INTERNATIONAL STANDARD

ISO 5667-22

First edition
2010-08-15

Water quality — Sampling —

Part 22:
Guidance on the design and installation of groundwater monitoring points

Qualité de l'eau — Échantillonnage —

Partie 22: Lignes directrices pour la conception et l'installation de points de contrôle des eaux souterraines

Reference number
ISO 5667-22:2010(E)

PDF disclaimer

This PDF file may contain embedded typefaces. In accordance with Adobe's licensing policy, this file may be printed or viewed but shall not be edited unless the typefaces which are embedded are licensed to and installed on the computer performing the editing. In downloading this file, parties accept therein the responsibility of not infringing Adobe's licensing policy. The ISO Central Secretariat accepts no liability in this area.

Adobe is a trademark of Adobe Systems Incorporated.

Details of the software products used to create this PDF file can be found in the General Info relative to the file; the PDF-creation parameters were optimized for printing. Every care has been taken to ensure that the file is suitable for use by ISO member bodies. In the unlikely event that a problem relating to it is found, please inform the Central Secretariat at the address given below.

COPYRIGHT PROTECTED DOCUMENT

© ISO 2010

All rights reserved. Unless otherwise specified, no part of this publication may be reproduced or utilized in any form or by any means, electronic or mechanical, including photocopying and microfilm, without permission in writing from either ISO at the address below or ISO's member body in the country of the requester.

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.org
Web www.iso.org

Published in Switzerland

Copyright International Organization for Standardization
Provided by IHS under license with various National Standards Bodies
No reproduction or networking permitted without license from IHS

Licensee=Aker Solutions/5944276100, User=Tiganik, Aleksander
Not for Resale, 10/07/2016 01:14:05 MDT

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 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 5667-22 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 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 the preservation and handling of sludge and sediment samples*
- *Part 16: Guidance on biotesting of samples*

- *Part 17: Guidance on sampling of bulk suspended solids*
- *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 the design and installation of groundwater monitoring points*
- *Part 23: Determination of priority pollutants in surface water using passive sampling*

Introduction

The guidance contained in this part of ISO 5667 covers design and installation of groundwater quality monitoring points (GQMPs). It should be used in parallel with other guidance on sampling groundwater and for 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:

a) establish whether any migration of contaminants, derived from the site, is occurring and characterize the spatial extent (both laterally and vertically) of any contamination and its form;

b) determine the direction, rate and variability of groundwater flow and contaminant migration;

c) provide data for undertaking a risk assessment;

d) 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;

e) monitor the performance and effectiveness of remedial measures or facility design;

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

g) assist in the selection of remedial measures and remediation process design.

The design and installation of groundwater monitoring points is critical to ensure that representative measurements are to be made of groundwater quality. A wide range of methods and materials is currently used with no, or very little, guidance on their applicability to the issues being addressed. This results in data and information that are at best difficult to interpret as well as being highly misleading; at worst, they are completely useless. The costs involved in installation, sampling and analysis are significant and the potential impacts of incorrect decisions made on poor quality data even greater. There is therefore a need to develop best practice guidance to establish a framework that can be adopted to ensure a much greater level of confidence in groundwater quality data.

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 potential sources of contaminants, pathways for migration, receptors, the purpose of the investigation and the environment into which the installations are to be emplaced need to be considered.

Water quality — Sampling —

Part 22:
Guidance on the design and installation of groundwater monitoring points

1 Scope

This part of ISO 5667 gives guidelines for the design, construction and installation of groundwater quality monitoring points to help ensure that representative samples of groundwater can be obtained. Within the guidance consideration is given to:

a) the impact of installation materials on the environment;

b) the impact of the installation on sample integrity;

c) the impact of the environment on the installation and the materials used in its construction.

These guidelines allow the impacts to be considered and accounted for when designing a groundwater sampling programme. They also allow an informed assessment of data and results obtained from existing installations, the construction of which can potentially have an impact on sample integrity.

These guidelines are intended for installations and monitoring in different environments including those where background or baseline groundwater conditions are being established or monitored and those in which impacts of contamination are being investigated.

2 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

2.1
annulus
void between any piping, tubing or casing and the piping, tubing or casing immediately surrounding it

2.2
aquifer
geological 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[8], 6.

2.3
bentonite
clay, formed by the decomposition of volcanic ash, that swells as it absorbs water

NOTE 1 Adapted from ISO 6707-1:2004[9], 3.2.18.

NOTE 2 Refined bentonite is used to make a watertight seal. Sodium is often added in the refining process to enhance the swelling properties.

2.4
dense non-aqueous phase liquids
DNAPL
organic compounds that have low water solubility and a density greater than that of water, e.g. chlorinated hydrocarbons such as trichloroethane

[ISO 6107-2:2006[7], 34]

2.5
effective porosity
proportion of saturated openings or pores within a water-bearing formation which contribute directly to the flow of groundwater

[ISO 6107-2:2006[7], 43]

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

2.6
geotextile wrap
synthetic inert woven material wrapped around the outside of the screen to prevent entry of solid particles into the borehole or piezometer without restricting flow of water

2.7
groundwater
water which is being held in, and can usually be recovered from, a saturated or unsaturated underground formation or artificial deposit such as made ground

NOTE Adapted from ISO 6107-1:2004[6], 41.

2.8
hydraulic conductivity
property of a water-bearing formation that relates to its capacity to transmit water through its internal, interconnected pathways

[ISO 6107-2:2006[7], 53]

2.9
light non-aqueous phase liquid
LNAPL
organic compounds which have low water solubility and a density less than that of water, e.g. petroleum products

[ISO 6107-2:2006[7], 59]

2.10
multi-level sampler
single installation for sampling groundwater from discrete depths within the subsurface

[ISO 6107-2:2006[7], 67]

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.

2.11
multiple boreholes
group of individual boreholes or piezometers installed separately to form a monitoring network adequate for the purposes of an investigation

2.12
nested piezometers
group of piezometers installed within a single larger diameter borehole

[ISO 6107-2:2006[7], 69]

NOTE In general, each piezometer is designed to allow sampling over a specific depth interval within the aquifer. Piezometer tips are surrounded by a sand pack which in turn is isolated from adjacent sampling points by installing a permanent impermeable seal between them to eliminate leakage between sample points.

2.13
packer
device or material for temporarily isolating specified vertical sections within boreholes in order to perform groundwater sampling from discrete zones or locations within the borehole or aquifer

[ISO 6107-2:2006[7], 75]

2.14
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

NOTE Adapted from ISO 6107-2:2006[7], 79, “perched water table”.

2.15
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 or groundwater sampling

NOTE Adapted from ISO 6107-2:2006[7], 81.

2.16
receptor
⟨sampling of ground water⟩ entity that is vulnerable to the adverse effect(s) of a hazardous substance or agent

[ISO 6107-2:2006[7], 100]

NOTE An entity is something that may suffer harm or damage if exposed to the hazard, e.g. humans, animals, aquatic ecosystems, vegetation or building services.

2.17
groundwater response zone
section of a borehole or groundwater monitoring point that is open to the host strata

2.18
saturated zone
part of an aquifer in which the pore spaces of the formation are completely water-saturated

[ISO 6107-2:2006[7], 119]

2.19
well screen
section of borehole casing that is perforated with either slots or holes to allow the entry of groundwater

2.20

tremmie pipe

narrow (25 mm to 50 mm) diameter plastic pipe placed down the annulus of an installation for the purpose of adding filter materials and sealants

2.21

unsaturated zone

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

[ISO 6107-2:2006[7], 150]

3 Principle

3.1 General

The installation and operation of groundwater monitoring points generally forms one part of an investigation or operation that also involves other technical considerations and objectives. This guidance includes consideration of the broader objectives of the investigation and the purpose of boreholes or monitoring points, and the need to build in flexibility.

The development of a design plan is recommended. This plan should consider all potential factors that can influence monitoring point installation and operation. This includes whether the facility is required for short-term or long-term use, the range of parameters that are to be measured or determined, acceptable tolerances, and quality of data. The design framework in Figure 1 can be used to support the process and allow the relevant factors and key considerations for monitoring point design and construction to be considered.

3.2 Monitoring objectives

The principal objective of all groundwater quality monitoring installations is to obtain a representative groundwater sample to be collected. The purpose for which the sample is being obtained should fall into one of three categories:

a) strategic: monitoring to obtain background or baseline information on groundwater quality and to identify wide-scale trends in quality due to changing natural conditions or pollution;

b) defensive: monitoring around a known activity such as a waste disposal site, around a sensitive receptor (e.g. a groundwater dependent wetland) or to monitor remediation of groundwater;

c) investigative: monitoring to investigate and characterise groundwater below or adjacent to areas of known or suspected contamination — this also includes monitoring of free-phase liquids (e.g. LNAPLs).

Objectives may change during the lifetime of a groundwater quality monitoring installation and they may also have multiple objectives at any one time. The monitoring installation should be designed to be as versatile as possible.

