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Water quality — Sampling —

Part 11:
Guidance on sampling of groundwaters

Qualité de l'eau — Échantillonnage —

Partie 11: Lignes directrices pour l'échantillonnage des eaux souterraines

Reference number
ISO 5667-11:2009(E)

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Foreword

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

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

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

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 5667-11 was prepared by Technical Committee ISO/TC 147, *Water quality*, Subcommittee SC 6, *Sampling (general methods)*.

This second edition cancels and replaces the first edition (ISO 5667-11:1993) and ISO 5667-18:2001, which have been technically revised.

ISO 5667 consists of the following parts, under the general title *Water quality — Sampling*:

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

— *Part 3: Guidance on the preservation and handling of water samples*

— *Part 4: Guidance on sampling from lakes, natural and man-made*

— *Part 5: Guidance on sampling of drinking water from treatment works and piped distribution systems*

— *Part 6: Guidance on sampling of rivers and streams*

— *Part 7: Guidance on sampling of water and steam in boiler plants*

— *Part 8: Guidance on the sampling of wet deposition*

— *Part 9: Guidance on sampling from marine waters*

— *Part 10: Guidance on sampling of waste waters*

— *Part 11: Guidance on sampling of groundwaters*

— *Part 12: Guidance on sampling of bottom sediments*

— *Part 13: Guidance on sampling of sludges from sewage and water treatment works*

— *Part 14: Guidance on quality assurance of environmental water sampling and handling*

— *Part 15: Guidance on preservation and handling of sludge and sediment samples*

- *Part 16: Guidance on biotesting of samples*
- *Part 17: Guidance on sampling of suspended sediments*
- *Part 19: Guidance on sampling of marine sediments*
- *Part 20: Guidance on the use of sampling data for decision making — Compliance with thresholds and classification systems*
- *Part 21: Guidance on sampling of drinking water distributed by tankers or means other than distribution pipes*
- *Part 22: Guidance on design and installation of groundwater sample points*
- *Part 23: Determination of significant pollutants in surface waters using passive sampling*

This part of ISO 5667 should be read in conjunction with other parts, in particular ISO 5667-1 and ISO 5667-3.

Introduction

This part of ISO 5667 is a revision of both ISO 5667-11:1993, *Guidance on sampling of groundwaters* and ISO 5667-18:2001, *Guidance on sampling of groundwater at contaminated sites*.

The guidance in this part of ISO 5667 can be used in parallel with other guidance on water quality sampling and/or investigation of contaminated or potentially contaminated sites, as any groundwater sampling from such sites is likely to form part of a much wider investigation programme.

Development of a groundwater sampling programme depends on the purposes of the investigation. A definition of the purpose of groundwater sampling is an essential prerequisite for identifying the principles to be applied to a particular sampling problem.

The principles set out in this part of ISO 5667 can be used to satisfy the following more detailed objectives:

a) to determine the suitability of groundwater as a source of drinking water or industrial/agricultural water;

b) to identify, at an early stage, contamination of aquifers caused by potentially hazardous surface or sub-surface activities (e.g. the operation of waste disposal sites, land contamination, industrial developments, mineral exploitation, agricultural practices, changes in land use) and its potential to impact on surface waters and other potential receptors in the vicinity of the site;

c) to establish whether migration of contaminants is occurring in order to assess the impact on groundwater quality and to calibrate and validate suitable groundwater quality models;

d) to develop an understanding of groundwater quality and flow variations, including those caused by deliberate actions (e.g. variations in groundwater pumping regimes, groundwater recharge caused by effluent, surface clean-up activities arising from contaminated sites), in order to achieve optimal resource management, provide data for undertaking risk assessment and to enable enforcement of pollution-control law;

e) to assist in the selection of remedial measures and remediation process design, and monitor the performance and effectiveness of these measures or facility design;

f) to demonstrate compliance with licence conditions, or collect evidence for regulatory purposes;

g) to identify and characterise discrete aquifer water bodies.

Examples of situations where this guidance can be used include:

- general surveys of groundwater quality for chemical and microbiological assessment;
- investigation of present or former industrial sites with a history of potentially contaminatory activities;
- groundwater investigation and monitoring of waste disposal (landfill) sites;
- investigation of sites where natural and/or artificial processes have led to potential land and groundwater contamination;
- investigation of sites where products have been spilled or released as a result of accidents or other unforeseen events, e.g. transportation accidents.

The guidance contained in this part of ISO 5667 covers selection of sampling points, selection of sampling installations and devices, groundwater parameter selection and sampling frequency.

Prescriptive guidance on methods and applications is not possible. Therefore, this guidance provides information on the most commonly applied, and available, techniques and lists their advantages, disadvantages and limitations of use where these are known. When considering design of sampling strategies, the properties of the groundwater (aquifer) system, monitoring point design, contaminant source(s), pathways for migration and the receptors need to be considered.

INTERNATIONAL STANDARD **ISO 5667-11:2009(E)**

Water quality — Sampling —

Part 11:
Guidance on sampling of groundwaters

1 Scope

This part of ISO 5667 provides guidance on the sampling of groundwaters. It informs the user of the necessary considerations when planning and undertaking groundwater sampling to survey the quality of groundwater supply, to detect and assess groundwater contamination and to assist in groundwater resource management, protection and remediation. This part of ISO 5667 does not apply to sampling related to the day-to-day operational control of groundwater abstractions for potable purposes. The guidance includes sampling of groundwater from both the saturated (below water table) zone and the unsaturated (above the water table) zone.

2 Normative references

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

ISO 772, *Hydrometry — Vocabulary and symbols*

ISO 5667-1:2006, *Water quality — Sampling — Part 1: Guidance on the design of sampling programmes and sampling techniques*

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

ISO 5667-14, *Water quality — Sampling — Part 14: Guidance on quality assurance of environmental water sampling and handling*

ISO 6107-2, *Water quality — Vocabulary — Part 2*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 6107-2, ISO 772 and the following apply.

3.1
piezometer
device consisting of a tube or pipe with a porous element or perforated section (surrounded by a filter) on the lower part (piezometer tip), which is installed and sealed into the ground at an appropriate level within the saturated zone for the purposes of water level measurement, hydraulic pressure measurement and/or groundwater sampling

NOTE Adapted from ISO 6107-2:2006.

3.2
nested piezometers
bundled piezometer installation

group of piezometers installed to different depths within a single larger diameter borehole

NOTE 1 In general, each piezometer should be designed to allow sampling over a specific depth interval within the aquifer. Piezometer tips are isolated from each other by installing a permanent impermeable seal between them.

NOTE 2 Adapted from ISO 6107-2:2006.

3.3
multiple boreholes
group of individual boreholes or piezometers installed to different depths separately, but in close proximity, to form a monitoring network adequate for the purposes of an investigation

NOTE Adapted from ISO 6107-2:2006.

3.4
multi-level sampler
single installation for sampling groundwater from discrete depths or depth intervals within the sub-surface

NOTE 1 The device can be installed directly into the ground or into a pre-existing, or purpose-drilled, borehole. When installed into a borehole, integral packers (or similar sealing devices) are used to isolate the individual horizons within the groundwater system that are to be sampled.

NOTE 2 Adapted from ISO 6107-2:2006.

3.5
aquifer
geological water-bearing formation (bed or stratum) of permeable rock, or unconsolidated material (e.g. sand and gravels) capable of yielding significant quantities of water

NOTE Adapted from ISO 6107-3:1993[4].

3.6
consolidated aquifer
aquifer comprising material which is compact due to cementation or compression

3.7
saturated zone
part of an aquifer in which the pore spaces of the formation are completely filled with water

[ISO 6107-2:2006]

3.8
unsaturated zone
part of an aquifer in which the pore spaces of the formation are not totally filled with water

[ISO 6107-2:2006]

3.9
groundwater
water in the saturated zone and/or unsaturated zone of an underground geological formation or artificial deposit such as made ground, e.g. fill material

3.10
perched groundwater
isolated body of groundwater, which is limited in lateral and vertical extent, located within the unsaturated zone overlying a much more extensive groundwater body and isolated above by a discontinuous poorly permeable surface (discontinuous aquitard)

NOTE Adapted from ISO 6107-2:2006, “perched water table”.

3.11
receptor
entity (human, animal, water, vegetation, building services, etc.) that is vulnerable to the adverse effect(s) of a hazardous substance or agent

NOTE Adapted from ISO 6107-2:2006.

3.12
packer
device or material that inflates or expands for temporarily isolating specified vertical sections within boreholes to allow groundwater sampling from discrete zones or locations within the borehole or aquifer

NOTE Adapted from ISO 6107-2:2006.

