Centre d'expertise en analyse environnementale du Québec

Sampling Guide for Environmental Analysis

BOOKLET 3

SAMPLING OF GROUNDWATER

English Version of the original French Edition

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Québec

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FOREWORD

This *Sampling Guide for Environmental Analyses* details a series of codes of practice to plan and conduct sampling activities. The purpose of the guide is to ensure the quality of samples collected and the validity of scientific information arising from these samples.

The creation of this document was an initiative of the Ministère de l'Environnement et de la Faune, more specifically the Direction des laboratoires, after information came to light revealing that samplers did not have the tools necessary to gain an immediate knowledge of sampling practices in Québec. This descriptive reference guide was developed to serve as an information tool for individuals to who carry out activities that are part of an environment characterization program.

From the outset, samplers have expressed a keen interest in having this type of reference document available. Not because all of the information in the guide is unpublished work; but because it was of interest and useful to include a summary of information contained in technical references or information based on practical sampling experience in Québec.

The *Sampling Guide for Environmental Analyses* consists of a series of booklets that deal specifically with sampling in different environments. Cahier 1 – *Généralités* [Booklet 1 - General], must accompany each booklet in the series. It provides a general framework for implementing a sampling program and discusses technical procedures relating to quality, legality, health and safety issues. It also recommends procedures to optimize sampling programs.

This third booklet, entitled “Sampling of Groundwater”, describes the types of equipment that are required to install wells, conduct sampling procedures and preserve samples.

We sincerely thank those individuals who have contributed to making this document possible.

May 2007

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INTRODUCTION

Demand for characterization studies of groundwater quality is growing because management of this resource has been deemed one of the priority actions of the environmental protection and conservation strategy. The success of characterization studies rests largely on the validity of groundwater samples collected. Steps that are part of the sample collection procedure, from location and construction of monitoring equipment, to delivery of samples to the laboratory, are potential sources of sample deterioration and contamination.

Enormous strides are currently being made in groundwater sampling techniques as an examination of official records from conferences and symposiums, and articles in scientific journals shows. Progress and development in new sampling techniques makes the need for implementing strict standards unnecessary. What's more, methods cannot apply to all groundwater contamination studies due to the wide variety of geological and hydrogeological conditions that exist. There is, however, a need for guidelines to help determine which methods should be chosen, based on field conditions and objectives

Ideally, each sampling point should have its own sampling equipment. Monitoring wells should be drilled using hollow-stem auger drills and should be constructed of inert material such as stainless steel and Teflon®. If accurate vertical definition is required, monitoring wells should be set up in individual boreholes. For practical and cost reasons, however, this recommendation cannot always be enforced. The degree of precision of a sampling program also depends on how much contamination is present.

This guide is therefore not an exhaustive overview of all possible techniques. The hydrogeologist in charge of a project is responsible for implementing a groundwater monitoring program. Adherence to the methods detailed herein does not guarantee the success of operations in all possible types of hydrogeological conditions.

A series of steps must be followed when collecting groundwater samples. They usually consist of the following sequence: drilling, setting up monitoring instruments, sampling, storage and transportation of samples. Each of these steps is a potential source of chemical or physical alteration of a sample. The principal sources of alteration include physical disturbances (water mixing) due to drilling operations, chemical and bacterial contamination due to drilling operations, chemical contamination and adsorption due to contact with monitoring equipment, sampling equipment and containers, and cross contamination from one sampling site to another due to contaminated equipment. Sample integrity therefore requires the following safeguards:

- the chemical composition of groundwater must not change significantly during its migration from the geological formation to the monitoring well;

- drilling methods and monitoring systems must not affect the chemical composition of groundwater;

- sampling equipment and sampling methods must not contribute to the alteration or contamination of water samples;

- preservation methods and the method of transportation must not alter the water's physical or chemical properties, which have an impact on the analyses conducted.

1. LOCATING SAMPLING POINTS

The decision of where to locate sampling points is the first step of implementing a sampling program. The choice should be based on where a contamination source is located, the area's hydrogeological characteristics and the physical and chemical properties of contaminants. If measuring points are not correctly positioned, the result will be a flawed interpretation of the extent and type of contamination. A study of existing geological and hydrogeological information at the site is therefore crucial before implementing a sampling program.

Knowledge of groundwater flow directions, in relation to where a contamination source is located is the most important factor when selecting a sampling point. If a monitoring well is set up in a hydraulic location upstream from a contamination source, you can determine natural and regional concentrations (natural levels) in the surrounding area. Ideally, one well should be selected to determine natural levels in each stratigraphic unit. The well should be located upstream and outside of the area that is deemed potentially contaminated. Other monitoring wells should be located in a hydraulic location downstream from the contamination source. Some should be located near the source to characterize contamination, and others further downstream will help determine the extent of contamination. Factors that affect the horizontal spacing between monitoring wells are listed in Table 1 (next page). The number of monitoring wells required and their exact location will be specified as the sampling program proceeds.

TABLE 1 - FACTORS THAT AFFECT HORIZONTAL SPACING BETWEEN WELLS

WELLS POSITIONED CLOSELY TOGETHER

- Liquid wastes are present;
- the site under study is a small area;
- there is permeable fill material near possible sources of contamination;
- there are underdrains, trench drains or other underground lines;
- the geology is complex (fractured formations close to one another, faults, folds, discontinued structures);
- the stratigraphic geology is polymictic;
- the site is located near a refill zone;
- a high hydraulic gradient;
- the topography has sharp contrasts;
- slight dispersivity at the site;
- high infiltration rate.

