situations.

- a) It is beneficial to know the average concentration and in some instances to know whether this is above or below a particular value (e.g. guideline value for human health risk). This might be required in respect of, for example, human health risk assessment, ecological risk assessment, waste disposal, pesticide residues, nutrient status, etc. The scale can be from a small hot spot (a few m²), garden (say 25 m²), field or larger area. Spatial composite samples (but how many?) or spot samples (e.g. taken randomly or on a regular grid) could be used. Guidance can be dimensionless (i.e. applied irrespective of the area of interest), but also needs to be concrete in terms of sites of a specified size. All this requires an understanding of variability.

NOTE 1 Some examples of when it might be necessary to determine average concentrations are provided in [Annex D](#). [Annex E](#) discusses the “scale of sampling” required both to determine average concentrations reliably and to understand variability within the target volume of soil. The examples in both Annexes refer to stockpiles but the same principles can be applied to determination of the quality of soil in a field or to a volume of *in situ* soil.

- b) It is necessary to locate a hot spot (or hot spots) or other area of interest (e.g. on a development site, the one garden in a hundred planned gardens that might be above a guideline value). Having found the area of interest (e.g. one high result in a hundred) it becomes a case of how to delineate and characterize the hot spot or area of interest. Delineation requires spot sampling using an appropriate sampling pattern, although the average concentration within the hot spot or variation within the hot spot might be of interest, depending on the objectives of the investigation.

NOTE 2 There might be role for judgemental/targeted sampling if the planned layout of the houses is known, e.g. by taking one or more samples from each proposed garden area.

- c) It is necessary to say which, if any, of the potential hypotheses in ISO 18400-203:2018, Annex A is true, i.e.:
- hypothesis of a “probably uncontaminated” site or zone;
 - hypothesis of a “probably contaminated” site;
 - hypotheses relating to spatial distribution of contamination:
 - 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.

NOTE 3 ISO 18400-203:2018, Annex A presents these as hypotheses to be addressed in the sampling strategy, but that carries with it an implicit requirement to say once the investigation has been carried out whether the preferred hypothesis has been proven and if so with what confidence.

7.3 Determining average concentrations

7.3.1 General

[Annex G](#) provides statistical expressions for estimating the mean of a population, its standard deviation, a percentile at the scale of the samples, and a percentage compliance with a given limit, as well as methods for calculating the uncertainty associated with these estimates.