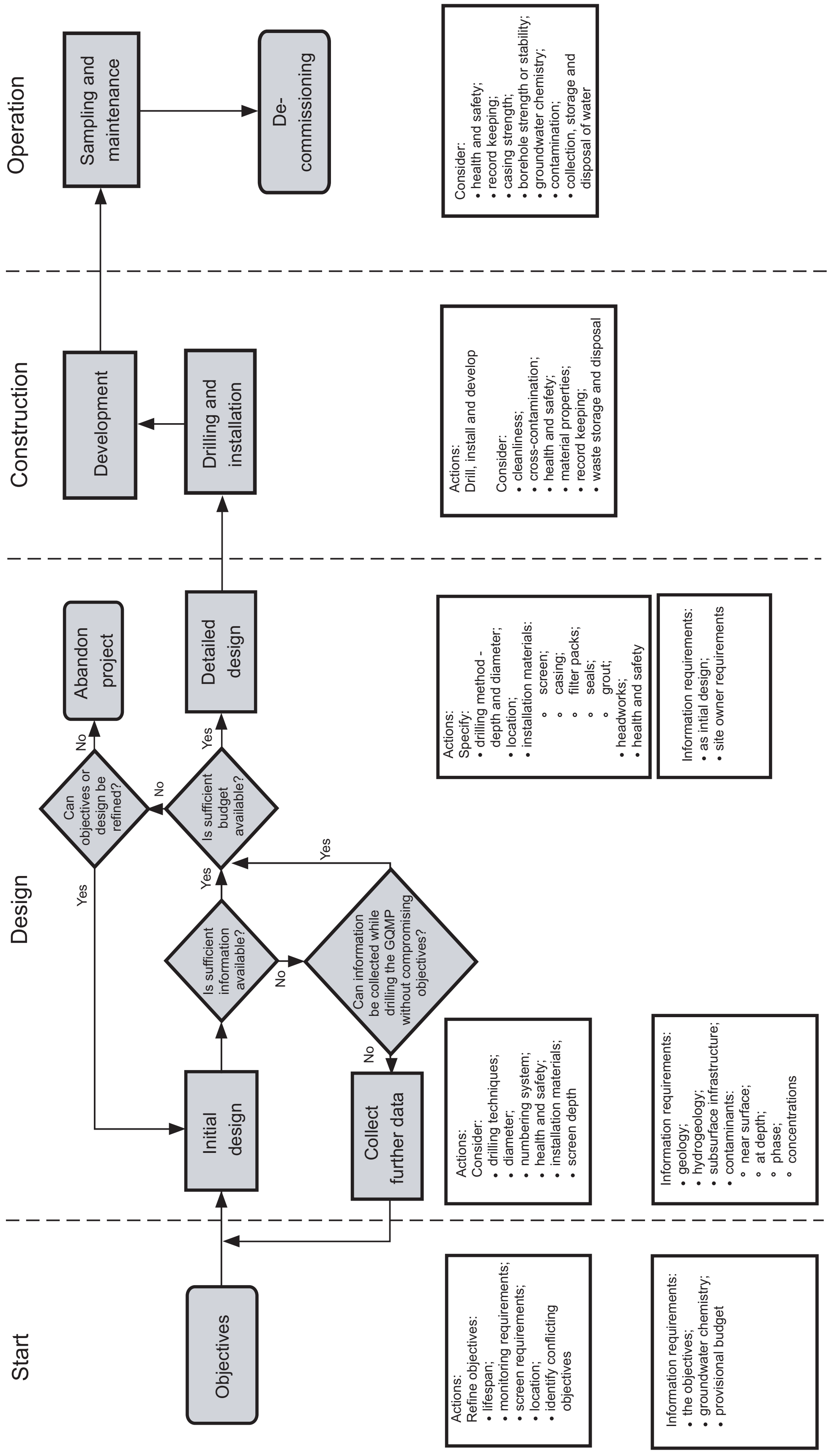


Figure 1 — Design and Installation flow chart

4 Design

4.1 Introduction

4.1.1 General

The design considerations for a groundwater quality monitoring installation can be divided into two phases: a) initial design and b) detailed design.

Initial design represents a preliminary assessment of the considerations, while detailed design represents a thorough in-depth examination of the issues and the decision-making leading to installation.

4.1.2 Initial design

The initial design phase should be a quick and relatively simple process. It should consider the design basics and available options. This includes drilling method (and flushing medium to be used), borehole location and depth, outline design and cost estimates, and identification of information gaps. This stage of work should form the basis of the information needed to hold preliminary discussions with stakeholders, clients, and drillers. Following the initial design stage, potential difficulties should have been identified along with potential solutions, the likely costs, and any significant health and safety issues.

4.1.3 Detailed design

At this stage, the groundwater quality monitoring installation design is developed in detail to allow the specification to be finalised, and procurement and construction commissioning processes to be put in place.

4.2 Conceptual model

4.2.1 General

An understanding of the subsurface environment is vital if the groundwater quality monitoring installation is to operate effectively. This understanding can be developed within the context of a conceptual site model. The conceptual site model represents a collection of information that allows the subsurface conditions to be visualised. For groundwater quality monitoring installations, it should comprise geological or hydrogeological information. The geological environment is the most significant factor in the selection of a drilling technique. The strata type and thickness influence drilling methodology, choice of materials and design of response zones. The degree of understanding required to allow a suitable design is determined by:

a) the (anticipated) complexity of the environment;

b) cost-benefit analysis, e.g. whether the cost of further investigation is justified by improved design or understanding;

c) type of installation being considered, e.g. multi-level installations require more detailed information.

Examples of the geological information that is required for soils and rock are listed in the following.

For soils, the following factors may influence drilling technique selection:

1) degree of cohesion, where fine soils are more likely to stand open than coarse soils;

2) density of coarse, granular deposits, where temporary casing is almost always required in granular deposits, which tend to “blow” below the water table and require the addition of water;

3) absence or presence of cobbles, boulders, and stones which some soil-drilling techniques may be unable to penetrate;

4) thickness, where difficult drilling conditions may often be overcome if the soil is thin, but may require specialist techniques when they are thick;

5) saturated or unsaturated conditions, where unsaturated sands may run into the hole while saturated sands may blow.

For rock, the important factors are:

i) rock strength, where weak rock can often be penetrated using soil-drilling techniques, while strong rock slows drilling progress and causes refusal of some techniques;

ii) depth or thickness to be penetrated;

iii) presence of weathered or weak zones, which may require the borehole to be supported by temporary casing;

iv) presence of voids such as fractures, solution features, and mine workings, which may cause loss of flushing medium.

4.2.2 Rock strength

The relative strength of a geological deposit affects the rate of drilling, the need for support of the borehole walls and the strength required of the installation materials. Loose, coarse and soft, fine deposits always need support with temporary casing or the use of drilling muds, except where direct push installation methods are used. Support may also be needed in highly-fractured rock where blocks or wedges may move into the borehole. Drilling through mine workings may encounter loose ground which can block the borehole.

Swelling clays can lead to difficulties during drilling and installation, as these deposits can swell into the borehole void, reducing the effective diameter. If support cannot be given to the borehole walls (either because of the drilling method or the risk of having temporary casing seize in the hole), then installation should immediately follow drilling to reduce the potential loss of the hole. Chemical additives may slow or eliminate the swelling effect; however, because of their potential effect on groundwater chemistry, additives should only be used after careful consideration.

Loose sands below the water table often “blow” into the borehole. This results from a head difference between the water level inside the temporary casing and the surrounding soil, leading to sand moving into the casing. This effect may be further enhanced by suction created by the drilling action, which draws more material inwards. The potential outcome is that the temporary casing fills with sand at a faster rate than the drilling operation can remove it, and it can then become difficult to remove the temporary casing. To minimise the effect of blowing, it may be necessary to maintain the water level inside the temporary casing above that of the outside, by adding water.

4.2.3 Depth

The required depth of the groundwater quality monitoring point (GQMP) influences the choice and quantity of casing materials and the choice of drilling technique (see 4.3). Most techniques are capable of drilling shallow boreholes, but as depth increases, so does its impact on the design. Some drilling techniques are limited in the depth to which they can penetrate because of physical constraints, such as excessive frictional resistance in augering and direct push techniques.

Cable tool drilling is usually limited by the rate of progress, which decreases with depth, and by the size of equipment needed, where larger rigs are required for deeper holes.

Rotary drilling techniques can be used in shallow boreholes, but the ancillary equipment and relatively expensive mobilization can constitute a large outlay.

The depth of the borehole and the depth to the water table determine the choice of installation materials and casing diameter. The casing string should be of sufficient strength to accommodate the extensional stresses incurred by its own mass when hanging in the borehole. The weakest point on a casing string is usually the joints, and material suitability is an important consideration for deep boreholes. For buoyant materials, the critical length when calculating the maximum extensional stress is the depth to the water table.

4.2.4 Hydrogeological considerations

The depth to the water table influences the choice of drilling method, casing and screen materials. For the drilling technique, some materials may behave differently when saturated or unsaturated, and the drilling penetration rate and strata stability may be affected. When drilling with a percussive rig, there may be a requirement to add water or flush to aid the recovery of drill cuttings.

Some casing materials are limited by the length that can be suspended in a borehole before failure occurs, usually at the joints. Many plastics have some buoyancy in water which means that the suspended length can be increased in a saturated borehole compared to a dry one.

Artesian conditions affect the drilling method, the headworks design, and the installation method. Special precautions should be taken where artesian heads are expected, as uncontrolled release of water could affect the environment or create a health and safety risk. Where artesian conditions are likely, specialist drilling advice should be sought.

Locating the water table and understanding its likely fluctuations are necessary to establish the depth and length of the screen. The location of the screen should be linked to the objectives and should be cut or preferably manufactured to size. Casing and screen sections come in standard lengths, typically 1 m or 3 m; if necessary, these can be cut to size on site.

In general, monitoring zones are located within permeable horizons and need to be accurately located. In multi-layered aquifer systems and where contamination is present, care is required to prevent different permeable horizons from becoming connected during drilling or installation. The driller's awareness of the objectives prior to the start of work benefits data recording during drilling and ensures that important changes in lithology and water strike information are not missed. The hydraulic properties of the strata affect the filter pack and screen design, the choice of development technique and the potential for loss of flush during rotary drilling, and may affect the choice of drilling technique. A guide to material selection is given in 4.5. Where the groundwater chemistry could be hazardous to health, additional health and safety requirements may be necessary. Groundwater conditions may also affect the choice of backfill and these should be considered before finalizing material selection.

The presence of separate phases (LNAPLs and DNAPLs) in the monitored horizon influences the design of the screen, the choice of casing material, and the drilling technique. The presence of non-aqueous phase liquid (NAPL) and its implications for screen design are discussed in 4.5.4. In the presence of free-phase organics, the casing should withstand corrosion by NAPL.

