INTERNATIONAL STANDARD

ISO 5667-18

First edition
2001-04-15

Water quality — Sampling —

Part 18:
Guidance on sampling of groundwater at contaminated sites

Qualité de l'eau — Échantillonnage —

Partie 18: Lignes directrices pour l'échantillonnage des eaux souterraines sur des sites contaminés

Reference number
ISO 5667-18:2001(E)

ISO copyright office
Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.ch
Web www.iso.ch

Printed in Switzerland

Contents

Page

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 3.

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 part of ISO 5667 may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

International Standard ISO 5667-18 was prepared by Technical Committee ISO/TC 147, *Water quality*, Subcommittee SC 6, *Sampling (general methods)*.

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

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

— *Part 2: Guidance on sampling techniques*

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

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

— *Part 5: Guidance on sampling of drinking water and water used for food and beverage processing*

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

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

— *Part 8: Guidance on 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 18: Guidance on sampling of groundwater at contaminated sites*

— *Part 19: Guidance on sampling of sediments in the marine environment*

Annex A forms a normative part of this part of ISO 5667.

Introduction

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

Groundwater sampling, in general, is carried out to determine whether or not the groundwater in or beneath a site is contaminated. It can also be used to satisfy the following additional objectives:

— to establish whether any migration of contaminants, derived from the site, is occurring and characterize the spatial extent of any contamination and its form;

— to determine the direction and rate of groundwater flow and contaminant migration;

— to provide data for undertaking a risk assessment;

— to provide an early warning system for the impact of contaminants on the quality of groundwater resources, surface waters and other potential receptors in the vicinity of the site;

— to monitor the performance and effectiveness of remedial measures or facility design.

— to demonstrate compliance with licence conditions, or collect evidence for regulatory purposes.

— to assist in the selection of remedial measures and remediation process design.

This guidance includes sampling of groundwater from both the saturated (below water table) zone and the unsaturated (above the water table) zone.

Development of a groundwater sampling programme depends on the purposes of the investigation. This part of ISO 5667 provides guidance to inform the user of the necessary considerations when planning and undertaking groundwater sampling from potentially contaminated sites. Examples of typical sites include:

— present or former industrial sites with a history of potentially contaminatory activities;

— waste disposal (landfill) sites;

— sites where natural and/or artificial processes have led to potential land and groundwater contamination;

— sites where products have been spilled e.g. as a result of transportation accidents.

The guidance contained in this part of ISO 5667 covers selection of sampling points, the 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 contaminant source, pathways for migration and the receptors need to be considered.

Water quality — Sampling —

Part 18:
Guidance on sampling of groundwater at contaminated sites

1 Scope

This part of ISO 5667 provides guidance on the sampling of groundwater at potentially contaminated sites. It is applicable to situations where contamination of the subsurface could exist as a result of downward migration of pollutants whose source is at the surface or just below it, and when the guidance provided in ISO 5667-11 is inappropriate.

2 Terms and definitions

For the purposes of this part of ISO 5667, the following terms and definitions apply.

2.1
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), that 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

2.2
nested piezometers
group of piezometers installed within a single larger-diameter borehole

NOTE 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.

2.3
multiple boreholes
group of individual boreholes or piezometers installed separately to form a monitoring network adequate for the purposes of an investigation

2.4
multi-level sampler
single installation for sampling groundwater from discrete depths within the sub-surface

NOTE The device can be driven directly into the ground, installed in a pre-existing borehole or installed in a purpose-drilled hole. When installed in a borehole, integral packers are used to isolate individual sample ports.

2.5
aquifer
geological formation (bed or stratum) of permeable rock or unconsolidated material (e.g. sand and gravels) capable of yielding significant quantities of water

2.6
aquitard
geologic stratum of formation of low permeability that impedes the flow of water between two aquifers

2.7
saturated zone
part of an aquifer in which the pore spaces of the formation are completely water-saturated

2.8
unsaturated zone
part of an aquifer in which the pore spaces of the formation are not totally water-saturated

2.9
groundwater
water in the saturated zone and/or unsaturated zone of an underground geological formation or artificial deposit such as made ground

2.10
perched water table
isolated body of groundwater, which is limited in lateral and vertical extent, located within the unsaturated zone overlying a much more extensive groundwater body

2.11
matrix potential
combination of forces, independent of gravity, acting on soil water (water contained within the pores of a soil/rock matrix) that exist as a result of the attraction of solid surfaces to water and the attraction of water molecules to each other

NOTE Generally, the smaller the particle size, the higher the matrix potential.