3.13
field capacity
maximum amount of water that a soil or rock can retain after gravitational water has drained away

NOTE Adapted from ISO 6107-2:2006.

3.14
dense non-aqueous phase liquids
DNAPLs
organic compounds that have very low water solubility and a density greater than that of water

EXAMPLE Chlorinated hydrocarbons such as trichloroethane.

NOTE 1 Adapted from ISO 6107-2:2006.

NOTE 2 When present in sufficient quantities, DNAPLs form a separate phase from the water.

3.15
light non-aqueous phase liquids
LNAPLs
organic compounds that have very low water solubility and a density less than that of water

EXAMPLE Petroleum products.

NOTE 1 Adapted from ISO 6107-2:2006.

NOTE 2 When present in sufficient quantities, LNAPLs form a separate phase from the water.

3.16
well
borehole
⟨groundwater sampling⟩ hole sunk into the ground, either by drilling (boring) or digging, to obtain groundwater or for observation purposes

NOTE This definition differs from the one given in both ISO 772:— and ISO 6707-1:2004[3].

3.17
spring
groundwater emerging naturally through the surface of the land

[ISO 6107-3:1993[4]]

3.18
pore water
water that fills the pores or cavities within a body of rock or soil

3.19
casing
tubular retaining structure, which is installed in a drilled borehole or excavated well, to maintain the borehole opening

[ISO 772:—]

NOTE In the context of groundwater sampling, "maintain the borehole opening" means the prevention of the ingress of solid aquifer material into the borehole or control of groundwater entry to the borehole at specific depths via a (well) screen. The structure can be temporary or permanent.

4 Sampling strategy and programme design

4.1 General

Groundwater sampling can be carried out as a single exercise, as part of a larger site or environmental investigation, or as part of a regional/national programme. Regardless of the purpose, a rational approach should be taken that clearly defines the objectives, determines the level of information needed, and identifies the various stages of the investigation. Consideration should also be given to practical constraints such as site access, infrastructure, and the distance between the site and analytical laboratories.

It should be noted that, normally, groundwater sampling from the saturated zone alone cannot fully assess the level of contamination in the subsurface in situations where an unsaturated zone of considerable thickness exists. The potential consequence of ignoring the unsaturated zone is that the unsaturated zone and groundwater system could become extensively contaminated before any tangible evidence of leakage or contamination is evident in samples collected from below the water table.

4.2 Selection of sampling point location

4.2.1 General

The location of monitoring installations, the design of the network, and the selection of monitoring points for investigating groundwater quality should take account of:

a) the hydrogeological setting of the investigation site;

b) the past and future use(s) of the site;

c) the purpose of the exercise;

d) the anticipated or known groundwater quality;

e) the nature and extent of any likely contamination.

All of these factors should be considered during the preliminary stages of the monitoring programme to enable the most appropriate and effective sampling strategy to be implemented. This information can be obtained by examining all available information held by site owners (or their agents), local, regional and national regulatory agencies and other data holders. Table 1 provides an overview of the steps involved in planning an investigation strategy and for sampling groundwater.

When using existing monitoring points to obtain and gain access to groundwater, it is necessary to determine borehole constructional details and characteristics to define from which strata the sample is being obtained. When new boreholes are being constructed specifically for sampling, the design of the borehole (e.g. the open area and length) and the method of construction need to be chosen, not only to meet the sampling requirement, but also to minimise contamination or disturbance of the aquifer.

4.2.2 Surveillance of groundwater quality for potable supply

When monitoring the quality of groundwater for potable supply use, boreholes, wells and springs that are sampled should be monitored for those parameters that are relevant to the use of the water. Where appropriate, national raw water sampling and monitoring requirements should be referred to for more detailed advice. When selecting sampling points for water supply surveillance, it is recommended that some boreholes remote from the abstraction are also monitored, in order to examine the effect of the abstraction on the dynamic characteristics of the aquifer (e.g. the natural groundwater flow, the variation in thickness of the saturated zone).

4.2.3 Point source contamination of groundwater

To establish the extent of groundwater contamination and the direction and rate of contaminant migration, monitoring points should be located inside and outside any contaminated area(s). Monitoring points outside the contaminant source area should be located in positions up gradient and down gradient of the sites with respect to the hydraulic gradient as a minimum. A greater number of sample points should be positioned down gradient, both inside and outside of any contaminant plume.

Where analysis indicates that complex geology underlies the site or that contaminants with a broad range of physical and chemical properties are likely to be present, increase the number of monitoring points to adequately characterise the contaminant distribution in three dimensions. In addition to investigating the lateral variation caused by heterogeneity, the sampling strategy should also be designed to investigate any vertical variations.

Care should be taken when identifying the prevailing flow regime as localised recharge to the subsurface can alter the regional hydraulic gradient. This can result in groundwater flow and contaminant transportation in a direction that is contrary to flow imposed by the regional gradient. Dense non-aqueous phase liquids (DNAPLs) can also move in a different direction and at a different rate to that of groundwater because their chemical and physical properties are different to those of water (density effects). Their migration is also affected by the geological structure of the low permeability layer underlying the saturated aquifer.

Light non-aqueous phase liquids (LNAPLs) also have different chemical properties to those of water. Their migration and distribution are affected by the geological structure, chemical interactions within the unsaturated zone and zone of water table fluctuation, as well as partitioning between aqueous and gaseous phases.

Where sampling is aimed at providing an early warning of the impact of contaminants on receptors, monitoring points should be located between the contaminant source (and plume) and the potential receptors as well as within the zone of contamination. For example, at landfill sites, monitoring points should be established around the outside of, but close to, the landfill at appropriate depths.

Sample points within the zone of contamination and outside (both up and down hydraulic gradient) should be installed to measure performance and effectiveness of remediation, for demonstrating compliance to licence conditions and to determine the quality of groundwater flowing into the area of investigation.

Table 1 — Procedural steps for sampling groundwater (adapted from Reference [13])

Step (with reference to other parts of ISO 5667)	Procedure		Essential elements	Notes
Investigation/monitoring strategy (ISO 5667-1)	Collation of available data ↓ Desk study ↓ Develop conceptual model ↓		Identify data sources	Geological, geochemical and hydrogeological characterisation
	Reconnaissance survey ↓		Design borehole/sampling point network and sampling programme	See 4.2, 4.3 and 4.4
Facility installation/selection	Assessment/selection of existing monitoring points ↓ Installation of monitoring points by drilling ↓ Borehole/well cleaning and development		Borehole design, material selection and installation technique	See Clause 5 See 6.1
Borehole/well inspection	Hydrologic measurements ↓		Water level measurements Hydraulic testing	Hydrogeological characterisation
Borehole/well purging	Removal or isolation of stagnant water ↓ Determination of purging parameters (e.g. EC, pH, temperature, redox potential)		Representative groundwater Verification of representative groundwater	See 6.1 See 6.2
Sample collection Filtration Field determinations (ISO 5667-1, ISO 5667-3, this part of ISO 5667)	**Unfiltered sample** Organics (all) Alkalinity/pH Dissolved gases Sensitive inorganic species, e.g. nitrite, ammonium Tracer metals for mobile (colloidal) loads Microbiological agents	**Field filtered sample** Dissolved trace metals for specific geochemical information Sulfide and other sensitive inorganics, e.g. iron(II) Major ions	Sample collection by appropriate mechanism Field determination of sensitive parameters, pH, electrical conductivity, temperature, redox potential, dissolved oxygen as appropriate Head-space free samples Minimal aeration or de-pressurisation Minimal air contact Sample preservation	See 5.2 and 5.3 See 6.4 and 6.5 Blanks and spiked samples should be prepared in accordance with ISO 5667-14
Storage and transport of samples (ISO 5667-3)			Minimal loss of sample integrity prior to analysis	See Clauses 7, 8 and 9

4.2.4 Diffuse contamination of groundwater

When designing monitoring networks to identify extensive diffuse-source pollution of aquifers, the use of existing sampling points in the form of large capacity production boreholes is recommended, as they can provide integrated samples from a large volume of the aquifer. However, in some cases of localised or low-intensity pollution, the use of this type of borehole can dilute the contamination to levels below the analytical detection limit: in these cases, smaller capacity pumped boreholes are recommended. The part of the aquifer which is most sensitive to pollution is that nearest the boundary between the saturated and unsaturated zones. At least one of the sampling boreholes should therefore have a screen near to the surface of the saturated zone. Other purpose-drilled boreholes should be completed and screened over different depth intervals of the aquifer. Sampling boreholes should be located throughout the area of interest. It is recommended that sites be chosen to represent the different hydrogeological and land-use conditions and areas considered to be particularly vulnerable to diffuse pollution.