The presence of free-phase contaminants also has implications for health and safety, and for contaminant migration during drilling. The contaminants likely to be encountered affect the choice of material (suitability in terms of sorption, contaminant release, risk of corrosion), the drilling method, and the health and safety assessment. Contaminated spoil and groundwater require special handling, storage, and disposal.

4.3 Drilling method and installation size

4.3.1 General

The choice of technique should be based upon consideration of:

a) ability to penetrate the formations anticipated;

b) depth and diameter requirements — borehole diameter is a function of the installation diameter and the need to leave space around the casing (the annulus) to permit effective installation of filters and sealing materials (a minimum annulus of 38 mm is recommended), also it might be necessary to start the borehole at a large diameter to achieve a suitable final diameter at depth;

c) impact on groundwater quality (particularly the use of flush);

d) sampling requirements for borehole logging;

e) extent of disturbance of the formations encountered (e.g. smearing of side walls);

f) the need to minimise cross-contamination by mobile contaminants between aquifer units;

g) the variability, complexity and requirements of the borehole, e.g. where low permeability layers are separating aquifers and it is essential these aquifers remain separate;

h) access restrictions;

i) availability;

j) relative costs;

k) other objectives [requirements for geotechnical, hydraulic testing or geophysical (well) logging].

A description of the drilling techniques most commonly used for the installation of GQMP is provided in Annex A.

4.3.2 Influence of geology on drilling technique selection

The nature of the underlying geology is the most significant factor in the selection of drilling techniques. For example, the presence of hard rock may preclude the use of cable tool rigs, while a need to employ temporary casing to prevent caving or collapse of loose deposits favour its use. In difficult ground conditions or where substantial drift overlies competent strata, a combination of cable tool and rotary drilling techniques may be required. Since geological conditions are often complex and may be poorly understood prior to drilling, a number of generic situations have been considered and are outlined in Tables 1 to 3. Each technique is rated for a range of different ground conditions. The tables should be used as a guide and site-specific information should be assessed prior to making a decision on drilling technique.

4.3.3 The influence of depth

For deeper boreholes (generally over 50 m), the number of techniques is limited and rotary and sonic drilling are usually the only suitable options. Cable drilling is suitable, depending on the size of the drilling rig, for depths up to 50 m.

4.3.4 Borehole diameter

The borehole diameter is dictated by the required installation diameter and the need to leave space around the casing (the annulus) to:

a) permit effective installation of filters and sealing materials;

b) allow for uneven sidewalls;

c) permit use of installation equipment;

d) minimize risk of installation materials blocking the hole (bridging).

Depending on depth, ground conditions, and drilling technique, it may be necessary to start the borehole at a larger diameter to achieve a suitable final diameter at depth — drilling costs generally increase as borehole diameter increases.

Table 1 — Drilling techniques for fine soils

Drilling method	Very soft to firm			Firm to hard			Deposits with cobbles or boulders
	Suitability	Stability	Sampling	Suitability	Stability	Sampling	Suitability
Cable tool[a]	✓✓	✓✓✓	✓✓	✓✓	✓✓✓	✓✓✓	✓✓
Rotary[b]	✓✓✓	✓✓	✓	✓✓	✓✓	✓	✓✓
Sonic[a]	✓✓	✓✓✓	✓✓	✓✓	✓✓✓	✓✓✓	✓✓
Direct push or jetting	✓✓✓	×	—	✓	—	—	×
Hollow stem auger	✓	×	✓	✓	✓	✓	×

Key

—	not relevant
×	inappropriate
✓	appropriate but not ideal
✓✓	appropriate
✓✓✓	most appropriate

[a] Using temporary casing.

[b] Drilling without cores.

Table 2 — Drilling techniques for coarse soils[a]

Drilling method	Dense sand			Loose sand[b]			Dense gravel			Loose gravel		
	Suitability	Stability	Sampling	Suitability	Stability	Sampling	Suitability	Stability	Sampling	Suitability	Stability	Sampling
Cable tool[c]	✓✓✓	✓✓✓	✓✓	✓✓	✓✓	✓✓	✓✓✓	✓✓✓	✓✓	✓✓	✓✓✓	✓✓
Rotary[d]	✓✓✓	✓✓	✓	x	x	✓✓	✓✓✓	✓✓	✓	✓	✓	✓✓
Sonic[c]	✓✓	✓✓✓	✓✓✓	✓✓	✓✓	✓✓	✓✓	✓✓✓	✓✓✓	✓✓	✓✓	✓✓
Direct push or jetting	×	—	—	✓✓✓	—	—	×	—	—	✓	—	—
Hollow stem auger	✓	✓✓	✓✓	✓✓	✓✓	✓✓	✓	✓✓	✓✓	✓✓	✓✓	✓✓

Key

—	not relevant
×	inappropriate
✓	appropriate but not ideal
✓✓	appropriate
✓✓✓	most appropriate

[a] The degree of consolidation and compaction of a material is used to determine whether it is “dense” or “loose”. A dense sand/gravel is one that is well compacted, has greater bulk density and has a greater shear strength than loose sands/gravels.

[b] In blowing sand, difficulties may be encountered with all techniques.

[c] Using temporary casing.

[d] Drilling without cores.

Table 3 — Drilling techniques for rock

Drift conditions	Weak to moderately weak rock (including weathered rock)	Moderately strong and strong rock
Cable tool	✓✓	×
Rotary	✓✓✓	✓✓✓
Rotary percussion	✓✓✓	✓✓✓

Key

×	inappropriate
✓	appropriate but not ideal
✓✓	appropriate
✓✓✓	most appropriate

4.4 Installation design

4.4.1 Monitoring point installation

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

a) single screened or unscreened wells, boreholes or piezometers [Figure 2 a) and b)];

b) nested piezometers in a single borehole completion [Figure 2 c)];

c) discrete horizon or multi-level samplers [Figure 2 d) and e)];

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

4.4.2 Locating response zone

The response zone is that part of the monitoring point open to the aquifer or geological formation from which a groundwater sample is to be collected. Its location is a function of the monitoring objectives, including the required depth, and the type of liquids. Factors that can influence response zone design include:

a) range of water table elevations;

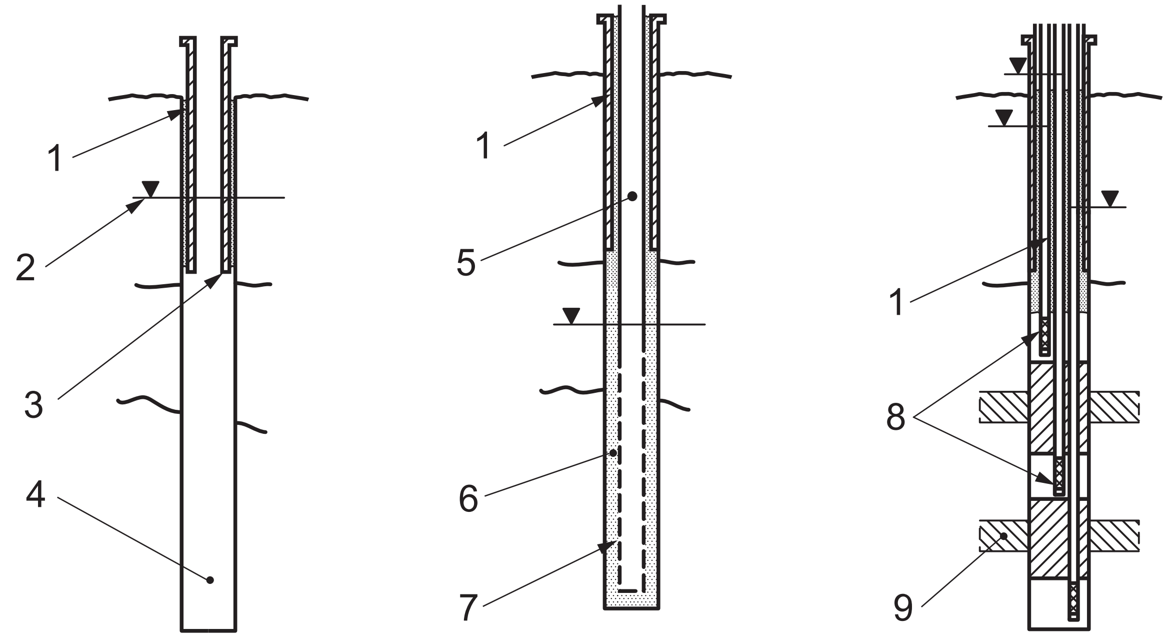
b) presence of NAPL;

c) thickness of unit to be monitored;

d) hydraulic performance requirements;

e) avoidance of vertical flows and cross-contamination.