2.12
check valve
mechanical valve which allows fluids to pass in only one direction

NOTE The pressure of fluids flowing through the valve in one direction has the effect of opening the valve and in the other of closing it.

2.13
receptor
entity that is vulnerable to the adverse effect(s) of a hazardous substance or agent

EXAMPLES Human, animal, water, vegetation, building services, etc.

2.14
packer
device or material for temporarily isolating specified vertical sections within boreholes in which to perform groundwater sampling from discrete zones or locations within the borehole or aquifer

2.15
hydraulic conductivity
property of a water-bearing formation that relates to its capacity to transmit water through its internal, interconnected pathways

2.16
effective porosity
proportion of saturated openings or pores within a water-bearing formation which contribute directly to the flow of groundwater

NOTE Effective porosity is represented as the ratio of this volume of pore space to the total volume of rock.

2.17
field capacity
maximum amount of water that a soil or rock can retain after gravitational water has drained away

2.18
dense non-aqueous phase liquids
DNAPL
organic compounds that have a low water solubility and a density greater than that of water

EXAMPLES Chlorinated hydrocarbons such as trichloroethane.

2.19
light non-aqueous phase liquid
LNAPL
organic compounds that have a low water solubility and a density less than that of water

EXAMPLE Petroleum products.

3 Sampling strategy and programme design

3.1 General

Groundwater sampling can be carried out as a single exercise or as part of a larger site or environmental investigation. 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.

It should be noted that, normally, groundwater sampling from the saturated zone alone cannot fully assess the level of contamination of a site 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.

3.2 Selection of sampling point location

The location of monitoring installations and the design of the network for sampling groundwater from (potentially) contaminated sites should take account of the following:

- the hydrogeological setting of the investigation site;
- the past and future use(s) of the site;
- the purpose of the exercise;
- the likely contaminants;
- the extent of contamination.

All of these factors should be considered during the preliminary stages of the site investigation programme to enable the most appropriate and effective sampling programme to be designed. 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 from sites that are potentially contaminated.

In addition to the scientific requirements, other factors can influence the location of sampling points. These include practical, environmental and safety considerations such as the ground slope, proximity of underground services (gas pipes, electricity cables etc) and overhead clearance for drilling rigs and other sampling devices.

To establish whether migration of contaminants is occurring and determining the direction and rate of this migration, monitoring points should be located inside and outside the contaminated area and both up and down the hydraulic gradient. A greater number of sample points should be positioned down gradient, both inside and outside of any contaminant plume.

Where site analysis indicates that the site is underlain by complex geology or that contaminants with a broad range of physical and chemical properties are likely to be present, an increased number of monitoring points should be installed for adequate characterization of the contaminant distribution. In addition to investigating the lateral variation caused by heterogeneity, the sampling strategy should also be designed to investigate any vertical variations.

Table 1 — Procedural steps for sampling groundwater (adapted from [9])

Step (with reference to other ISO standards)	**Procedure**		**Essential elements**	**Notes**
Investigation/monitoring strategy (ISO 5667-1)	Collation of available data ↓ Desk study ↓ Develop conceptual model ↓ Reconnaissance survey ↓		Identify data sources Design borehole/sampling point network and sampling programme	Geological, geochemical and hydrogeological characterization See 3.2, 3.3 and 3.4
Facility installation	Installation of monitoring points by drilling ↓ Well cleaning and development		Borehole design, material selection and installation technique	See clause 4 See 5.1
Well inspection	Hydrologic measurements ↓		Water level measurements Hydraulic testing	Hydrogeological characterization
Well purging	Removal or isolation of stagnant water ↓ Determination of well-purging parameters (e.g. EC, pH, temperature, redox potential)		Representative groundwater Verification of representative groundwater	See 5.1 See 5.2
Sample collection Filtration Field determinations (ISO 5667-2, ISO 5667-11, ISO 5667-3)	⟵	⟶	Sample collection by appropriate mechanism	See 4.2 and 4.3
	Unfiltered sample	Field filtered sample	Field determination of sensitive parameters, pH, electrical conductivity, temperature, redox potential, dissolved oxygen as appropriate	
	Organics (all)	Alkalinity/pH	Head-space free samples	See 5.4, 5.5 and 5.6
	Dissolved gases	Dissolved trace metals for specific geochemical information	Minimal aeration or de-pressurization	
	Sensitive inorganic species, e.g. nitrite, ammonium, iron(II)	Sulfide and other sensitive inorganics	Minimal air contact	Blanks and spiked samples should be prepared in accordance with ISO 5667-14
	Tracer metals for mobile (colloidal) loads	Major cations and anions	Sample preservation	
Storage and transport of samples (ISO 5667-3)			Minimal loss of sample integrity prior to analysis	See 5.7, clauses 6, 7 and 8