4.3 Groundwater parameter selection

The parameters selected for analysis should reflect the nature of the investigation and/or the former, current, and proposed future use of the site. In some cases, certain parameters and/or contaminants will be the subject of national regulations. Focusing only on these, however, could be inadequate for providing the complete picture of groundwater quality under different geochemical and hydrogeological conditions. For example, where organic contaminants are susceptible to degradation, the list of analytes should also include the degradation products, which in some cases can also be hazardous. An example of this is the degradation of trichloroethylene (TCE), a DNAPL. One of its potential degradation products is vinyl chloride, a relatively soluble and highly volatile organic compound (VOC).

Consideration should also be given to baseline or natural groundwater quality and its variation. Elevated concentrations can already be present in the environment being investigated as a result of natural sources of contamination.

4.4 Sampling frequency

The analytical results from sampling need to provide estimates of the required information within the tolerable errors defined by the objectives of the monitoring programme. For example, if the investigation is designed to map an established contaminant plume, a single event sampling exercise can be adequate. In this case, sampling should be completed as rapidly as possible to minimise the effects of temporal variation. Where the development of a plume is to be monitored and/or the impacts on groundwater resources considered, the frequency should be based on the prevailing hydrogeological and environmental conditions, the objectives of the study and the contaminants present.

Where monitoring is required to provide early warning, where there are compliance issues or for performance assessment of remedial measures, in general, a recommended minimum sampling frequency is quarterly for most chemical constituents (e.g. major ions) and monthly for those that are more mobile and reactive (e.g. VOCs and dissolved gases). More sophisticated methods for determining sampling frequencies are available and an example is provided in Annex A. This example, adapted from Reference [12], considers the prevailing hydrogeological conditions — hydraulic gradient, hydraulic conductivity, effective porosity and the effects of dispersion — to estimate a sampling frequency. Where contaminants are subject to retardation or other processes, the sampling frequencies will need to be adjusted to take these into account as appropriate.

For quality surveillance of potable supplies including mineral waters (or any other use-related monitoring activity), the temporal variation in quality at a single point is the most important factor. For most determinands, monthly or even less frequent sampling will normally be adequate when the purpose of sampling is to assess the suitability of groundwater as a source of drinking water. More frequent sampling over a longer time period, e.g. 1 year, might be required to minimise any public health risks in situations where groundwater is used for potable supplies without disinfection.

Where environmental conditions indicate that changes in groundwater quality can occur more rapidly, for example in karst groundwater systems, more frequent sampling should be carried out. In these cases, the exact frequency should be determined by examination of all influencing natural and artificial factors. Examples of short-term influencing factors include tidal influences and localised rainfall events as well as ground disturbance caused by ground engineering activities. Seasonal and more frequent variations in weather and climate can influence the rate of infiltration of contaminants through the unsaturated zone. A rise in water table can also lead to the release (or re-release) of contaminants into the groundwater and/or bring the contaminant source closer to the groundwater.

Continuous monitoring of pH, temperature and electrical conductivity (EC) can provide a useful means of identifying the need to increase or decrease the sampling frequency for determinands that are to be characterised by sampling. If continuous monitoring indicates that the rate of quality changes is increasing, the sampling frequency should be increased for any determinands of interest. Conversely, if the rate of change decreases, or stops, the sampling frequency can be reduced.

In cases where there has been a considerable change in quality of any continuously monitored determinand, it is advisable to consider also extending the range of determinands to be routinely analysed, as a precaution.

Continuous monitoring is also a useful means of identifying the most appropriate time to sample pumped observation boreholes which are being used to obtain representative samples of aquifer water. Where significant variations are recorded [i.e. ±10 %, in terms of concentration (mass per volume) within the pumped discharge], this probably indicates local transient conditions within the borehole itself during the early stages of pumping, and samples should not be collected until the monitoring suggests that an equilibrium has been reached. If no significant quality variations occur, the sample can be collected after the borehole has been completely purged.

5 Types of monitoring installation and sampling method

5.1 General

Installations suitable for groundwater monitoring typically involve placement (or use) of access tubes for portable sampling devices or burial of sensors or samplers *in situ*. These installations can be positioned within the saturated zone (below the water table) or above it (unsaturated zone). In addition to sampling groundwater, installations below the water table can be used to measure water levels; installations above the water table can measure free-phase LNAPLs, soil gas, and soil moisture content.

In order to achieve representative sampling, the sampling method needs to be capable of withdrawing samples whose composition reflects the actual spatial and temporal composition of the groundwater under study.

5.2 Unsaturated zone monitoring

5.2.1 Introduction

Sampling techniques that are used for collection of groundwater from the unsaturated zone can be divided into two types:

a) solid sampling followed by extraction of groundwater (pore fluids);

b) unsaturated pore-fluid sampling.

5.2.2 Extraction from solid samples

5.2.2.1 General

The extraction of pore fluids from solid samples is the most widely used method for sampling groundwater in the unsaturated zone. Collection of solid samples as part of this method can also allow useful geological information to be obtained. There are two broad categories of solid sampling methods: hand-operated and power-operated. Table 2 indicates a range of suitable techniques that can be used for extracting solid samples for pore fluid collection. Further guidance is given in ISO 10381-2[6].

The removal of solid samples from the ground is, however, a destructive form of sampling that, although necessary, does not allow subsequent re-sampling from the same location. It therefore precludes taking samples at a later date for analysis of trends.

Table 2 — A range of methods suitable for soil and rock sampling

Method		Soil /rock type	Maximum depth	Drilling fluid/flush [a]	Diameter range
Trial pitting	Hand powered	All soil types and unconsolidated rocks	Maximum 6 m (but generally to 4 m)	No	Depends on depth of pit and soil/rock type
Tube sampling	Hand powered	Soils, clay and fine grained unconsolidated geological materials	Approx. 10 m	No	25 mm to 75 mm
Auger	Hand powered (e.g. hollow stem)	Soils, clay and unconsolidated geological materials	Approx. 5 m	No	50 mm to 100 mm
		Soils, clay and unconsolidated geological materials	Approx. 30 m	No	75 mm to 300 mm
Cable tool (e.g. shell and auger drilling or light percussion drilling)		Soils, clay and unconsolidated geological materials	80 m to 90 m	No/Yes — water	150 mm to 300 mm
Rotary					
Direct and reverse rotary with flush		All types of geological materials and made ground	>100 m	Yes — Air, water, mud, foam, etc.	100 mm to 200 mm
Sonic		All types of geological materials and made ground	>100 m	No — uses high frequency vibration to fluidise cuttings	100 mm to 150 mm

[a] Drilling fluids are required to lift drill cuttings, support the borehole while drilling and lubricate and cool the drill bit. Use of techniques where drilling fluids are required can adversely affect sample quality.

5.2.2.2 Hand-operated samplers

These are typically tube-type or auger samplers. The tube samplers consist of a variable length rod with a hollow sample chamber (of variable length and diameter). It is hammered or vibrated into the ground to obtain a sample. Augers have cutting bits at their lower end and a sample chamber (open at top and bottom) directly above. The sampler is rotated into the ground by hand.

A variation on the simple tube sampler is the piston sampler. In piston samplers, a central piston inside the tube closes the tube until the sampler is at the required depth. The piston is then withdrawn to expose the sample tube and the device driven further into the ground until a sample is obtained.

5.2.2.3 Power-operated sampling rigs

Standard drilling techniques can be used for sampling the unsaturated zone. However, drill rigs such as cable tool and rotary units should not be used because of the need to use drilling fluids. Drilling fluids help to lift drill cuttings, support the borehole during drilling, and lubricate and cool the drill bit. The types of fluids include water, mud, foam and air. However, the introduction of these fluids into the ground and their circulation, often under high pressure, can potentially impact on the quality of the samples being collected or introduce extraneous contamination. The use of air flush drilling should also be avoided where determinands include VOCs and other sensitive chemicals. Large diameter samples collected using these techniques can be sub-sampled to minimise the problems of cross-contamination caused by drilling.

Solid and hollow stem augers can be used for sampling. For solid stem auger methods, samples are collected from the cuttings returned to the surface by the rotary action of the auger flights. This, however, can lead to problems of cross-contamination and sample mixing. For hollow stem methods, a central rod and cutting bit is removed from within the auger column and replaced with a thin-walled sampler for collection of a relatively undisturbed sample. Continuous-sampling tube samplers can also be used with hollow stem auger drilling for improved sample recovery.

Pore waters are then extracted from the recovered solid material by either centrifuging or mechanical squeezing as soon as possible after collection. The groundwater extract should be preserved in accordance with ISO 5667-3 before analysis.