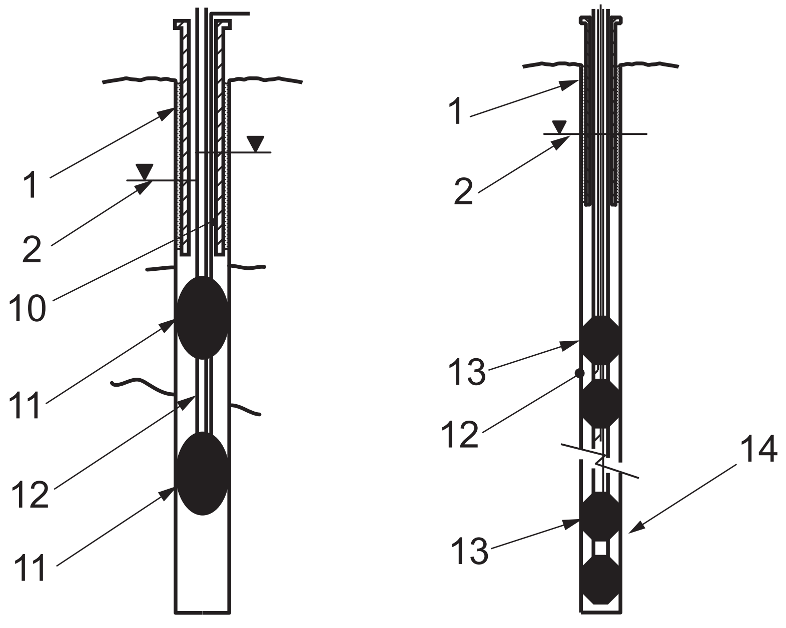
Long response zones should be avoided where possible, as these can induce vertical flow and contaminant movement and may therefore disturb the natural flow patterns and geochemistry. They may also form preferential pathways for contaminant migration. In this part of ISO 5667, long response zones are assumed to be greater than 3 m.



a) **Open borehole**

b) **Screened borehole or piezometer**

c) **Nested piezometer**



d) **Borehole with packers**

e) **Multi-level sampler**

Key

1	sealing material
2	water table
3	casing pipe
4	open well or borehole
5	well casing or piezometer pipe
6	gravel pack
7	slotted well or piezometer screen
8	piezometer
9	aquitard
10	packer gas inflation line
11	packer
12	isolated borehole section
13	packer or sealing material
14	sample port

Figure 2 — Major types of monitoring installation

Table 4 — Advantages and disadvantages of different monitoring point installations

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

Where monitoring for the presence of DNAPLs is required, users should note that the lower parts of most screen lengths do not contain slots or holes, as this is where the threads are located. Where the intention is to measure DNAPL at the base of a permeable unit, the hole should be slightly over-deepened to permit DNAPL sitting at the base of the unit to enter the GQMP, although care should be taken to ensure that DNAPL does not infiltrate deeper into the aquifer system. Where this approach has been adopted, allowance should be made in subsequent measurements of DNAPL thickness to take account of the “sump” created at the bottom of the GQMP.

4.4.3 Multi-level monitoring

Multi-level monitoring (MLM) systems represent a cost-effective and efficient method of installing a number of GQMPs through an aquifer system where an understanding of vertical hydrogeological processes and contaminant distribution is required.

Clustered piezometers in separate boreholes can also be used to monitor the vertical variation in groundwater quality in a similar manner to MLM systems. However, there is a potential lateral variation in the sampling results, which may be significant in some settings, and in general there are increased drilling and installation costs.

4.5 Construction material selection

4.5.1 General

Installations for groundwater sampling should be constructed with materials that do 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 5 identifies some of the commonly available construction materials and their properties. When selecting materials, the important points to consider include:

a) ability to meet sampling requirements;

b) resistance to chemical attack;

c) adequate physical strength;

d) minimal impact on groundwater sample;

e) ability to yield adequate sample.

Table 5 — Common borehole installation construction materials

Material	Comments
Fluoropolymers	
PTFE (polytetrafluoroethylene)	Ideal in the most aggressive environments as they are nearly totally resistant to chemical and biological attack.
ETFE (ethylene tetrafluoroethylene)	Expensive and difficult to handle and joint forming strength limited. These materials are not suitable for deep or large diameter installations.
FEP (fluorinated ethylene propylene)	Recommended for use where organic compounds and trace metals are important.
FRP (fibre-reinforced polymers)	
Metals	
Carbon steel	Generally stronger, more rigid and less temperature sensitive than plastics. More suitable for large diameter and deeper installations.
Low carbon steel	Potential for corrosion with the resultant products affecting groundwater quality.
Galvanized steel	Stainless steel performs well in most corrosive environments.
Stainless steel	Some susceptibility to corrosion where there is significant microbial activity.
	Can introduce metal contamination and particularly influence trace metal concentrations.
Thermoplastics	
uPVC (unplasticized polyvinyl chloride)	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 can bend if installed in a larger diameter hole. This can lead to difficulties in installing/removing sampling equipment and so plastics with a larger wall thickness can be required.
HDPE (high density polyethylene)	Generally resistant to corrosion in short- to medium-term.
ABS (acrylonitrile butadiene styrene)	Organic contaminants pose a threat of chemical attack, especially to PVC. Sorption of contaminants can also occur.
Polypropylene	Low-cost materials, ideal for most general contaminated land/groundwater investigations.
	O-ring seals incorporated into threaded coupling can give leaktight joints.
	The use of transparent plastics can facilitate the use of borehole CCTV/video cameras.

A variety of materials are introduced into the ground as part of borehole construction, such as:

1) well screen and well casing [e.g. high density polyethylene (HDPE), unplasticized polyvinyl chloride (uPVC), polytetrafluoroethylene (PTFE), stainless steel];

2) multi-level sampling devices;

3) geotextile wraps;

4) filter packs (sand or gravel);

5) sealing materials (e.g. bentonite);

6) headworks;

7) pumping and sampling equipment.

Introducing materials into a previously undisturbed environment can result in chemical and biological alteration of both the materials and the groundwater. This in turn may reduce material performance, e.g. through clogging or failure through weakening and collapse. If the groundwater is altered, the samples obtained may not be representative, which may compromise the objectives of monitoring. Consequently, materials and method of installation are major considerations in the design process. Some considerations are:

i) the chemical environment in which the installation is placed — aggressive environments (saline, free-phase, low or high pH) rapidly degrade or corrode some materials;

ii) effect of materials on contaminants, such as sorption, oxidation, reduction;

iii) effect of contaminants on materials: corrosion, solution, strength, leaching;

iv) effect of materials on groundwater: leaching, oxidation, pH;

v) effect of flushing fluids on the environment: aeration, mixing, clogging, reducing environment;

vi) economic considerations.

The likely concentrations of key determinants should also be considered and can be divided into the following broad categories:

i) gross — present at high concentrations or as free-phase;

ii) low — substances thought to be present as minor constituents but at concentrations well above their detection limits;

iii) trace concentrations — substances assumed to be absent or present at concentrations close to detection limits.

The use of degreasants, lubricants, drilling muds, and oils during drilling should be avoided if at all possible, particularly when considering sampling for organic compounds.

4.5.2 Casing materials

Components and materials in the borehole need to survive for the projected lifespan of the installation. Pressures on materials can come from corrosion, gravitational forces, water pressure differentials (especially during development and sampling) and lateral pressures from ground movement and swelling clays.

Metals other than stainless steel are not generally considered suitable for use in a GQMP as they are subject to corrosion. Metal corrosion reduces the lifespan of an installation, through weakening and possible collapse, and may also affect groundwater chemistry in the GQMP and the surrounding aquifer, e.g. through the release of iron and trace metals.

The choice of casing material is therefore limited to plastics (HDPE, PTFE, ABS, uPVC), stainless steel and, in some cases, unusual materials such as fibreglass, silica or ceramics. The relative strengths of different materials are shown in Table 6.

Table 6 — Relative strengths of casing materials

Casing material	Compressional strength	Tensile strength	Fragility or impact strength
Stainless steel	✓✓✓	✓✓✓	✓✓✓
Plastics			
HDPE	✓	✓	✓✓
PTFE/FEP	✓	✓	✓
uPVC	✓✓	✓✓	✓
FRP	✓✓	✓✓	✓

Key

✓	low
✓✓	moderate
✓✓✓	high

The casing material also has the potential to affect the surrounding water quality through both release and sorption of chemical compounds. A summary of the suitability of different casing types in different chemical environments is shown in Tables 7 to 9.

Table 7 — Susceptibility of casing materials to degradation in the presence of free-phase contaminants

Casing material	LNAPL (hydrocarbons)	DNAPL (chlorinated solvents)
Stainless steel	✓✓✓	✓✓✓
Plastics		
HDPE	✓✓✓	✓
uPVC	×	×
ABS	×	×
PTFE/FEP	✓✓✓	✓✓✓
FRP	✓✓✓	✓✓

Key

×	not appropriate
✓	appropriate but not ideal
✓✓	appropriate
✓✓✓	most appropriate

Table 8 — Susceptibility of casing materials to corrosion in aggressive groundwater conditions

Casing material	Groundwater conditions			
	Acidic	Alkaline	Reducing	High salinity
Stainless steel	✓✓	✓✓✓	✓✓	×
Plastics				
HDPE	✓✓✓	✓✓✓	?	✓✓✓
uPVC	✓✓✓	✓✓✓	?	✓✓✓
ABS	✓✓	✓✓	?	✓✓✓
PTFE/PTFE-FEP	✓✓✓	✓✓✓	?	✓✓✓
FRP	✓✓	✓✓✓	?	✓✓✓

Key

?	insufficient data available to draw conclusions
×	not appropriate
✓	appropriate but not ideal
✓✓	appropriate
✓✓✓	most appropriate

Table 9 — Casing suitability for target determinants

Casing material	Dissolved contaminants				
	Metals	Minerals or major ions	BTEX[a] or PAHS[b]	Chlorinated solvents	Pesticides or PCB[c]
Stainless steel	×	✓✓	✓✓✓	✓✓✓	✓✓✓
Plastics					
HDPE	✓✓✓	✓✓✓	✓✓✓	✓✓✓	✓✓
uPVC	✓✓✓	✓✓✓	✓✓✓	✓	✓
ABS	✓✓✓	✓✓✓	×	×	?
PTFE/PTFE-FEP	✓✓✓	✓✓✓	✓✓✓	✓✓✓	✓✓✓
FRP	✓✓✓	✓✓✓	✓✓✓	✓✓✓	?

Key

?	insufficient data available to draw conclusions
×	not appropriate
✓	appropriate but not ideal
✓✓	appropriate
✓✓✓	most appropriate

[a] Benzene, toluene, ethylbenzene, and xylenes.

[b] Polycyclic aromatic hydrocarbons.

[c] Polychlorinated biphenyls.