Care should be taken when identifying the prevailing flow regime as localized 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 properties are different to those of water. 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 and their migration and distribution will be affected by the geological structure and chemical interactions within the unsaturated zone and zone of water table fluctuation.

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, e.g. at landfill sites, monitoring points should be established around the outside of, but close to, the landfill.

Sample points within the zone of contamination and outside (both up and down the hydraulic gradient) should be installed to measure performance and effectiveness of remediation and for demonstrating compliance to licence conditions.

3.3 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 contaminants will be the subject of national regulations. Focussing only on these, however, could be inadequate for providing the complete picture of contamination 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 compound.

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

3.4 Sampling frequency

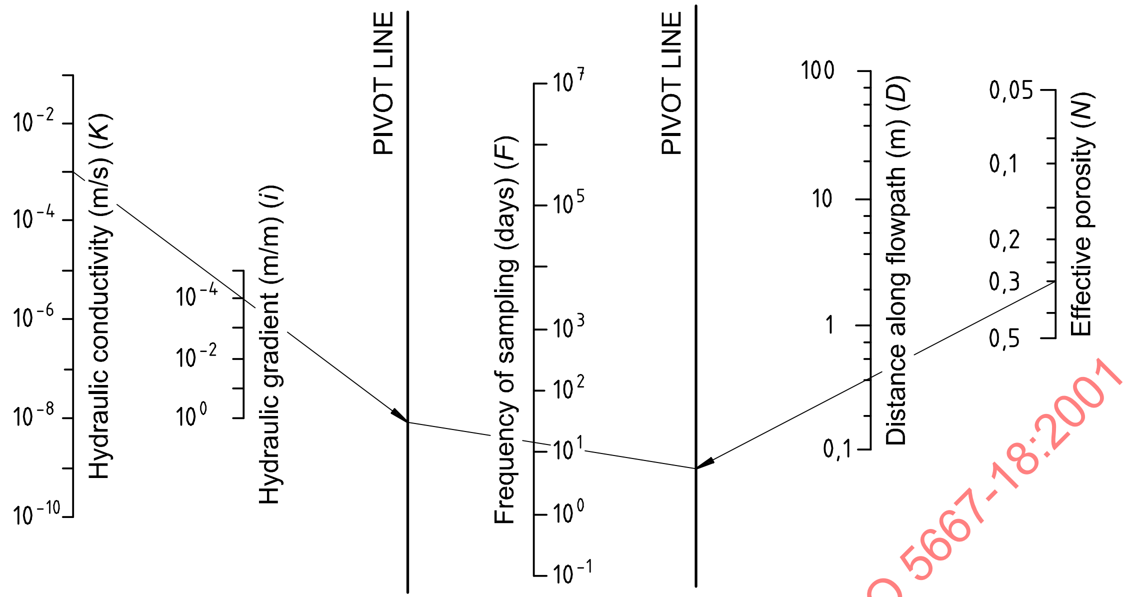
The frequency of sampling depends on the objectives of the investigation. If the investigation is designed to map an established contaminant plume, a single-event sampling exercise may be used. In this case, sampling should be completed as rapidly as possible to minimize the effects of temporal variation. 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, etc.) and monthly for those that are more mobile and reactive (e.g. VOCs and dissolved gases).

However, where environmental conditions indicate that changes can occur more rapidly, 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 localized rainfall as well as ground disturbance caused by ground engineering activities.