5.2.3 Pore-liquid sampling

5.2.3.1 General

Two types of method can be used to extract pore liquid directly from the subsurface: percolate soil water samplers and vacuum soil water samplers. Both have advantages over solid sampling (see 5.2.2) in allowing sequential sampling from fixed locations in the unsaturated zone to determine trends. The choice of sampler depends on the objectives of the monitoring. Advantages and disadvantages of both types are shown in Table 3.

Table 3 — Advantages and disadvantages of pore liquid samplers

Sampler type	Advantages	Disadvantages
Vacuum samplers	• Can be installed up to a depth of 15 m • Relatively easy to install • Minimal ground disturbance required during installation • Multi-level installations are possible	• Excess pressure will damage samplers without check-valves • Porous cup can become clogged and/or adsorb chemical constituents • Redox/pH changes can alter chemistry • Vacuum/pressures required to extract sample can affect VOC sampling
Percolate soil water samplers	• Enables sampling of flow through macropores as well as interstitial water • Larger sample volumes possible • Less potential for volatilisation of organic compounds • No need for continuous vacuum	• Difficult to install. Not always possible in contaminated soils • Installation can alter natural flow • Less control over sample collection • Pan type samplers will only function when field capacity is exceeded • The use of a wick to draw water into the sampler can lead to chromatographic effects that can lead to collection of chemically unrepresentative groundwater samples

5.2.3.2 Vacuum samplers (lysimeters)

These samplers, installed in the ground, use a vacuum (applied at the surface) to draw porewater into the sample collector. They consist of a porous cup (or similar) on the end of a sampling tube that is installed into a borehole. In their simplest form, they have a limited maximum installation depth, but a number of modifications can be made to improve sampling and increase the depth range over which the samplers can be used. These modifications include incorporating a sampling device above the porous cup similar to that described in 5.3.2.4. The choice of material used in the porous part of the sampling device is important. Not all materials are suitable for all chemical parameters. For example for pesticides, porous glass is recommended, for metals and trace metals, porous plastic and for other inorganics, such as nitrate and sulfate, high purity ceramic.

5.2.3.3 Percolate soil water samplers

These samplers, which include pan and wick types, rely on gravity and/or capillary action to intercept both matrix water and water flowing along preferential pathways (e.g. fissures) in the unsaturated zone. Installation of the samplers requires excavation of a trench and tunnel and the installation of the sampler in the roof of the tunnel to intercept soil water. The sampler is constructed of a suitable non-porous inert material which can have a wick incorporated to draw water (which is under tension) into the sampler as well as intercepting its downward movement.

5.3 Saturated zone

5.3.1 General

Any structure that provides a means of reaching the saturated zone can be used for groundwater sampling purposes. The most commonly encountered means include supply boreholes, wells, and observation boreholes. Trial pits and trenches can also be deep enough to reach groundwater where the water table is close to ground level. In addition, discharging water at springs can be sampled.

While existing wells can provide background information, adequately characterise the groundwater quality of a pumped supply, and provide evidence that contamination of groundwater has occurred, they are unlikely to be adequate for characterising the source and extent of any contamination. It is likely, therefore, that additional monitoring installations will be required as part of a specific site investigation. Vertical stratification in groundwater quality can be natural or a consequence of pollution. For example, diffuse pollution usually results in a more polluted layer of groundwater at the top of the saturated aquifer, whereas pollutants that are more dense than water tend to accumulate above a less permeable layer at depth, or at the base of the aquifer. Sampling methods therefore need to be capable of detecting vertical as well as lateral variations in groundwater quality.

The method of sampling also needs to reflect the complexities of groundwater flow in that it should take account of the aquifer flow mechanism (whether fissure or intergranular), the direction of the flow and the hydraulic gradients in the aquifer, which can produce strong natural flows up or down the borehole column itself.

Where perched groundwater is to be sampled, the methods described in this clause are generally applicable. However, where shallow bodies of perched water are ephemeral, well sampling facilities should be combined with suction (unsaturated zone) sampling devices.

When installing monitoring facilities in locations where perched groundwater is present, the techniques used for investigation or installation of monitoring equipment should be chosen with care. To minimise the potential for introducing artificial migration pathways (see 6.5) deep, open, fully penetrating screened boreholes should not be installed.

The design of monitoring installations is also dependent on the nature of the groundwater investigation. Careful consideration should be given to the materials used in the construction of monitoring points to ensure that these do not contaminate or otherwise affect the samples being collected. Where free-phase contaminants such as DNAPLs and LNAPLs are present, the properties of these contaminants and their potential distribution within the groundwater system should also be considered during construction of monitoring points. For further information on monitoring point design and installation see ISO 5667-22[2].

5.3.2 Types of sampling equipment

5.3.2.1 General

Traditionally, two common sampling methods are employed, namely pumped sampling and depth sampling. Both have their uses and limitations, which need to be carefully considered when identifying the scope for their use.

A wide range of sampling devices is available for the sampling of groundwater from the saturated zone, including portable devices which can be rapidly installed, operated and removed, and permanent installations for dedicated sampling. The most commonly used systems are described in 5.3.2.2 to 5.3.2.9. A guide to their suitability for sampling different chemical parameters is provided in Table 4. Table 4 gives general guidance only and those methods indicated as suitable might not be appropriate for all chemical parameters and in all environments. The user should consider carefully the objectives of the study. In some cases it can be necessary to use more than one type of sampling device.

Table 4 — A guide to the suitability of sampling methods for different groundwater parameters

Sampling — device	**Groundwater parameters [✓ = suitable, (✓) = limited suitability, — = not generally suitable]**												
	EC	pH	Alkalinity	Redox (Eh)	Major ions	Trace metals	Nitrates	Dissolved gases	Non-volatile organic compounds	VOCs	TOC (total organic carbon)	TOX (total organic halogen)	Microbiological agents
Depth sampler — bailer (open)	✓	—	✓	—	✓	✓	✓	—	✓	—	✓	—	✓
Discrete depth sampler — bailer (closed) or shut-in-sampler	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Inertial pump	✓	✓	✓	✓	✓	✓	✓	—	✓	✓	✓	—	✓
Bladder pump	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Gas-drive pump	✓	—	—	—	✓	✓	✓	—	✓	—	—	—	—
Gas-lift pump	✓	—	—	—	✓	✓	✓	—	—	—	—	—	—
Submersible impeller pump [a]	✓	✓	(✓)	(✓)	✓	✓	✓	(✓)	✓	(✓)	(✓)	(✓)	(✓)
Suction (surface) pump	✓	—	✓	—	✓	✓	✓	—	✓	—	—	—	✓

NOTE This table is provided as a general guide only. The selection of an appropriate device depends on the objectives of the study, the performance and properties of the device, and the environmental conditions. Under certain conditions, a combination of sampling devices should be considered and some devices might not be appropriate for all parameters.

[a] Where a flow-regulated submersible impeller pump is used and operated at flow rates of less than two thirds of maximum pressure head (flow rate), then this sampling device may be suitable for all parameters.

Pumped samples from production boreholes used for potable or other supplies can comprise a mixture of water entering the open or screened length of the borehole from different depths. This sampling method is, therefore, only recommended where groundwater quality is vertically uniform or where a composite vertical sample of approximately average composition is all that is required, as might be the case when sampling water abstracted from a borehole for potable supply purposes. In these cases, depending on the well-head construction, the water sample should be collected at a point as close as possible to where the water reaches the surface if down-hole sampling is not possible. This is to minimise sample instability problems or geochemical changes.

The most effective methods of taking samples from an aquifer in which groundwater quality varies with depth are to sample specific aquifer horizons using specially constructed observation boreholes or, alternatively, to sample from sealed sections of boreholes. In the former, portable pumping equipment can be used to pump samples from a series of observation boreholes in relatively close proximity, each completed and screened to enable samples to be drawn from a different depth range of the aquifer. In the latter, samples are pumped from a sealed section of a borehole by means of a packer-pump assembly, thereby providing a means of obtaining a discrete sample of water within a specific depth range of the aquifer (see 4.2.4). This sampling method is only recommended for use in consolidated aquifers: it is not appropriate for use in boreholes completed with a screen and gravel pack.

5.3.2.2 Depth samplers

Depth samplers are designed to sample groundwater at a specific depth within the borehole or piezometer. They are available in a number of forms and are also commonly known as “grab samplers”, “spot samplers” or “bailers”.

The simplest device is a bottle or other sample container that is lowered down the borehole to below the water surface. The sample container is allowed to fill and is then withdrawn from the borehole. This method only allows samples of groundwater from the uppermost part of the saturated zone to be collected with any reliability. It should only be used in exceptional circumstances for sampling groundwater. Care should also be taken to avoid dislodging any material from the wall of the borehole to avoid sample contamination.