Consideration should also be given to materials associated with the casing. Rubber O-rings, for example, may be unsuitable for use between casing lengths in the presence of organic contaminants since they may degrade or cause sorption. More suitable O-rings manufactured from proprietary materials may be available.

When joining lengths of casing, the use of glues and welds should be avoided because of the risk of introducing additional chemicals into the environment. Screw threads are the most commonly used and generally the most appropriate joining mechanism, although the threads represent weak points in the casing length. All joints should be flush on the inside of the casing to reduce the risk of snagging or trapping of sampling equipment. They should also be flush on the outside to permit the insertion of a tremmie pipe down the annulus and to avoid bridging of backfill materials.

Threaded joints between casing lengths should not be lubricated by any material that may compromise the GQMP. Greases containing metals or hydrocarbons should never be used.

4.5.3 Filter packs

A filter pack is required to prevent the influx of fines into the borehole and to stabilize the flow to the sampling point. Turbid samples or samples with a high suspended solids content can affect analysis. Silt entering the borehole can clog the screened section.

The filter pack should be matched to the aquifer and to the size of the screen openings (usually referred to as slot size). An appropriately designed filter pack and screen prevent or limit the entry of fine material into the casing. Accurate filter design requires a particle size distribution (PSD), preferably from sieve analysis, but an estimate of the PSD can be made from visual inspection for the geological formation.

An example of a simple rule for the design of a filter pack is as follows (after Reference [17]):

$$\frac{D_{15,\,\mathrm{f}}}{D_{85,\,\mathrm{a}}} < 4 < \frac{D_{15,\,\mathrm{f}}}{D_{15,\,\mathrm{a}}}$$

where

$D_{15,\,\mathrm{f}}$	is the nominal size of openings of a sieve through which 15 % mass fraction of filter material passes;
$D_{15,\,\mathrm{a}}$	is the nominal size of openings of a sieve through which 15 % mass fraction of aquifer material passes;
$D_{85,\,\mathrm{a}}$	is the nominal size of openings of a sieve through which 85 % mass fraction of aquifer material passes.

It is also good practice to match the grading curve of the filter pack to that of the formation — in other words, they should have the same shape, but the filter pack should have a larger grain size by a factor of four to six times (see Figure 3).

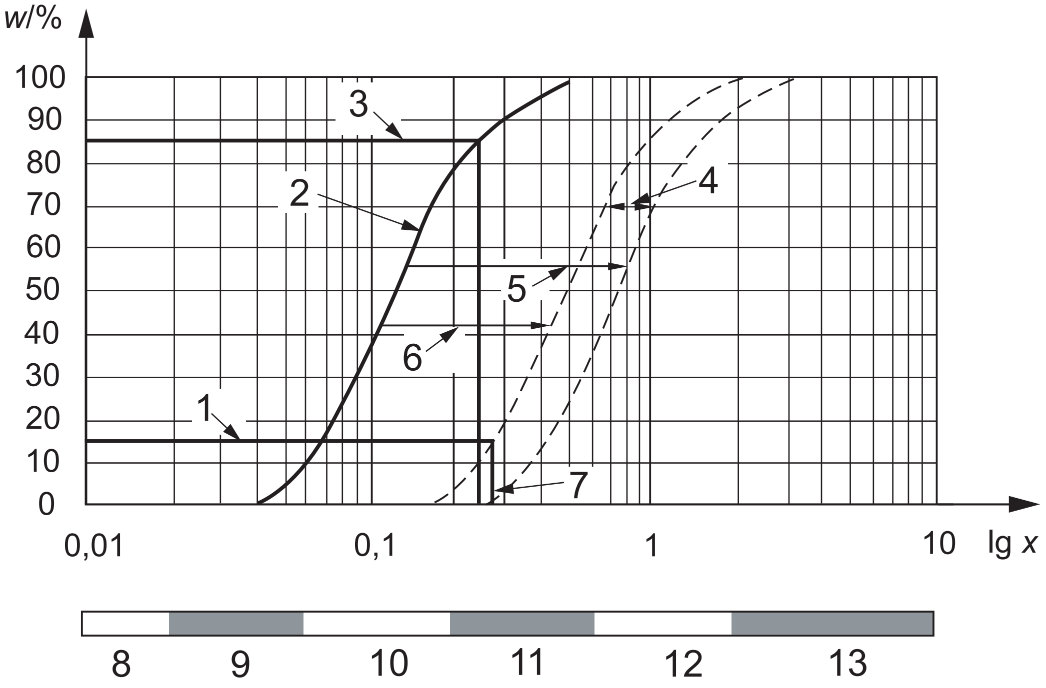
Other methods for the design of filter packs can be found in relevant literature but in general they are based on a similar approach and only vary in minor detail.

The filter pack material should also be inert — a mass fraction of more than 95 % silica or preferably 99 % mass fraction silica. It should also be free of reactive minerals such as:

a) iron, which can form an electron acceptor for degradation of organics;

b) carbonates, which may alter the groundwater chemistry and can dissolve and recrystallize leading to a reduction in the permeability of the filter pack;

c) organic material (such as unwashed fluvial sands) that can sorb organic materials.



Key

1	D_{15} aquifer
2	aquifer grain size distribution
3	D_{85} aquifer
4	filter pack "envelope"
5	aquifer PSD times 6
6	aquifer PSD times 4
7	D_{15} filter
8	clay
9	silt
10	fine sand
11	medium sand
12	coarse sand
13	gravel
w	mass fraction passing though the sieve
x	grain size, in millimetres

Figure 3 — Filter pack design (after Reference [17])

4.5.4 Screen selection

Installation design should also consider the size of openings (slot size), screen type and open area of the GQMP to ensure protection from fouling through silting and biological activity and to allow sufficient ingress of water for sampling. Well screen should be obtained from recognized suppliers to the water well industry.

Four different screen types are commonly used:

a) continuous slot (steel or plastic) with predetermined slot width;

b) cut slots to predetermined size;

c) porous, permeable plastic casing;

d) bridge-slotted screen.

The continuous wire wrap screen is formed from a single length of wire coiled into a cylinder around a number of supporting struts. The wire is wedge shaped in section with the apex pointing toward the centre of the borehole. This shape minimizes the potential for clogging, allowing small grains to be pulled into the installation rather than clogging the screen. Continuous slot screens are currently available in plastics and stainless steel and have the highest proportion of open area to facilitate water inflow.

Slotted well screen in uPVC or other plastics is the cheapest and most frequently used screen type. Slots are produced by the manufacturer to the required width and frequency. Open area is determined by the number of slots, their width and the diameter of the screen. High open area screens with narrow slots can lead to fragile and flimsy casing. Very narrow cut slots, in weak material and in deep boreholes where large loads may be imposed, may deform and partially close. Appropriate wall thickness and material specifications are critical for deep installations.

Permeable plastic casing (available from a single supplier) is manufactured from HDPE. The screen has a range of pore sizes and porosities which allow water to penetrate through the casing. These screens are designed for boreholes where filter packs may not be suitable or cannot be used.

The size of openings of the screen should be selected to minimize the ingress of fine materials into the borehole and to maximize the hydraulic performance. In fine formations it is difficult to construct slot sizes which are sufficiently small to prevent the ingress of fine particles, and a geotextile wrap is often used.

The required slot size of the screen is determined from the grain size of the filter pack, which in turn is designed with reference to formation grain size. The screen slots should be small enough to prevent 90 % mass fraction of the filter pack material entering the GQMP, i.e. equivalent to the grain size of the finest 10 % mass fraction (the D_{10} of the PSD) of the filter material. In fine deposits (silts and clays) or in formations where there is a high proportion of silt or clay, the screen and filter should be supplemented with a geotextile wrap and a fine sand filter pack used. Where a geotextile wrap is used, consideration should be given to its mesh size, particularly when hydraulic testing of the borehole is proposed, and to the material employed due to the potential risk of release or sorption of organic substances. Geotextiles may be prone to clogging, although this may be remedied with backwashing.

4.5.5 Sealing and backfilling the borehole

The annular space from the top of the filter pack to ground level (or other monitoring zones in multiple installations) should be backfilled with a material that:

a) prevents interconnection of aquifer units;

b) prevents preferential flow of contaminants or recharge;

c) supports and protects the casing.

This is achieved by placing a seal immediately above the filter zone and then backfilling the remainder of the annular space with a low permeability grout.

The choice of material depends upon the geological and hydrogeological setting, the risk of contaminant mobilization along the borehole and the available budget. In general, seals are made from bentonite (pellets, granules or slurry) and grouts are made up of cement grout, bentonite grout or a cement and bentonite mix. To prevent these materials entering the screened section of the borehole — grout contamination is a common problem with installations — a seal should always be placed on top of the filter pack.

4.6 Headworks

Borehole headworks form the interface between the borehole and the surface environment, and serve to complete the borehole and to allow continued access over time. In designing headworks, a number of issues require consideration:

a) security — headworks should prevent unwanted access to the borehole by humans or burrowing animals;

b) protection — headworks should protect the borehole from the elements, from entry of water or other foreign material and from activities at the surface (such as vehicle movements);

c) accommodation of equipment — headworks may be required to have space for the storage of equipment such as data loggers and dedicated sampling devices;

d) visibility — where headworks need to be clearly visible, an appropriate design and colour scheme should be chosen; where visibility is not desired, the design should reduce visual impact.

A variety of commonly used headwork designs is described in Table 10 and example diagrams are given in Annex B. The diagrams are intended to be generic baselines which can be copied, annotated, and used in specifications. In general, where no particular preference is stated, an above-ground design should be used. The above-ground design is less likely to suffer from inundation, is easier to find in the field and is generally easier to secure. In most cases, however, the headworks design is determined by consideration of the requirements of the site owner or user and by the need to incorporate monitoring equipment.

All headwork designs should provide a degree of protection to the borehole to prevent access of recharge and contaminants to the grout and casing interface or the grout and ground interface.