One example of how sampling frequency can be determined using prevailing hydrogeological properties (including hydraulic gradient, hydraulic conductivity and effective porosity) is shown in Figure 1. Relevant hydrogeological parameters have been used to develop a nomogram, which has been adapted from [8] to include the effects of dispersion, for rapid estimation of 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. A worked example is described in annex A.

Other environmental conditions can also influence the temporal distribution and concentration of contaminants in groundwater and soil water and these should be considered during development of the sampling strategy. 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.



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

Figure 1 — Nomogram for estimating sampling frequency (from [8])

4 Types of monitoring installation

4.1 General

Installations suitable for groundwater monitoring typically involve placement of access tubes for portable sampling devices or burial of sensors or samplers *in situ*. These installations may 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 and installations above the water table can measure soil gas and soil moisture content.

4.2 Unsaturated zone monitoring

4.2.1 Introduction

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

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

— unsaturated pore fluid sampling.

4.2.2 Extraction from solid samples

4.2.2.1 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 lists a range of suitable techniques that can be used for extracting solid samples for pore fluid collection.

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	Approximately 10 m	no	25 mm to 75 mm
Auger	Hand-powered (e.g. “hollow stem”)	Soils, clay and unconsolidated geological materials	Approximately 5 m	no	50 mm to 100 mm
			Approximately 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 (e.g. “direct” and “reverse rotary”)		All types of geological materials and made ground	>100 m	yes air, water, mud, foam etc.	100 mm to 200 mm

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

4.2.2.2 Hand-operated samplers

These are typically tube-type or auger samplers. The tube samplers consist of a variable-length rod with hollow sample chamber (of variable length and diameter). It is hammered 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.

4.2.2.3 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 whilst drilling and lubricate and cool the drill bit. The type 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 volatile organics and other sensitive chemicals. Large diameter samples collected using these techniques can be sub-sampled to minimize 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 by 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. It is important that the groundwater extract be preserved in accordance with ISO 5667-3 before analysis.

4.2.3 Pore-liquid sampling

4.2.3.1 General

Two types of method can be used to extract pore liquid directly from the subsurface, namely 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 may affect sampling of volatile compounds.
Percolate soil water samplers	• Enables sampling of flow through macropores as well as interstitial water. • Larger sample volumes possible. • Less potential for volatilization 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 chromato-graphic effects that in turn can lead to collection of chemically unrepre-sentative groundwater samples.

4.2.3.2 Vacuum samplers

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 gas-driven sampling device (see 4.3.3.5) above the porous cup.

4.2.3.3 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 nonporous inert material which may have a wick incorporated to draw water (which is under tension) into the sampler as well as intercepting its downward movement.

4.3 Saturated zone monitoring

4.3.1 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.

Whilst existing wells can provide background information and evidence that contamination of groundwater has occurred, the network available is unlikely to be adequate for characterizing the source and extent of contamination. It is likely, therefore, that an additional monitoring installation will be required as part of a specific site investigation.

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 minimize the potential for introducing artificial migration pathways (see 5.5), deep, open, fully penetrating screened boreholes should not be installed.

The design of monitoring installations is also dependent on the nature of the contaminants being investigated. 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 be considered during construction of monitoring points.