An alternative device is one that consists of a tube (or cylinder) equipped with a check-valve at the lower end. This device is lowered down the borehole to the required depth and then withdrawn with the sample. The action of lowering and raising operates the check-valve (open in downward travel and closed in upward travel) and enables a sample from the required depth to be collected, thereby allowing improved vertical resolution. More sophisticated samplers are equipped with valves at both ends to improve sample integrity. Instead of a check valve, these valves can be operated by electricity, gas pressure, vacuum or by mechanical messenger. For deeper boreholes, a powered winch can be used for lowering the device. Sampler size should be chosen to enable adequate sample volume and minimum disturbance of the borehole water. These sampling devices are also most suitable for sampling LNAPLs and DNAPLs.

Depth samples should never be collected from within the solid casing of a borehole, since the water cannot have originated at the depth at which the sampling device is activated and, under static conditions, can have altered in quality due to chemical or microbiological activity.

Within boreholes that have long, open or vertical, screened sections, depth sampling can only be of limited value because natural or induced vertical flows within the borehole can make the origin of the samples uncertain. Depth sampling is only suitable if the origins of the samples (in terms of the depths of water inflow into the borehole) are known. This can be achieved by determining the depths of water inflow to the borehole and flows within the borehole column from interpretation of downhole logs of temperature, conductivity and flow under pumping and static conditions.

Where it is necessary to purge boreholes (see 6.1) from which depth samples are to be taken, it is recommended that the borehole be gently pumped prior to sampling. It is not recommended to use an air-lift pumping device for purging operations, since this can bring about changes in the chemical equilibrium of the groundwater caused by the introduction of dissolved oxygen. It will also lead to volatilisation of any organic contaminants.

5.3.2.3 Inertial pumps

Inertial pumps consist of a continuous length of tube equipped with a non-return valve at the lower end. The tube is lowered down the borehole to the required depth and then operated by successively lifting and lowering the tube over a short distance (between 0,3 m and 0,5 m). The movement can be achieved manually or by a mechanical lifting device. The valve should always stay at least 500 mm under water to prevent mixing of water and air. In wells with sufficient water, the lowest level of the valve should be above the screened part of the well. This will prevent unnecessary movement of water in the screened part of the well with resulting higher turbidity. In boreholes or wells with a diameter greater than 100 mm, rigid pipe may be needed instead of rigid tubing to operate the pump.

During the lowering part of the "lift-lower" cycle, the non-return valve is opened and this allows water to enter the tube. The water is then lifted upwards during the lifting stage of the cycle. Successive cycles continue to lift the water upward to the surface. The volume of liquid lifted depends on the diameter of the sampler, the length of lift and the length of the submerged part of the tube. Although there is no theoretical limitation on the maximum depth from which a sample can be taken, practical limitations effectively restrict this method to lifting groundwater from a maximum of 60 m.

Inertial pumps are very simple in design and easy to assemble, and so are often installed as dedicated pumps or are used with single use polyethylene tubes. Inertial pumps vary in diameter, from less than 10 mm upwards, so can be used to purge and sample even the smallest diameter boreholes or piezometers.

5.3.2.4 Bladder pumps

A bladder pump comprises a sample chamber that has a check valve at its base (inlet), another check valve at the outlet and a gas-inflatable bladder inside. The pump is lowered to the required depth, and the bladder successively inflated and deflated using compressed gas. The action of inflation and deflation successively fills the sampler and lifts the sample towards the ground surface through a delivery hose. The cycle is continued until sufficient sample volume (or flow rate) is obtained. The pumps are available in a range of sizes and can be used for sampling piezometers with diameters as low as 18 mm.

5.3.2.5 Gas drive pumps

The gas drive pump is a variation of the bladder pump design. It should not be confused with gas-lift pumping described in 5.3.2.6. Gas drive pumps do not contain a bladder inside the sample chamber. Instead, the outlet tube extends (inside the sampler) to a point close to the lower end of the sampler and the gas inlet point is at the top. Sequential pressurisation and venting of the sample chamber allows water to be discharged to the surface and then the sampler re-filled. The cycle is continued until sufficient sample volume is obtained. The gas used should ideally be inert, e.g. nitrogen (oxygen "free").

A disadvantage of this method is that the volume and pressure of the drive gas is difficult to determine and often causes gas to be mixed with the sample. This may adversely affect the quality of sample and reduces the reliability of this sampling method.

This type of pump is well suited to sampling from narrow diameter monitoring points with very deep water levels.

5.3.2.6 Gas lift pumps

Gas lift pumps operate by the application of compressed gas (either air or some other non-reactive compressed gas) within the external case of the borehole. The pressure of the gas forces the sample to rise up an open ended tube that has been placed inside the borehole. At the lower end of the inserted tube, the gas mixes with water to provide a buoyant force to bring it to the surface. A number of disadvantages exist with this method:

a) the sample is often delivered to the surface as an aerosol (which can be hazardous);

b) the mixing of gas and water can adversely affect the quality of the sample (especially if VOCs are present);

c) the high pressures required can lead to equipment damage; and

d) the method can lead to gas being forced into the geological formation.

5.3.2.7 Submersible impeller pumps

A wide range of submersible pumps is available. This type of pump can be specified to lift water from great depths and achieve a wide-range of flow rates. More recently, smaller variable speed pumps have become available which can be used in boreholes down to 50 mm in diameter. These pumps are ideal for purging and sampling monitoring boreholes, and can operate at heads of up to 90 m under optimum conditions.

5.3.2.8 Surface pumps

These pumps are positioned at the surface and are generally suction-lift pumps. There are three main types available: surface impeller pumps, vacuum pumps and low flow/volume positive displacement (peristaltic) pumps.

A vacuum pump is operated by applying a vacuum to a sample bottle (or sample bottles connected in-line) which is in turn connected to the sample delivery tube in the borehole or well. Water can be lifted in this way from a maximum of 6 m to 8 m below the ground surface. The vacuum can cause significant degassing of VOCs and other chemical alterations of samples. This method of sampling is therefore not recommended.

Surface impeller pumps operate in a similar way to their submersible equivalents. However, they are generally not manufactured of materials that are sufficiently inert and in order to be operated they often require “priming”. There is therefore the potential for sample contamination and so this method of sampling is not recommended.

Low flow/volume positive displacement (peristaltic) pumps apply a short lasting vacuum directly to the sample delivery tubing running down into a monitoring borehole, piezometer or well. Priming is not needed as these pumps can pump both liquids and gases. Samples do not come into contact with air and the vacuum applied is only applicable during initial rising of the water in the sample delivery tubing. Greater lifts are possible with peristaltic pumps but the lift should be limited to 6 m to prevent the risk of significant degassing.

5.3.2.9 Other methods

Alternative methods for sampling are available which use modified versions of techniques previously described and additional equipment. An example, which facilitates point sampling, is the use of packers to isolate a zone(s) within an open borehole. One approach is to use two packers to isolate a section of the borehole and then use one of the previously described methods to extract samples. Where there is concern that cross-flow could occur, additional packers above and below those isolating the sample zone can be installed. Independent, simultaneous pumping from these zones at the time of sampling can minimise any cross-flow.

Another example is the design of multi-level samplers. Some allow instruments to be lowered down a central tube to extract sealed samples from discrete depths.

6 Sampling procedures

6.1 Purging

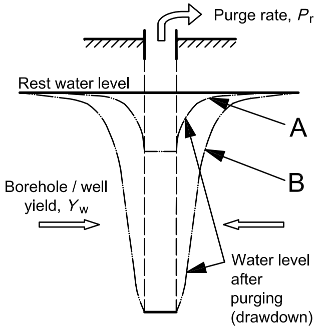
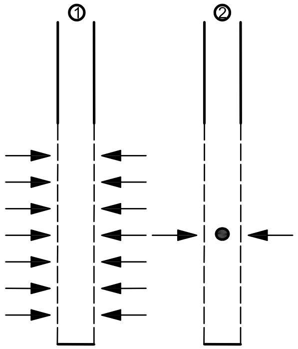
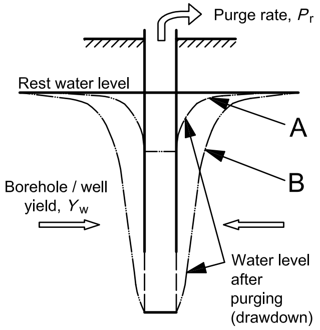
6.1.1 General