Table 10 — Headwork types

Headwork type	Advantages	Disadvantages
Raised tube	Less likely to flood	Highly visible, making it prone to vandalism
	Easy to find	Forms an obstruction to vehicles
	Visible and therefore less likely to be run over or ploughed up	Storage of instruments may be limited
	Easy to secure (such as with a padlock)	Risk of collision damage (risk to and from livestock)
	Easier to work with for sampling (no need to bend right down) and does not involve heavy lifting	
	Able to contain small artesian heads (up to 1,5 m)	
Flush stop cock-type cover	Unobtrusive	Vulnerable to flooding
	Less susceptible to ground disturbance	Difficult to locate in vegetated areas and may be inadvertently buried during site works
	Suitable to be walked or driven over	May be difficult to secure effectively
		Can be mistaken for a disposal point (sewer or soakaway)
		Access is limited
		Storage of instruments may not be possible
Manhole chamber	Unobtrusive	Vulnerable to flooding
	Can be driven over if carefully installed	Can be heavy to lift
	Permits storage of instruments	

4.7 Surface environment

In locating the GQMP, the design should consider health and safety implications, headworks, and landowner requirements. A visit to the proposed location should be made prior to the design being finalized to consider:

a) access routes, access limitations and arrangements for ongoing access;

b) facilities (water, power, storage areas);

c) potential for disturbance or damage;

d) health and safety — need for security or uneven ground or hazard identification;

e) nuisance (disturbance to residents or occupants from noise and dust, unwanted access such as vandalism).

The visit should be documented and photographs of the proposed drilling sites and access routes taken.

The range of potential environmental factors that can affect the installation and influence the design should be identified and mitigating measures for each identified. These factors include:

1) surface topography and effects of surface and meteorological events, e.g. flooding, UV effects;

2) vegetation and its effects;

3) security and protection from attack by animals, vermin and humans;

4) “trafficability” — ability to withstand external mechanical influences.

Protective options should be identified, ranging from the use of special completion designs through to the adequate marking of monitoring points to allow future location.

5 Construction phase

5.1 General

The quality of the GQMP installation depends upon the design being correctly and competently implemented. The installation of GQMPs requires supervision by an appropriately qualified and experienced person. The supervisor's principal role is to ensure that the monitoring installation is constructed in accordance with the specification and good practice. The supervisor is also responsible for keeping accurate “as built” records.

5.2 Record keeping

It is of little use to carefully construct a GQMP if the details of the construction are not accurately and permanently recorded. Records should be adequate for accurate completion of “as built” drawings, giving details of observations during drilling, water encountered, and installation depths and dimensions. A lack of essential information on the construction details, even where a high-quality installation has been built, means that the quality of the subsequent samples is not known. At the time of construction, records need to be kept of:

a) dates of drilling;

b) location of borehole and accurately dimensioned sketch plan showing construction details and borehole completions;

c) type of drilling rig and technique used;

d) drilling contractor;

e) measures taken to avoid cross-contamination;

f) measures taken to clean equipment before drilling and installation;

g) rate of progress during drilling;

h) formations encountered with an appropriate level of description;

i) water strikes and rest water levels;

j) problems encountered during drilling such as sidewall collapse — this helps subsequent drilling operations;

k) type of flush used;

l) quantities of water or other flushing media added and source of water/flush;

m) materials used during construction — dimensions and properties of casing, well screens, filter packs and grouts, etc.;

n) well development measures undertaken (such as type of development, duration, volume and quality of water removed);

o) observations during well cleaning and purging, including water levels, water clarity and odour, etc.

5.3 Borehole drilling practice

5.3.1 General

A description of standard drilling techniques and practices can be found in numerous publications. A number of basic best practices are presented below, but these should be considered in line with other guidance documents.

5.3.2 Cleanliness

All equipment should be washed with clean water prior to or upon arrival at the site, to prevent contamination from the previous job or from equipment transportation. When drilling into contaminated land or where movement of contaminants may be a problem, washing should also be undertaken between boreholes and between stages if telescopic drilling is being used. When drilling multiple boreholes, users should work from the least contaminated to the most contaminated location. Steam cleaning or jet washing is the most suitable technique for removing debris and contaminants, and should be used at locations where the discharge water does not pose an environmental risk. A detergent (preferably warm) may be applied prior to rinsing to mobilize both mineral and organic contaminants.

5.3.3 Use of lubricants

Lubricant use should be minimized and should only be used on temporary casing or drilling equipment and not on well screen or permanent casing. Lubricants should be restricted to degradable, inert or non-interfering types. Metallic greases such as those containing copper or lead and hydrocarbon-based lubricants should not be used.

If lubricants of any description are used, this should be noted in the drilling records and the presence considered when interpreting sampling results.

5.3.4 Waste collection and disposal

The collection and disposal of drill cuttings and water resulting from drilling, GQMP development, and testing need to be considered prior to site work, as does the potential presence of contaminated spoil.

As far as possible, a clean working environment should be maintained around the borehole during drilling to reduce cross-contamination and in some cases for health and safety considerations.

Waste generated by the drilling process should be appropriately disposed of. Contaminated material requires testing to determine the most appropriate disposal route. Disposal of waste imposes a duty of care on those responsible for generating the waste.

5.4 Installation practice

5.4.1 General

Prior to undertaking the installation, the drill site should be cleaned up, particularly when drill cuttings are contaminated (or are potentially contaminated) so that there is no risk of cross-contamination of any installation materials.

Unless installation materials arrive on site wrapped and cleaned at point of dispatch, they should be washed down to remove any lubricants or degreasers that may have been used during their manufacture.

Where materials arrive on site unwrapped, or if they are stored for significant periods of time, it may be necessary to wash down materials even if factory cleaning has taken place, to remove road dirt and other contaminants. As with the cleaning of drilling equipment, this should be undertaken with clean water in a location where the water generated does not pose an environmental risk.

The order of installation is:

a) backfill (if the borehole has been over-drilled) to the installation depth;

b) screen and casing;

c) filter pack;

d) sand bridge (if required);

e) bentonite seal;

f) grout seal;

g) protective headworks.

Where backfill has been added to the borehole, sufficient time should be allowed to ensure that the backfill material has settled in the borehole and, in the case of bentonite pellets or slurry, has hydrated. Installation over a surface of unhydrated bentonite pellets may lead to adverse pressure on the casing, resulting in damage or collapse as the pellets swell.

5.4.2 Well screen and casing

Screen and casing materials need to be installed into a clean hole with a minimum of suspended debris in the water column. The borehole should be bailed or flushed prior to placing the materials.

In boreholes deeper than 10 m and where the straightness of an installation is important, the use of centralizers should be considered. When using centralizers, there is an increased risk of bridging and snagging and as such, additional care needs to be given to the installation of the filter pack and other backfill materials. Centralizers are also required for inclined boreholes to ensure that the installation does not rest on the lower sidewall of the borehole.

During installation, the casing and screen should be suspended in the hole at the required level, and should not be allowed to rest on the base of the hole during addition of the filter pack and other backfill materials. This ensures that the screened section is not embedded in the sediment at the bottom of the hole and improves the straightness of the finished installation.

Where artesian conditions are encountered, well casing and screens should be firmly secured in place to avoid the groundwater pressure from lifting the installation out of the ground. Where necessary, expert drilling advice should be sought and borehole completions secured to the ground using bolts and fastening of sufficient strength.

5.4.3 Filter pack

The filter pack is installed around the well screen. The annulus of a borehole deeper than 15 m should be backfilled with the aid of a tremmie pipe to ensure an even distribution of materials and to reduce the risk of materials bridging in the annulus. The filter pack should be added in small volumes and regularly measured using a weighted tape. An indication of the required volume and mass of filter materials is given in this subclause; however, because of the irregular nature of borehole walls, this is only intended as a guide. Following the installation of the filter pack, the sand bridge (or secondary filter pack) should be undertaken in an identical manner.

The pipe should be big enough to accommodate the fill materials but small enough to fit comfortably in the annulus. The base of the pipe should be maintained at least 1 m above the base of the annulus to allow materials to settle freely without clogging the tremmie pipe.

The use of tremmie methods is strongly recommended for a good quality installation at any depth. However, in shallow boreholes with a large annular space, and where there is a short column of water in the annulus, direct placement of the filter pack into the annulus may be permitted.

Water may need to be added down the tremmie pipe to prevent clogging, particularly when adding a sand filter. The volume of water added should be recorded and should be kept to a minimum.

5.4.4 Bentonite seal

A bentonite seal is installed above the filter pack. In boreholes with a long column of water above the installation, there is a potential for bentonite pellets to become hydrated before reaching the top of the filter zone or sand bridge. Specially treated pellets (either baked or coated) should therefore be used. These slow the rate of hydration and prevent bridging. Coated pellets should be used when employing tremmie methods. In deep boreholes where the potential for bridging of pellets is an issue, bentonite may be added to the borehole as a slurry via a tremmie pipe. An alternative is to use pre-shaped bentonite blocks. To allow accurate sealing, sand catchers should be used above and in between the blocks to prevent sand or particulate movement within the borehole.

Following the addition of the bentonite seal, it should be allowed to hydrate sufficiently prior to the injection of the grout. In dry boreholes, clean water should be added to promote hydration. At least 3 h should be allowed for hydration to take place before injecting grout.

5.4.5 Grout

In deeper (more than 15 m) boreholes, grout should be added to the top of the bentonite seal using a tremmie pipe. Addition of grout displaces water in the annulus back into the formation or out of the top of the borehole. When grouting shallow boreholes (less than 15 m), it may be acceptable to add the grout to the top of the borehole and allow it to settle to the base of the hole. Grouting should be undertaken after suitable time is left for bentonite seals to hydrate, to reduce the potential for grout contamination of the filter pack.