4.3.2 Monitoring point installation

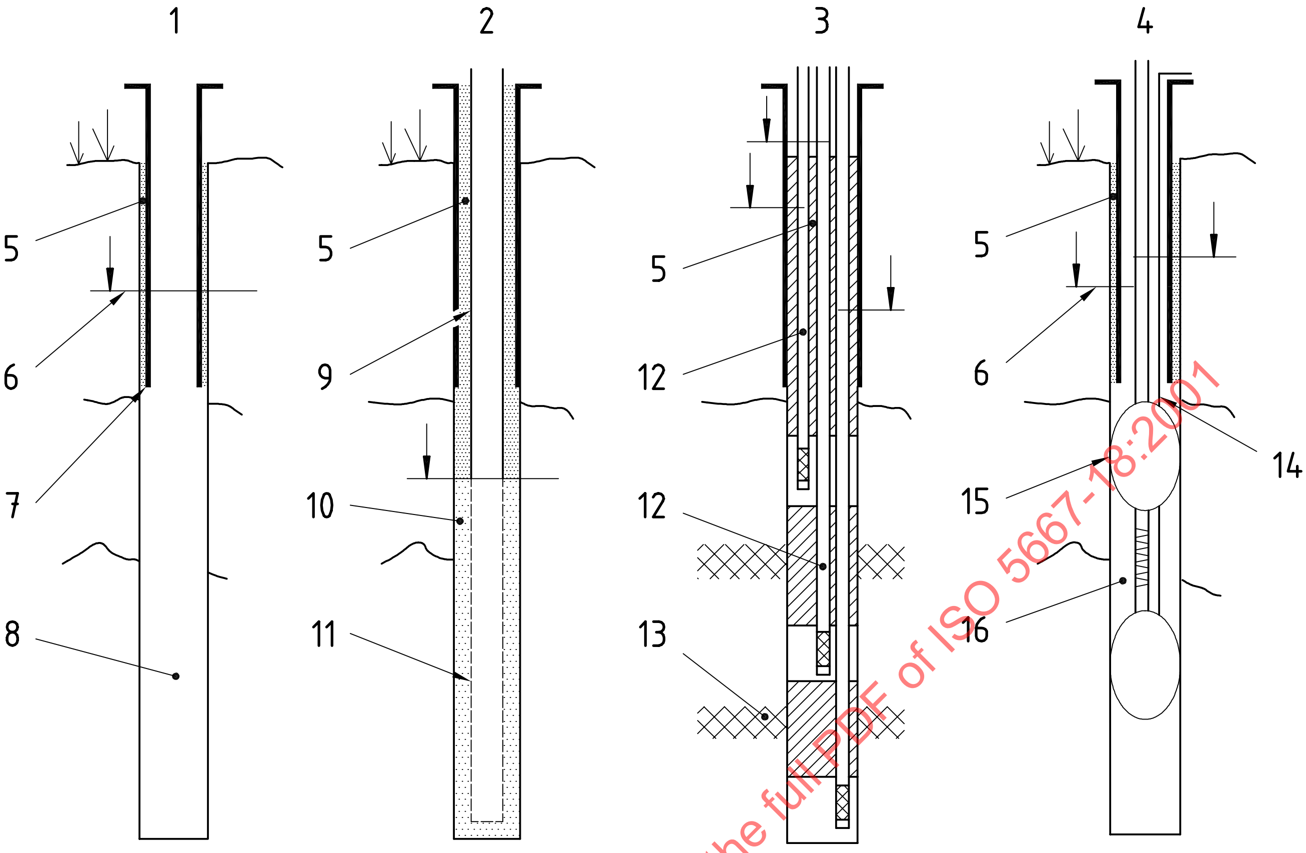
There are three major types of monitoring point installation for collection of groundwater samples (Figure 2). These are:

a) single-screened/unscreened wells, boreholes or piezometers,

b) nested piezometers in a single borehole completion;

c) multi-level samplers.

The advantages and disadvantages of each are shown in Table 4.



Key

1 Open borehole

2 Screened borehole/piezometer

3 Nested piezometers

4 Borehole with packers

5 Sealing material

6 Water table level

7 Casing pipe

8 Open well or borehole

9 Well casing or piezometer pipe

10 Gravel pack

11 Slotted well or piezometer screen

12 Piezometer

13 Aquitard

14 Packer gas inflation line

15 Packer

16 Isolated borehole section

Figure 2 — Major types of monitoring installation

Table 4 — Advantages and disadvantages of different monitoring point installations