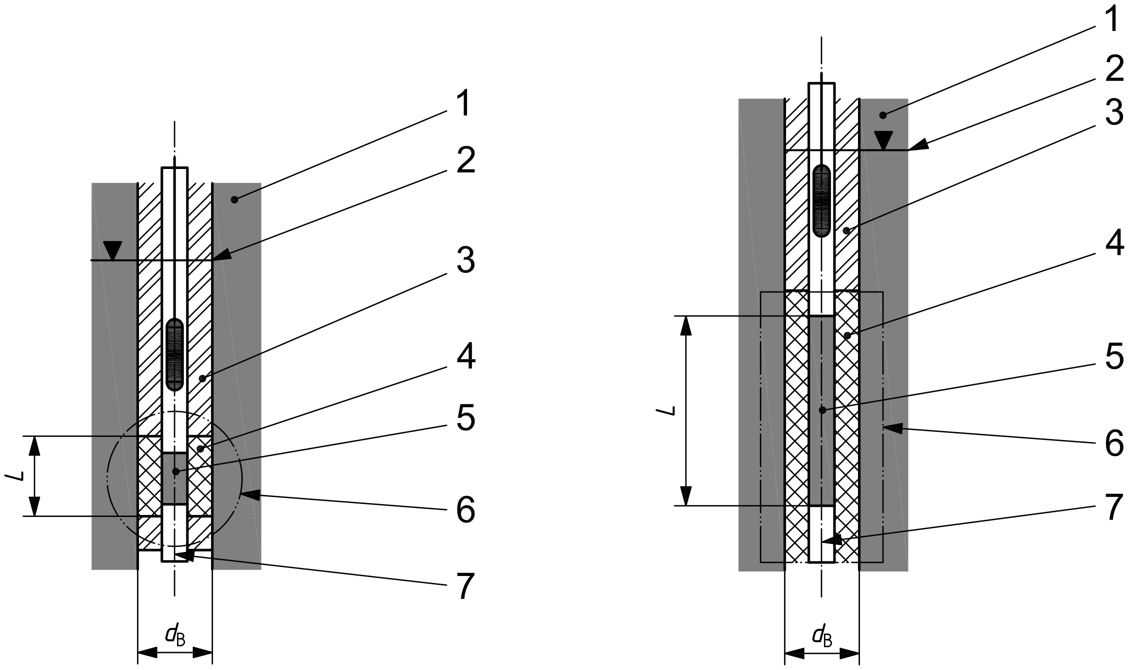
One of the most important aspects of sampling is to collect representative material. Water within a monitoring point that has not recently been purged can be unrepresentative of the groundwater in the surrounding strata for many reasons. The water can become trapped in the monitoring point and remain in contact with the walls of the installation for many months between sampling events. If the installation is open to the atmosphere, oxidation can occur and provide a pathway for VOCs to escape. Additionally, debris can collect in the sampling device.

Purging should therefore immediately precede any sampling of groundwater to remove the stagnant water from the installation. This is achieved by pumping a sufficient volume before a sample is taken. The purge volume will be dependent on the design of the monitoring point, e.g. the diameter and depth of the water column. The water level should therefore always be measured prior to purging.

Purging should be carried out at a flow rate less than that utilised for development of the well and greater than that proposed for sampling. The volume of water to be purged will vary depending on the monitoring point type, its construction and the hydrogeological conditions (well yield). Table 5 shows examples of borehole purging strategies for different situations. Depending on the conditions (see Table 5), the general recommendation is that where an integrated/composite sample is required, the purge volume should be at least three times the volume of water in the borehole. Figure 1 illustrates how purging volumes can be calculated.

Table 5 — Well purging strategies related to monitoring point design

Borehole design	Relationship of well yield, Y_w, and purge rate, P_r	Possible purging strategy to achieve sample objective		Notes/key
		Integrated/composite sample	Point/spot sample	SAMPLE OBJECTIVE
- Open-screened/unscreened boreholes - Water level below or close to top of screen  	A $Y_w > P_r$	❶ use of alternative strategies (e.g. ❷,❸,❹,❺,❻,❼) should be justified in comparative trials against ❶	❺,❻	
	B $Y_w < P_r$ **Key** 1 purged water, P_r 2 well yield 3 water level after purging (drawdown)	❹ (allow water level to recover by at least 50 % before sampling)	Where P_r is greater than Y_w, mixing of borehole waters will occur making point/spot sampling impossible	① Integrated/composite sample – mixed sample representative of entire open/screened section ② Spot sample – sample representative of groundwater at specific depth
- Short-screened boreholes/piezometers - Water level above top of screen  	A $Y_w > P_r$	❶ or after proof by comparative trials ❷,❸,❺,❼	❺,❻ or ❶,❷,❸	**PURGING STRATEGY** ❶ 3 × borehole volume ❷ 1 × borehole volume ❸ Time purge based on hydraulic properties ❹ De-water, purge and recover ❺ Micro-purging ❻ No purging – depth sample ❼ No purging – surface sample
	B $Y_w < P_r$	❹ (allow water table to recover above screened interval before sampling)	Where P_r is greater than Y_w, mixing of borehole waters will occur making point/spot sampling impossible	



a) **Short screen sampling point**

b) **Long screen sampling point**

Key

1	aquifer
2	water level
3	sealing material(s)
4	gravel/sand filter
5	filter screen
6	zone to be purged
7	piezometer/sampling tube
d_B	diameter of the borehole
L	length of zone from which the sample is drawn

NOTE Purge volume, $V_p = 3(\pi / 4)d_B^2 L$.

Figure 1 — Purging of discrete horizon sampling devices, e.g. piezometers and multi-level samplers

For point samples, micro-purging or a discrete depth sampler should be used. To ensure that purging has been effective, it is recommended that monitoring of chemical parameters is carried out during the purging operation. The parameters that can be measured include:

a) EC;

b) pH;

c) temperature;

d) redox potential (Eh);

e) dissolved oxygen (DO);

f) turbidity; and

g) contaminant specific parameters.

As a minimum, EC should be measured.

When purging, it is recommended that the pump intake be located at a depth of 1 m to 2 m below the lowest level of groundwater fluctuation in the monitoring point where the open section of the monitoring point extends above the water table. Where the open section is constantly below the water table, it should be located at a position 1 m to 2 m below the top of the open section. An exception to this might be where the borehole is monitoring a confined aquifer at depth, but the water level (or piezometric surface) is close to the ground level. In this case, for practical reasons, the pump intake should be located at 1 m to 2 m below the lowest level of water level fluctuation.

The implications of purging, within the framework of the overall investigation, should be considered carefully. The impacts of purging should be considered alongside the benefits in improved sample integrity. For investigation of a potentially contaminated site, where the contaminants are located at discrete locations or free-phase contaminants (LNAPLs and DNAPLs) are present, the impact of purging can be to redistribute or spread the contaminants. This can lead to erroneous results and/or exacerbation of problems. Where this is the case, micro-purging (see 6.1.2) should be considered and/or samples of pre-purge and post-purge water collected and analysed during preliminary stages of investigation to enable comparison of sample results to be made. This information can then be used to optimise the procedures used for subsequent sampling activities. Where LNAPLs or DNAPLs are present, the thickness(es) of these layers should be measured prior to sampling.

It is important that consideration be given to the disposal of the purged water as it can be contaminated. Adequate provision for disposal of potentially contaminated water should be made. This can involve arranging for its removal to an authorised disposal site. Disposal down the same well or another nearby could be unacceptable or be subject to authorisation.

Where perched groundwater boreholes are being sampled, purging can lead to a rapid removal of the groundwater body due to its limited lateral extent and depth. Care should therefore be taken or micro-purging used.

6.1.2 Micro-purging

Where large volume purging is impractical, hazardous or could adversely affect the contaminant distribution in the subsurface (e.g. for deep boreholes) micro-purging can be adopted as an alternative purging strategy (Reference [15]). This method removes only small volumes of water from the monitoring installation at the location from which the sample is to be taken. It is most suited to open boreholes or piezometers with long screen lengths where the formation has significant permeability. It is not directly comparable to whole borehole purging and should be chosen with care and consideration of the objectives.

The type of pump or sampler used for micro-purging should be selected with care. Only those devices that are able to minimise disturbance of the water in the borehole column should be used. Inertial pumps, bailers and other grab samplers are not recommended for micro-purging.

The purge pump inlet should be located at the horizon from which the sample is to be collected. The borehole should then be purged using a low-flow pump to remove the water from the chosen section of borehole and to induce localised inflow of groundwater. The same pump should subsequently be used for sampling without removal to reduce the chance of mixing in the borehole.

Micro-purging reduces the volume of effluent generated and hence makes disposal easier. It also has the advantage of reducing turbidity and volatilisation. During micro-purging, parameters such as EC, pH, temperature, turbidity and other contaminant-specific determinands should be monitored and purging continued until the variation in these parameters becomes stable. Stability is defined as a constant concentration of a parameter, within a defined variance, held over a pre-defined period of time. The selection of parameters should be based on site-specific conditions but as a minimum, EC should be measured.