5.4.6 Headworks

The headworks complete the borehole and may be installed before or after well development. On completion, the top of the borehole casing should be horizontal to allow a consistent dip datum, and cut-off pipes should be avoided where possible. The top of the casing should preferably be the end of a casing length fitted with threads to allow extension or adaptation at a later date (this may be significant where a borehole has the potential to become artesian). The top of the casing should be as high as possible within the headworks design to minimize the risk of inundation of the GQMP.

5.5 Borehole development

Borehole development is a vital step in the commissioning of a GQMP. 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. Development is the process of returning the conditions around the GQMP to as close to those prior to drilling as possible. This involves pumping and cleaning to remove any fluids added to the formation during drilling, and the removal of fine material from the borehole and surroundings.

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 can also be required as a precursor during routine monitoring, especially if there has been a long interval between borehole or 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, i.e. chemical parameters are stable. This should be determined by measuring chemical parameters during pumping. The parameters that can be measured include:

a) electrical conductivity (EC);

b) pH;

c) temperature;

d) redox potential (E_h);

e) dissolved oxygen (DO);

f) turbidity;

g) contaminant-specific parameters.

As a minimum, EC should be measured. If measurement of chemical parameters is not possible, a minimum of three borehole volumes (plus the volume of any water or fluid added during drilling) should be purged as part of the development process. Overall, the need and extent for well development 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 1 week prior to sampling and in low permeability material, e.g. for 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 because this adversely affects the quality of the sample.

6 Post-construction activities

6.1 Routine inspections and maintenance

In the context of these guidelines, maintenance refers to routine activities and is distinguished from rehabilitation which is an infrequent activity undertaken to restore borehole performance. Where a borehole is sampled infrequently, regular inspection visits should be considered to assess its condition.

Correctly installed GQMPs should not, in general, need much maintenance. Maintenance is most likely needed for headworks, particularly in areas with heavy traffic. These may become damaged as a result of trafficking, ground movement (such as shrinkage or swelling of clays) or from sampling use (e.g. where sampling devices are clamped to the headworks). Maintenance may also be needed to remove accumulated silt by pumping (usually undertaken during sampling).

Regular maintenance may also be required to maintain access to a GQMP, for example, where it is in an area of thick vegetation or at risk of burial or inundation by sediments. Such maintenance may form a requirement under a site working plan or agreement that includes maintenance responsibilities and contingency plans.

6.2 Rehabilitation

GQMP function may deteriorate over time for a number of reasons, including:

a) fouling by chemical, biochemical or biological material;

b) silting due to invasion of the filter pack, screen, and casing by fine materials;

c) mechanical failure of casing due to ground movement;

d) corrosion or degradation of GQMP materials;

e) accidental or deliberate damage.

Where the deterioration can be reversed, some rehabilitation may be desirable or necessary. Primarily this involves addressing problems of deteriorating hydraulic performance which have occurred as a result of fouling or silting. The need for rehabilitation can often be reduced or eliminated through good design, installation, development and sampling practices. In this sense rehabilitation uses the techniques described in 5.5 to clean out the borehole. For older installations, greater care may be required as materials may have lost strength following prolonged exposure to the environment.

Rehabilitation options are limited by the original construction, including its diameter, strength and screen length. In addition, the use of chemical treatments to undertake such work needs to be carefully considered to determine whether such an approach is compatible with the monitoring objectives.

The time and effort spent on rehabilitation are functions of the value of the GQMP and the difficulty in replacing it. It should be noted, however, that constructing a new borehole may lead to changes in key parameters due to natural variability or use of different materials and a new borehole may take some time to acclimatize. It is therefore better, where possible, to retain an existing borehole.

7 Safety precautions

The activities involved in sampling groundwater from (potentially) contaminated land and the environment are potentially hazardous. A risk assessment should be performed prior to undertaking the work and remedial actions should be taken to minimize 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, reference should be made to ISO 5667-11[4].

8 Quality assurance and quality control

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

a) clear statement of objectives;

b) clear assignment of responsibilities;

c) procurement of appropriate expertise;

d) development of technical specification;

e) methods for monitoring and improving quality of operations;

f) good communication.

The sampling process is a continuous process with sequential tasks. If any component fails, the process fails.

ISO 5667-14[5] describes a variety of techniques for monitoring the quality of all types of water samples.

Annex A
(informative)

Common drilling techniques used in GQMP installation

Table A.1 — Common drilling techniques used in GQMP installation

Description	Advantages	Disadvantages
Cable tool		
A rig with a winch is used to repeatedly drop a weighted tool. A number of tools are available which can chisel, cut, crush and remove material	Widely available Suitable for all soil and some rock types	Progress is slow in most consolidated deposits Difficult to penetrate cobbles and boulders
Due to the action of the tool there is a risk of instability and temporary casing is often advanced as the hole deepens	Good sample return	Many down-hole geophysical methods do not work inside temporary casing
Installation of the casing and backfill materials takes place within the string of temporary casing (where this is used), which is removed in stages	Rapid and relatively inexpensive set up	Water is often required to aid drilling in unsaturated strata
Drilling depths are limited by rig size (commonly depths of <50 m) and diameters are a minimum of 150 mm	Temporary casing prevents collapse of loose strata and reduces risk of cross-contamination	Installation and removal of the temporary casing can cause smearing of borehole walls
Rotary — General		
A cutting bit is mounted on a rotating drill pipe with a circulating flushing fluid to remove debris and cool the bit. The fluid and bit have a number of variants and there is a wide range of rig sizes	Drilling rates can be very rapid (even in strong rock) and can reach to considerable depths	Fissured strata has the potential to slip into the borehole and trap the drill bit
In unstable formations a flush can be chosen that invades the borehole wall and provides temporary stability	Cores can provide excellent strata information	Loss of flush (into fissures/voids) can slow drilling rates and compromise subsequent samples. Initial set up and mobilization can be expensive
Drill-bit and flush choice depend upon the expected strata and the borehole depth. A range of borehole diameters can be drilled	Boreholes can be left open in stable deposits to facilitate geophysics and other down-hole testing methods (e.g. packer testing)	Sample recovery can be poor
In conventional drilling, the flush is injected into the hole through the drilling string and discharges from the vicinity of the drill bit. The returning fluid and drill cuttings are forced upwards within the annulus of the hole to the surface where they are collected. The flush may be recirculated. In the reverse circulation method, the drilling fluid is injected down the annulus, outside of the drill string and abstracted though the drill stem	The addition of specialist equipment to the rig can allow drilling in strongly artesian conditions Advantages, in addition to those for standard rotary drilling are principally the minimization of invasion of the formation by the drilling fluid	If liquids are used as the flush there is a need for storage and re-circulation on site This may be significant if contaminated groundwater is present or space is limited A long section of open hole may lead to contaminant mobilization from one aquifer system to another
This method lowers the pressure on the formation and significantly reduces the invasion of the drilling fluid into the aquifer. In general, only water is used as a flush		

Table A.1 (*continued*)

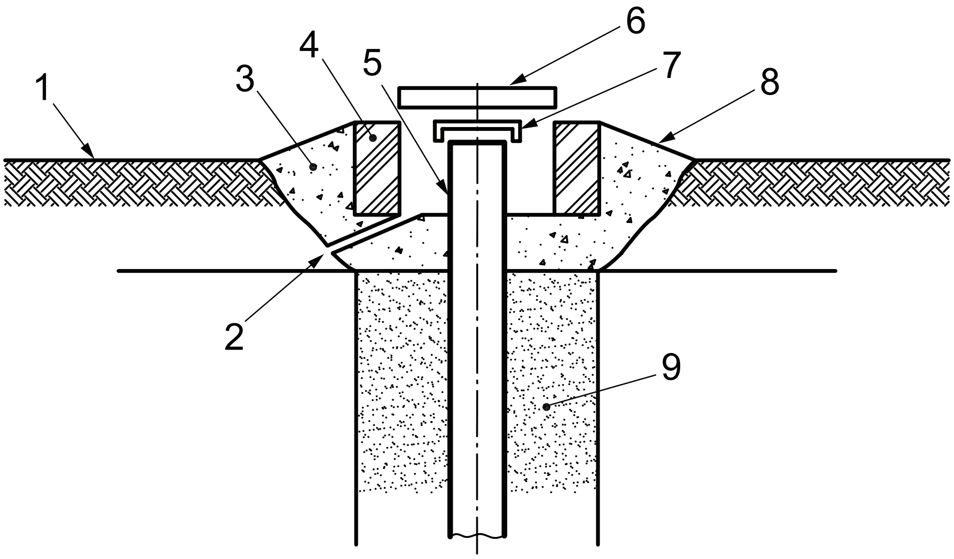
Description	Advantages	Disadvantages
Rotary (air flush)		
Air flush can be used as a drilling fluid to aid the return of drill cuttings to the surface. The addition of small amounts of water to an air flush provides a mist flush Reverse circulation using air can be used	Air flush can be used in fractured strata Readily available Flush does not require treatment or disposal	Introduction of large quantities of air to groundwater may produce significant changes in chemistry In unstable strata, temporary casing needs to be used May mobilize volatile organic compounds
Rotary (percussive)		
The addition of a hammer bit powered by compressed air allows a much more rapid rate of penetration when rotary drilling. Reverse circulation can not be used when using percussive drilling	Rapid penetration	Poor sample returns Introduction of large volumes of air into the aquifer
Rotary (water flush)		
Water is used in place of air to lubricate the drill bit and return cuttings to the surface This requires the provision of circulation tanks or pits on site and a suitable water source Reverse circulation drilling is commonly undertaken using a water flush	Reduces the generation of dust Readily available	The addition of water affects groundwater chemistry in the immediate vicinity of the borehole In unstable strata temporary casing needs to be used
Rotary (mud flush)		
Mud is a drilling fluid comprising water with an additive to provide additional viscosity and density Mineral (such as bentonite) and chemical (e.g. guar gum) muds are available	Loose borehole walls can be stabilized The use of “heavy” muds can aid drilling in artesian conditions Restricts fluid invasion of the formation	The addition of mud (and any degradation products) affects the hydraulics of the borehole wall and the aquifer and groundwater chemistry
Unusual or uncommon techniques		
Sonic drilling		
Based on a rotary rig, sonic drilling adds a high frequency vibration to the rotating bit. This vibration increases penetration speed in unconsolidated granular deposits and stony layers and rock	Sample recovery can be excellent (using cores) Drilling fluids are not needed when drilling soils Drilling speed can be very rapid in “suitable deposits” The amount of waste spoil generated can be less than conventional drilling as aquifer material can be displaced into the borehole walls	Vibration of the drill bit can cause heating of the drill bit leading to volatilization of volatile organics