Type	Advantages	Disadvantages
Single screened/unscreened borehole/well/piezometer	— Simple, can be designed for all types of geological formation. — Easy to install. — No potential for vertical cross-contamination between sampling points. — Flexibility in well diameter. — Sampler collection method not restricted. — With angled holes it is possible to get beneath source and/or intercept vertical fissures. — A number of boreholes of different depths may be installed in a small area to establish a multiple borehole array	— Can lead to short-circuiting of system and exacerbate problem. — Unable to provide information on vertical variations in aquifer, e.g. stratification. — Incorrect placement of screen may lead to pollutants by-passing well. — Concentrations represent means over screened length. Large purge volumes may be required.
In addition to those described above, ***Multiple borehole arrays*** have the following additional advantages and disadvantages	— Allows vertical variation to be investigated. — Simple design and operation. — Potential for cross-contamination between different levels eliminated. — Diameter of well only limited by drilling method. — Array design can enable complete vertical coverage.	— Can cause excessive ground disturbance in closely spaced arrays. — Relatively expensive.
Nested piezometers	— Allow vertical variations to be investigated. — Smaller diameters/internal diameters require less purging. — Sampling locations can be targeted. — Can allow variations in hydrogeological properties to be determined, e.g. head, hydraulic conductivity.	— Poor installation and sealing can lead to vertical leakage. — Number of sampling points can be restricted by borehole diameter. Maximum practical number is three per borehole. — Smaller diameter of piezometers can restrict sampling options. — In low hydraulic conductivity zones, low storage volumes can make it difficult to collect sufficient sample volume.
Multi-level samplers	— Allow discrete sampling from specific points/horizons. — Easier to operate than most other installations. — Minimal purge volumes. — Minimal aquifer disturbance during sampling.	— Installation difficult — Requires specialist knowledge and can be expensive. — Number of sampling points may be limited by borehole diameter. — Poor installation may lead to cross-contamination. — Sampling method restricted to shallow depth without incurring high costs.

4.3.3 Types of sampling equipment

4.3.3.1 General

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 below. A guide to their suitability for sampling different chemical parameters is provided in Table 5. This table gives general guidance only and those methods indicated as suitable may 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 may be necessary to use more than one type of sampling device.

Table 5 — A guide to the suitability of sampling methods for different groundwater parameters

Sampling device	Groundwater parameters [a]												
	a)	b)	c)	d)	e)	f)	g)	h)	i)	j)	k)	l)	m)
Depth sampler/bailer solidus (open)	✓		✓		✓	✓	✓		✓		✓		✓
Depth sampler/bailer solidus (closed) or shut-in-sampler	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Inertial pump	✓	✓	✓		✓	✓	✓		✓				✓
Bladder pump	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Gas-driven pump	✓				✓	✓	✓		✓				
Gas-lift pump	✓				✓	✓	✓						
Submersible pump	✓	✓	(✓)	(✓)	✓	✓	✓	(✓)	✓	(✓)	(✓)	(✓)	(✓)
Suction (surface) pumps	✓	✓	✓		✓	✓	✓		✓				✓

[a] Groundwater parameters [✓ = suitable, (✓) = limited suitability]

a) Electrical conductivity (κ)
b) pH
c) Alkalinity
d) Redox (E_h)
e) Major ions
f) Trace metals
g) Nitrates
h) Dissolved gases
i) Non-volatile organics
j) VOCs (volatile organic compounds)
k) TOC (total organic carbon)
l) TOX (total organic halogen)
m) Microbiological agents

NOTE This table is provided as a general guide only. The selection of an appropriate device will depend 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 may not be appropriate for all determinands.

4.3.3.2 Depths 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” 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.

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.

4.3.3.3 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 (from 0,3 to 0,5 m). The movement can be achieved manually or by a mechanical lifting device.

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 and the length of lift. 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.

4.3.3.4 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 25 mm.

4.3.3.5 Gas-driven pumps

The gas-driven pump is a variation of the bladder pump design. It should not be confused with gas-lift pumping described in 4.3.3.6. Gas-driven 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 pressurization 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.

4.3.3.6 Gas-lift pumps

Gas-lift pumps operate by the application of compressed air within the external case of the borehole. The pressure of the air 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:

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

— the mixing of gas and water can adversely affect the quality of the sample (especially if volatile compounds are present);

— the high pressures required can lead to equipment damage; and

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

4.3.3.7 Submersible 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.

4.3.3.8 Surface pumps

These pumps are positioned at the surface and are generally suction-lift pumps. They can range from large capacity pumps down to low flow/volume positive displacement (peristaltic) pumps. In many cases, the pumps require priming to initiate pumping and they can only operate at heads of up to 8 m.

4.3.3.9 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 (Figure 2) 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 minimize any cross-flow.