Micro-purging is also applicable for identifying stratification (vertical variation in water quality) within the borehole. This can yield important information about contaminant distribution and movement within the saturated zone which would otherwise be obscured where whole borehole purging techniques are used.

6.2 Trial pits

Where groundwater is intercepted during trial pitting, this water can be sampled by lowering a sample container into the water or by collection of water that has issued from the wall of the trial pit. It should be noted that the quality of the sample can be affected by the disturbance of the ground caused during trial pit excavation and by mixing of groundwater in the base of the pit.

Trial pit samples are of limited value and their use should only be considered where the objective of the study is to provide only a gross indication of presence or absence of contaminants in the near surface. Trial pit samples are unsuitable for establishing the presence of contamination at depth and for detailed plume mapping. They do, however, provide a facility for rapid low-cost screening of a site that will then allow a more effective complex sampling and/or operational strategy to be implemented, should this be necessary.

To obtain a more representative sample of groundwater, a piezometer can be installed into the ground below the base of the trial pit or alongside it. Piezometers should not, however, be installed into a back-filled trial pit because of the questionable nature of the data that would be derived from samples collected from such a monitoring point.

6.3 Sampling of free-phase contaminants (DNAPLs and LNAPLs)

6.3.1 LNAPLs

LNAPLs are less dense than water and can therefore float on the surface of the groundwater and concentrate at the water table. They can also be found in the unsaturated zone and create dissolved plumes in the saturated zone. Sampling facilities, therefore, should be designed to collect samples from these areas. Ideally, the screen intake of monitoring points should extend from just above to below the full distance of water table fluctuation.

When sampling a monitoring point for LNAPL contaminants, these should be sampled prior to purging because of the mixing and disturbance that this causes. When measuring the vertical thickness of LNAPLs in a borehole, it should be noted that the thickness in the borehole can be greater than that in the aquifer as a result of an exaggeration effect caused by a capillary pressure differential between the borehole and the surrounding formation.

6.3.2 DNAPLs

DNAPLs are more dense than water and can move downwards through the unsaturated and saturated zones towards the base of the aquifer. As they migrate downwards, they can be intercepted by horizons with lower permeability than the surrounding formation, e.g. a clay lens or layer in a sand and gravel aquifer. This interception can lead to temporary or permanent residence or “ponding” of the free-phase contaminant.

The movement of the DNAPL at the base of the aquifer is controlled by the topography of the underlying low permeability material and in some cases migration of DNAPLs can be in the opposite direction to that of natural groundwater flow. Additionally, due to the nature of DNAPLs, dissolved plumes can be produced and be vertically and laterally extensive.

Sampling for DNAPLs requires knowledge of the location of the DNAPL “pools” throughout the groundwater system. As a minimum, where DNAPL contamination is suspected, monitoring points should penetrate the full thickness of the permeable strata. Due to the nature of DNAPLs, detection of free-phase liquid is difficult unless supporting evidence and data can focus investigations.

6.4 Materials for sampling equipment

Refer to ISO 5667-1 for general information and guidance on the choice of materials for sampling equipment and bottles. Care should be taken to prevent materials used for collection of the sample and its subsequent storage from interfering with the integrity of the sample at the time of collection and thereafter. Where a multi-determinand analysis is required, the option of collecting a suite of samples in containers manufactured of different materials should be considered. Where this occurs, quality assurance (QA)/quality control procedures should be implemented to maintain sample integrity. Guidance on QA of environmental water sampling is provided in ISO 5667-14.

6.5 Prevention of contamination

Extreme caution should be exercised when designing a monitoring strategy to minimise the risk of inducing uncontrollable migration pathways. Investigation programmes should also proceed with care. As part of the investigation, a number of non-invasive techniques can be employed to assist in programme design and development of a conceptual model. These include geophysical techniques and soil gas surveys as well as examination of existing geological, geophysical and hydrogeological information.

Other situations that cause groundwater contamination can arise and these should be considered during the planning process. One example is the sampling from trial pits. The disturbance caused by excavation of the trial pit can lead to the mixing of waters and/or the mobilisation of contaminants (see 6.3).

6.5.1 Contamination introduced by installation of monitoring points and sampling

In general, concerns over contamination arise from the sampling procedure. There are a number of ways in which the samples can become contaminated, some of which have been discussed in previous clauses. One area of concern is the use of sampling equipment. Ideally each monitoring installation should have dedicated sampling equipment so that there can be no cross-contamination. However, it is often not practically or economically viable to do this. In this case, the equipment should be de-contaminated after each sample has been taken and before being transferred to the next monitoring point. Depending on the contaminants present, appropriate cleaning agents (which themselves do not cause contamination), should be used. In some cases, replacement of parts of the sampling equipment is unavoidable, e.g. plastic tubing, where satisfactory cleaning cannot be carried out.

Quality control procedures should be established to confirm that de-contamination procedures are adequate. The sampling programme should be designed to start with the least contaminated boreholes first and progress to the most contaminated last. Further guidance on handling environmental water samples and the requirements for the collection of field and other blank samples is provided in ISO 5667-14.

6.5.2 Preservation, stabilisation and transport of samples

Groundwater samples are often taken at sites remote from laboratory facilities. The manner in which groundwater samples are stored and handled before analysis is therefore extremely important, if results are to be representative of conditions at the time of sampling. For general guidance on these aspects, refer to ISO 5667-1, ISO 5667-3 and ISO 5667-14, but account should also be taken of the following specific guidance.

The most significant problem in groundwater sampling is that of obtaining an accurate indication of water quality in the sub-surface. Problems can arise because of the physical and chemical changes that occur as samples are removed from the aquifer. Groundwater might be supersaturated with respect to dissolved gases and most groundwater sampling methods result in the sample undergoing temperature and pressure changes which can alter such variables as pH, EC, electrochemical potential, sulfide content and dissolved gas content (particularly oxygen and carbon dioxide). In turn, these changes can alter the speciation of some constituents. Atmospheric contact can bring about similar changes and can also result in oxidation, increased microbiological activity, precipitation, volatilisation and changes in appearance (e.g. colour and turbidity). It is therefore important that the sample delivery tubes should not contain any air (or gas) bubbles during sampling. When sampling groundwater, it is important that as many determinations as is practical are carried out on-site, or as soon as possible after sample collection. This is particularly important for temperature, pH, electrochemical potential, EC, alkalinity and dissolved gases (especially oxygen). A continuous measurement technique is preferred and is best carried out using flow-through cell systems that prevent contact between the sample and the atmosphere. When filling, hold sample bottles vertical and insert the sample delivery tube so that it does not touch the sample. Raise the tube during filling so that it remains not more than 10 mm above the water level. Cap samples immediately after filling. If contact with air needs to be avoided and preservatives have not been added, fill the sample bottle slowly to overflowing, allowing at least two bottle volumes to overflow before sealing and checking that no air bubbles are trapped.

On-site filtration of samples is recommended for stabilising samples, particularly where speciation is under study. A wide range of filtration media is available and includes cellulose-based membrane filters, glass fibre filters and polycarbonate filters. No single medium can be universally recommended, although glass fibre filters have some advantage over other media of similar pore size (e.g. cellulose filters), since they become blocked less frequently, yet provide similar filtration efficiency in terms of particle size retention. The recommended pore size for general purpose groundwater work is 0,4 µm to 0,5 µm, although other pore sizes might be preferred, depending upon the particular sampling purpose and the determinand of interest. Whatever medium is used for filtration, it is recommended that subsequent results (following analysis) be reported as “filterable” species (quoting the appropriate pore size of the filter) rather than “dissolved” species. It is particularly important that on-site filtration of anaerobic groundwater be carried out under anaerobic conditions and with no air bubbles in the sample line.

In all cases, it should be ensured that sample containers are delivered to the laboratory in a tightly sealed condition, protected from the effects of light and excessive heat. If this is not done, sample quality can change rapidly due to gas exchange, chemical reactions and the metabolism of micro-organisms. It should also be ensured that samples which cannot be analysed within a day are stabilised or preserved. Where samples have to be stored before analysis, ISO 5667-3 provides guidance on the required storage conditions.

7 Safety precautions

General guidance on safety matters is given in ISO 5667-1, but the following safety aspects should be considered when sampling groundwaters.

The activities involved in sampling groundwater from (potentially) contaminated land and the environment are potentially hazardous. It is important that all national and local health and safety regulations be addressed and only appropriately trained and qualified persons design and carry out monitoring programmes. A risk assessment should be performed prior to undertaking the work and remedial actions should be taken to minimise risks. Risks arising from the following sources should be considered:

a) the materials being handled (samples, chemicals, etc.);

b) mechanical hazards (drilling rigs, vehicles, etc.);

c) electrical equipment (generators, pumps, etc.);

d) environment (personal protection, gases, ground stability, etc.).