Table A.1 (*continued*)

Description	Advantages	Disadvantages
Direct push		
A narrow diameter well point (<50 mm) attached to the bottom of a casing length is driven by hand or machinery Alternatively, a length of temporary casing can be driven into the ground and the inside cleared by bailing Installation can then be undertaken within this casing, which is then withdrawn Cone penetrometer (CPT) equipment can also be used to drive monitoring installations into the ground	Inexpensive Rapid Minimal aquifer disruption in fine granular deposits	No sample recovery or geological information Unable to penetrate dense materials or deposits containing cobbles or boulders Limited depth of penetration Risk of smearing clays Unable to seal off discrete layers Steel drive tube or casing (used for strength) can interfere with groundwater chemistry No filter pack installation possible
Jetting		
As a modification to the direct push this technique uses a jet of water emanating from the tip of the casing	Inexpensive Rapid	No sample recovery Limited to sands Limited depth of penetration Requires clean and plentiful water supply
Directional drilling		
Directional drilling is a variant of rotary drilling where the rig has the ability to angle the mast and as such, dictate the direction of progress of the drill bit	Possible to drill boreholes under structures or features of interest Possible to intercept vertical fractures Possible to monitor surface/ groundwater interfaces with a longer screen section	Support of borehole walls required Installation of casing and monitoring equipment can be difficult Expensive
Augering — Solid auger, hollow stem auger and hand auger		
Rotation of a helix with vertical pressure allows penetration of loose or weak strata Augering can be undertaken by hand to shallow depths and at narrow diameters Motorized equipment can drill deeper and at a greater diameter	Hand augering is inexpensive and rapid Drilling fluids are not required Hollow stem augers provide an open void for installation materials	Unable to penetrate strong rock Hollow stem auger is unable to progress in presence of cobbles or boulders Installations in unstable ground are not possible using solid stem augers Smearing of clays may occur

Annex B
(informative)

Headwork completion design examples

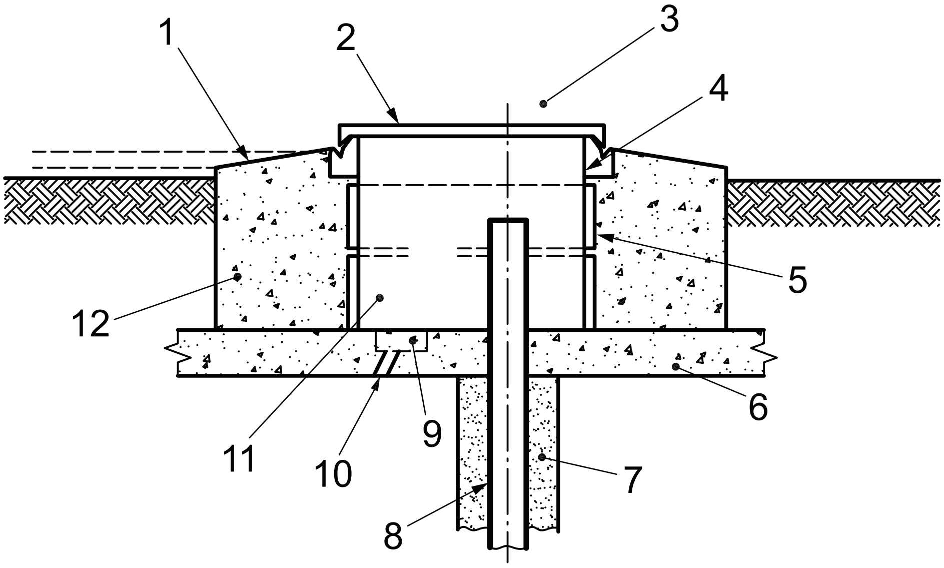


Key

1	ground level
2	drain hole pipe [a]
3	concrete base
4	cover housing
5	plain casing
6	lockable vented cover
7	vented cap
8	slope to promote run-off
9	grout

[a] The drain should be installed with caution due to the potential for back flow and subsequent flooding.

Figure B.1 — Headworks — Stopcock cover completion



Key

1	slope to promote run-off	7	grout backfill
2	cover	8	plain casing
3	clearance to allow access	9	sump
4	cover housing	10	drain hole/pipe
5	concrete ring or brick course	11	space to accommodate instruments
6	concrete base	12	concrete pad

NOTE 1 The chamber should vent to atmosphere.

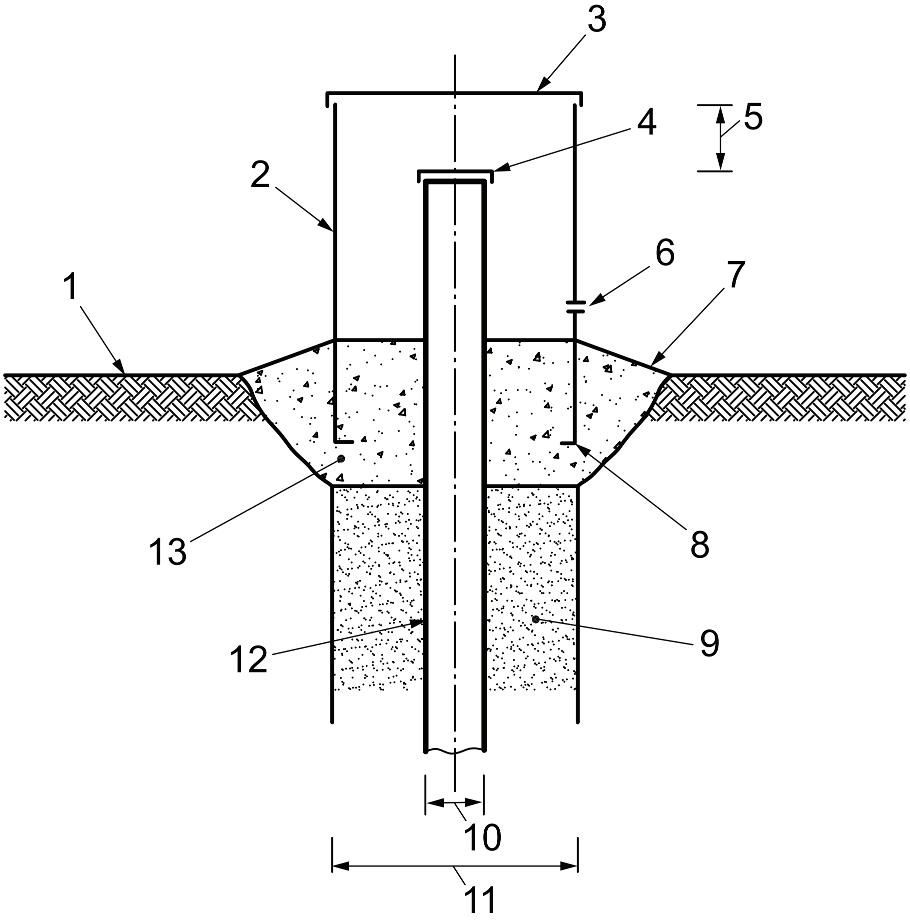
NOTE 2 The concrete and cover should be able to support traffic, if applicable.

NOTE 3 Concrete should be laid to reduce flooding.

NOTE 4 In confined spaces, health and safety requirements may apply.

NOTE 5 The drain should be installed with caution due to the potential for back flow and subsequent flooding.

Figure B.2 — Headworks — Below-ground chamber completion



Key

1 ground level
2 standpipe
3 lockable vented cover
4 vented cap
5 space for instrumentation
6 drain hole
7 slope to promote run-off
8 footings to stabilize in concrete
9 grout
10 casing diameter
11 borehole diameter
12 plain casing
13 concrete base

Figure B.3 — Headworks — Standpipe completion

Bibliography

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

[2] ISO 5667-2:1991, *Water quality — Sampling — Part 2: Guidance on sampling techniques*1)

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

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

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

[6] ISO 6107-1:2004, *Water quality — Vocabulary — Part 1*

[7] ISO 6107-2:2006, *Water quality — Vocabulary — Part 2*

[8] ISO 6107-3:1993, *Water quality — Vocabulary — Part 3*

[9] ISO 6707-1:2004, *Building and civil engineering — Vocabulary — Part 1: General terms*

[10] ISO 10381-1, *Soil quality — Sampling — Part 1: Guidance on the design of sampling programmes*

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

[12] ISO 10381-3, *Soil quality — Sampling — Part 3: Guidance on safety*

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

[14] ISO 10381-5, *Soil quality — Sampling — Part 5: Guidance on the procedure for the investigation of urban and industrial sites with regard to soil contamination*

[15] ISO 10381-6, *Soil quality — Sampling — Part 6: Guidance on the collection, handling and storage of soil under aerobic conditions for the assessment of microbiological processes, biomass and diversity in the laboratory*

[16] ISO 15175, *Soil quality — Characterization of soil related to groundwater protection*

[17] TERZAGHI, K, PECK, R.B., MESRI, G. *Soil mechanics in engineering practice*, 3rd edition. New York, NY: Wiley, 1996. 549 p.

---

1) Superseded by ISO 5667-1:2006[1].

ICS 13.060.45

Price based on 36 pages