4.4 Construction materials for sampling installations

Installations for groundwater sampling should be constructed with materials that will not interact with or otherwise modify (through sorption, leaching or other chemical reaction) the composition of the groundwater or contaminants in the ground. Adequate selection of materials to suit the physical ground conditions is also important to avoid failure or poor performance of the monitoring point. Table 6 identifies some of the commonly available construction materials and their properties. When selecting materials, the important points to consider include:

- ability to meet sampling requirements;
- resistance to chemical attack;
- adequate physical strength;
- minimal impact on groundwater sample;
- ability to yield adequate sample.

Completions of boreholes and any equipment installed to facilitate sampling should therefore be manufactured from materials that meet operational requirements. Whilst different conditions will be encountered at different sites, in general, chemically inert materials such as PTFE (polytetrafluoroethene) and stainless steel should be used where subsurface contaminants could include organic compounds and where intermediate to long-term monitoring is required. Where groundwater is acidic or alkaline, only PTFE should be used.

Where the investigation is only short term and/or the contaminants do not include organic compounds then alternative materials, including PVC (polyvinyl chloride) and HDPE (high density polyethene), are appropriate.

Whilst PTFE and stainless steel are relatively expensive, their use should be specified where alternatives would compromise the objectives of the project.

Where organic contaminants are being investigated, pipe couplings should be connected using leaktight threaded joints instead of solvent-based cements. All other parts of the sampling apparatus which will be in contact with the groundwater and sample prior to collection should also be manufactured of appropriate materials.

Where sampling is carried out using existing boreholes, an assessment of their suitability should be made to check fitness for purpose. This assessment should consist of an examination of borehole completion details and a physical inspection of the borehole construction to establish its current status.

Table 6 — Common borehole installation construction materials

Material	**Comments**	**Chemical parameter suitability** (see Table 5)
Fluoropolymer materials: PTFE (polytetrafluoroethene) TFE (tetrafluoroethene) FEP (fluorinated ethylene propene)	Ideal in the most aggressive environments as they are nearly totally resistant to chemical and biological attack. Expensive and difficult to handle, and joint-forming strength limited. These materials are not suitable for deep or large-diameter installations. Recommended for use where organic compounds and trace metals are important.	a to m (all)
Metals: Carbon steel Low carbon steel Galvanized steel Stainless steel	Generally stronger, more rigid and less temperature-sensitive than plastics. More suitable for large-diameter and deeper installations. Potential for corrosion, with the resultant products affecting groundwater quality. Stainless steel performs well in most corrosive environments. Some susceptibility to corrosion where there is significant microbial activity. May introduce metal contamination and particularly influence trace metal concentrations.	a to e, g to m
Thermoplastics: PVC (polyvinyl chloride) HDPE (high density polyethene)	Materials less rigid and weaker than metals but wide availability and specification makes them versatile. Can be used for both shallow and deep installations where borehole diameters are not too large. In the case of deeper holes, the casing may bend if installed in a larger-diameter hole. This may lead to difficulties in installing sampling equipment etc. Generally resistant to corrosion in short- to medium-term. Organic contaminants pose a threat of chemical attack, especially to PVC. Sorption of contaminants may also occur. Low cost materials, ideal for most general contaminated land/groundwater investigations.	a to h, m

5 Sampling procedures

5.1 Well cleaning and development

After installation of monitoring devices in the saturated zone (borehole, piezometer, multi-level sampler, etc.) the installation should be cleaned and developed prior to sampling for groundwater.

The purpose of cleaning the well is to remove any materials that have entered the borehole during drilling and completion, prior to well development. This may also be required as a precursor during routine monitoring exercise, especially if there has been a long interval between borehole/monitoring point installation and sampling.

The purpose of developing the monitoring installation is to settle any packing that has been used during installation, and to allow free flow of liquids to and through the well screen. Development is achieved by pumping and the process should continue until the purged water is visibly clean and of a constant quality. This should be determined by measuring chemical parameters during pumping. The parameters that can be measured include:

— electrical conductivity (κ);

— pH;

— temperature;

— redox potential (E_h);

— turbidity; and

— contaminant-specific parameters.

As a minimum, κ should be measured. If measurement of chemical parameters is not possible, a minimum of three borehole volumes (plus the volume of any water/fluid added during drilling) should be purged as part of the development process. Overall, the need and extent for well development will depend on the nature of the monitoring point installation and the purpose of the investigation.