For further guidance, see ISO 5667-1.

WARNING — The surface area around wells and boreholes should always be regarded with some caution since there can be a risk of surface collapse, especially around old wells. Staging and ladders within shafts can be unsafe and it is essential that a proper safety harness be worn when entering wells. At least two persons should be present during any sampling operation: one person should always remain at the surface in a position to summon assistance if hazardous conditions develop or if there is any risk to the person undertaking the sampling operation in the well.

Where sampling takes place in a confined place (e.g. within a well, borehole, well head or basement) the atmosphere should be tested on each occasion for oxygen deficiency and the presence of inflammable gases, hydrogen sulfide or any other toxic gases and vapours that could be present. It can even be necessary to carry out these procedures in unconfined spaces when severe contamination of any area surrounding a groundwater installation is being investigated. It is essential that suitable protective clothing always be worn when undertaking sampling operations, and under no circumstances should any routine sampling activity continue if safety checks indicate that potentially unsafe conditions exist. If samples have to be withdrawn in this type of situation, special procedures will be required which might need to be agreed upon by the statutory agency responsible for local or national health and safety matters (e.g. during the use of breathing apparatus or when sampling in confined spaces).

When dealing with groundwater installations which are subject to heavy contamination, it is important to carefully examine all relevant information regarding the sources of the contamination, in order to define the nature of the necessary safety checks. In situations where it is essential for investigations to take place close to a source of heavy contamination, operations should be conducted to windward, if possible, and eating, drinking and smoking should be strictly prohibited within the area of investigation. It can be prudent to carry out medical checks on investigators immediately after operational work, and periodically at suitable intervals thereafter.

8 Sample identification and records

An identification system that provides an unambiguous method for sample tracking should be adopted. It is essential that a clear and unambiguous labelling system be used for samples to enable effective management of samples, accurate presentation of results, and interpretation. Guidance on sample identification and record procedures is contained in this part of ISO 5667. In addition, other relevant information should be recorded and reported so that any repeat sampling can be carried out and any variability in results examined. This information should include details of the sampling site, its nature, construction, any other environmental data which are relevant, and information for the analyst, e.g. whether there are known or suspected toxic substances in the sample(s).

The details given on any combination of sample labels and reports depends on the objectives of the particular sampling exercise, but should include all the information necessary to enable a repetition of sampling to take place under identical conditions. Matters which could be considered for inclusion are:

a) name and location of the sampling point;

b) date and time of sample collection;

c) nature of aquifer and water bearing strata;

d) type of sampling point (e.g. borehole, well or spring);

e) any relevant descriptive information (e.g. well dimensions);

f) pumping status and depth of pump suction and/or discharge;

g) water level within the well or borehole;

h) method of sample collection;

i) depth of sampling;

j) sample appearance at the time of collection (e.g. colour, clarity and odour);

k) results of on-site analysis (e.g. pH, dissolved oxygen);

l) details of any sample preservation techniques employed;

m) details of any on-site filtration used (e.g. filter pore size);

n) details of any sample storage method employed/required;

o) name (or initials) of the sample collector;

p) information on known/suspected contaminants.

Annex B provides an example of a report that could be used in situations where all this sampling information is collected.

9 Quality assurance/quality control

In a site investigation context, achieving quality requires the following:

a) a clear statement of objectives;

b) clear assignment of responsibilities;

c) procurement of appropriate expertise;

d) development of technical specification including data quality objectives;

e) methods for monitoring and improving quality of operations;

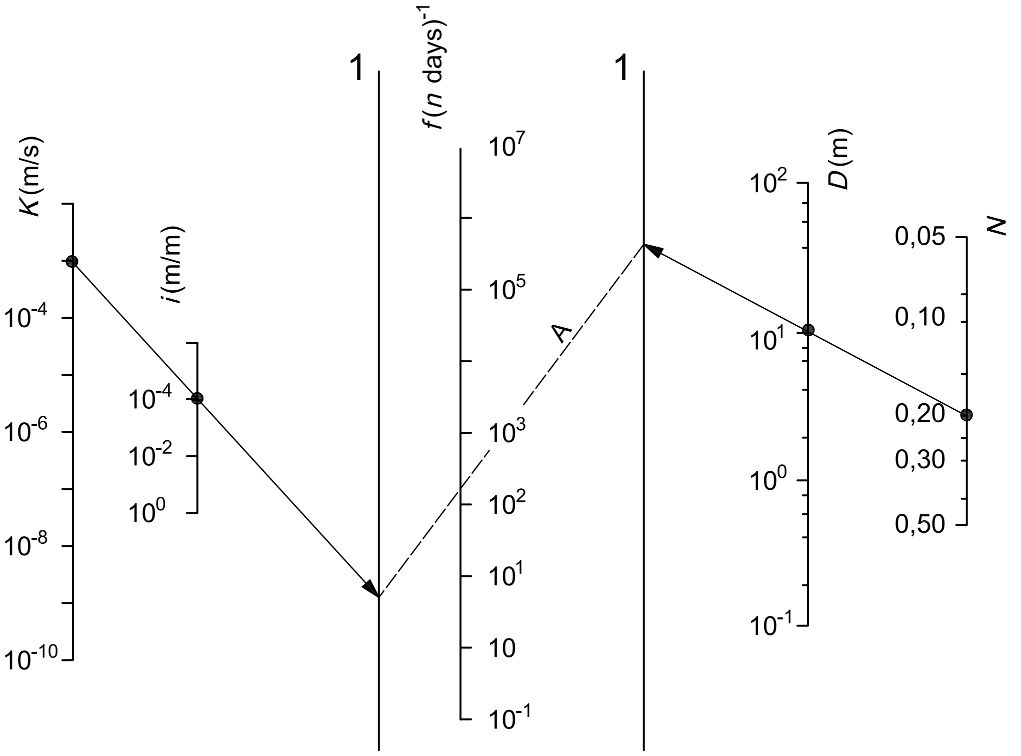
f) good communication.

ISO 5667-14 describes a variety of techniques for monitoring the quality of all types of water samples.

Annex A
(informative)

Calculation of sampling frequency using nomogram

An example of how an appropriate sampling frequency can be determined using prevailing hydrogeological properties (including hydraulic gradient, hydraulic conductivity and effective porosity) is presented here. Relevant hydrogeological parameters have been used to develop a nomogram, which has been adapted from Reference [12] to include the effects of dispersion, for rapid estimation of an appropriate sampling frequency. Dispersion has the effect of distributing the contaminant both along the flow path and perpendicular to it. The modification applied leads to a 10 % increase in sample frequency.



Key

1	pivot line
D	distance, in metres, along the flowpath
f	frequency of sampling, expressed as once per period of n days
i	hydraulic gradient, in metres per metre
K	hydraulic conductivity, in metres per second
N	effective porosity

$$f = \left(\frac{DN}{86\,400\ Ki}\right) - 0{,}1\left(\frac{DN}{86\,400\ Ki}\right)$$

Figure A.1 — Nomogram for calculating sampling frequency

EXAMPLE

Unconsolidated sands and gravels underlie the site. This formation has an average hydraulic conductivity of 1 × 10^{-3} m/s and an effective porosity of 0,20. The average hydraulic gradient across the site is seasonally constant at 0,000 1.

The frequency of sampling needs to be determined at a monitoring point 10 m from the known source of pollution.

Using the hydrogeological properties and other parameters, points are marked on each of the vertical axes. A straight line is then drawn through each pair of points which lie either side of the pivot line. The straight line through each pair of points is then extended as far as the nearest pivot line. To determine the sampling frequency, a further straight line is drawn between the two pivot line intersection points. The point at which this line crosses the sampling frequency, f, axis is the recommended minimum frequency. In this case the minimum frequency is 416 days.

Annex B
(informative)

Example of a report — Sampling from groundwaters

Reasons for sampling: ....

....

Location of sampling point: ....

Nature of sampling point: ....

Nature of aquifer: ....

Date: ....
day month year

Weather conditions: ....

Water level (before purge): ....

Purging strategy: ....

Purge flow rate: ....

Purge time: ....

Purge volume: ....

Water level (before sampling): ....

Time: Start .... End .... of sampling

Sampling method: ....

Sample depth: ....

Sample pump flow rate: ....

Sample appearance: ....

....

....

....

Details of preservation techniques employed: ....

....

Details of sample storage method employed/required: ....

Name/initials of sample collector: ....

Other remarks, e.g. evidence of contamination: ....

....

....

....

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1) Superseded by ISO 5667-1:2006.

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