Ideally, well cleaning and development should take place immediately after installation of the sampling facility or at least one week prior to sampling and in low permeability material, e.g. clays, the exercise should be completed twice with at least 48 h between each exercise.

During the well development phase, attention should be paid to the yield performance of the well and the rate of decline and recovery in water level caused by pumping. This information can be used later to select suitable flow rates for purging and sampling to maintain optimum conditions. For example a purge flow rate that results in the emptying of the borehole in a formation with low permeability should not be chosen.

5.2 Purging

5.2.1 General

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

Purging should therefore immediately precede any sampling of groundwater to remove the stagnant water from the borehole. This is achieved by pumping sufficient volume out of the borehole before a sample is taken. The purge volume will be dependant on the diameter of the well and depth of the water column. Purging should be undertaken at a flow rate less than was utilized for development of the well and greater than that proposed for sampling. Table 7 shows an example of a well purging strategy.

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 an 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 re-distribute or spread the contaminants. This can lead to erroneous results and/or exacerbation of problems. Where this is the case, micro-purging (see 5.2.2) 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 optimize the procedures used for subsequent sampling activities.

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 authorized disposal site. Disposal down the same well or another nearby could be unacceptable or be subject to receiving authorization.

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

5.2.2 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. 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.

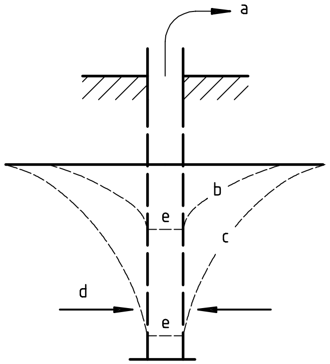
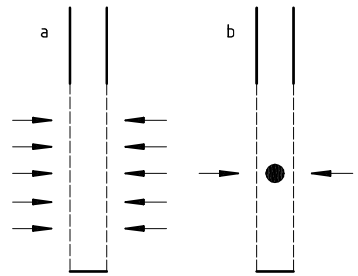
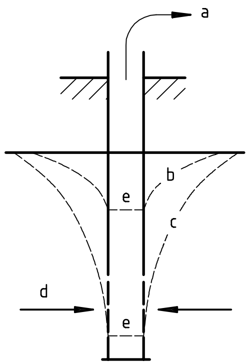
The type of pump or sampler used for micro-purging should be selected with care. Only those devices that are able to minimize disturbance of the water in the borehole column should be used. Inertial pumps, bailers and other grab samplers are not recommended for micro-purging.

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 localized 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 volatilization. During micro-purging, parameters such as electrical conductivity (κ), pH, temperature, turbidity and other contaminant-specific determinands should be monitored and purging continued until the variation in these parameters become 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 κ 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.

Table 7 — Well-purging strategies related to monitoring point design

Borehole design	Relationship of well yield (WY) and purge rate (PR)	Possible purging strategy to achieve sample objective: Integrated/composite sample	Possible purging strategy to achieve sample objective: Point/spot sample	Sample objective
• Open screened/ unscreened boreholes • Water level below or close to top of screen and base of casing  a Purged water (PR) b WY > PR c WY < PR d Well yield (WY) e Water level after purging (drawdown)	WY > PR	❶ use of alternative strategies (e.g. ❷, ❸, ❹, ❺, ❻, ❼) should be justified in comparative trials against ❶	❺, ❻	 a Integrated/Composite sample – mixed sample representative of entire open/screened section b Spot sample – sample representative of groundwater at specific depth
	WY < PR	❹ (allow water level to recover by at least 50 % before sampling)	Where PR is greater than WY, mixing of borehole waters will occur, making point/spot sampling impossible	
• Short-screened boreholes/ piezometers • Water level above top of screen  a Purged water b WY > PR c WY < PR d Well yield e Water level after purging (drawdown)	WY > PR	❶ or, after proof by comparative trials, ❷, ❸, ❺, ❼	❺, ❻ or ❶, ❷, ❸	**Purging stategy** 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
	WY < PR	❹ (allow water table to recover above screened interval before sampling)	Where the PR is greater than the WY, mixing of borehole waters will occur, making point/spot sampling impossible	