WELLS POSITIONED WELL APART

- The geology is regular (no fractured formations, no faults, no folds, continuous structures);
- uniform stratigraphic geology;
- low hydraulic gradient;
- high dispersivity at the site;
- low infiltration rates.

The vertical distribution of sampling points is based on the stratigraphic geology. Ideally, there should be one sampling point for each hydrostratigraphic unit that is traversed. If samples are collected for the purpose of determining if groundwater has been contaminated by a recent contamination source located near the surface, at least the first permeable zone that is come across from the contamination source must be sampled. Setting up a sampling point in this area will serve as a warning of the migration of the contamination zone.

Knowledge about the physical properties of contaminants, particularly solubility and density, will help guide the sampling program. Non-miscible liquids, which are lighter than water, remain at the top of the water table. The distribution of denser liquids, however, is more complex, so they are found at greater depths.

2. LAYOUT AND INSTALLATION OF MONITORING INSTRUMENTS IN THE SATURATED ZONE

Before beginning this section, which explains how monitoring instruments are set up and laid out, the distinction should be made between a monitoring well and a piezometer. Monitoring wells are used to collect water samples, to detect and sample non-miscible liquids and to measure water levels. A piezometer is used gauge water levels for the purpose of determining the direction of groundwater flow and velocity[1]. In a groundwater sampling program, monitoring wells are used.

2.1. Types of wells

The four most common types of monitoring wells include: open wells, traditional wells, multilevel wells in a borehole and well nests. The advantages and disadvantages of each type are discussed below.

2.1.1. Open well

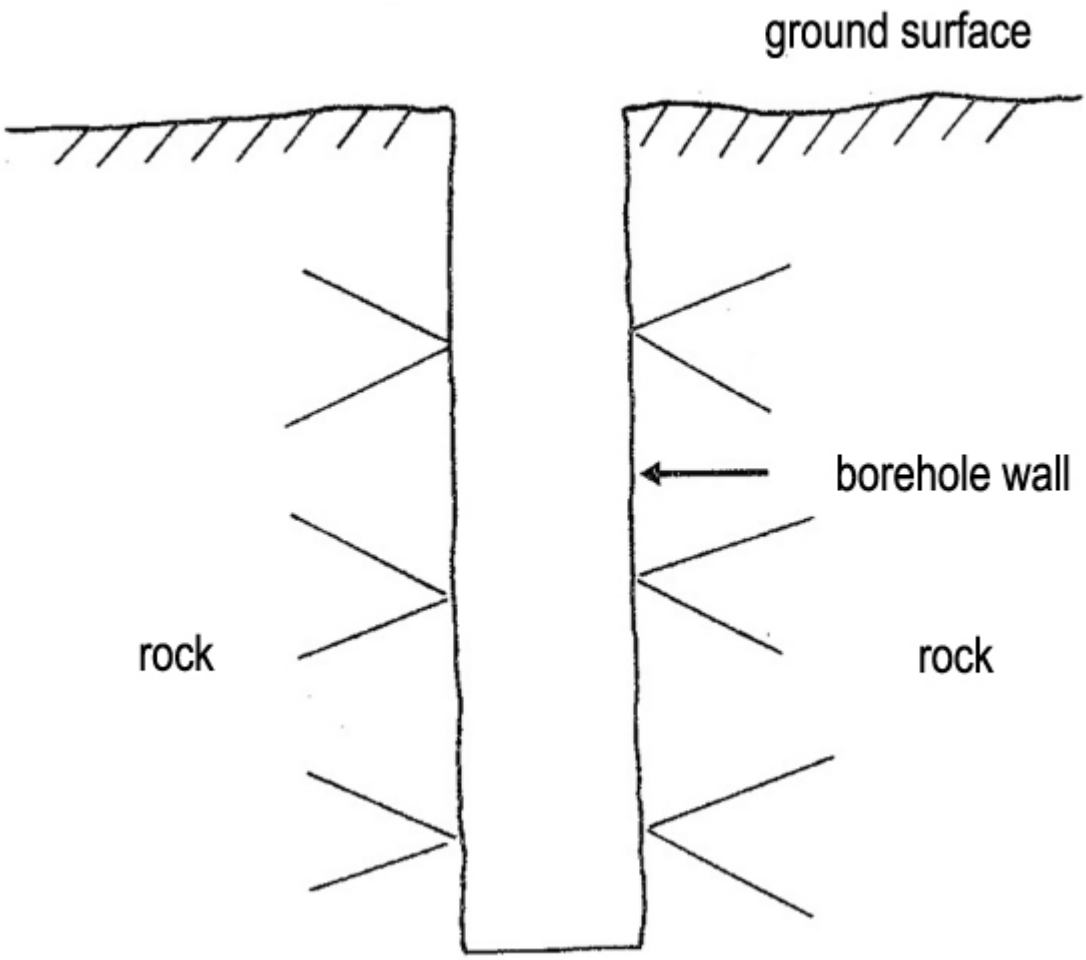
This method of monitoring consists of sampling groundwater from an open well that contains no piping (Figure 1). It is the simplest monitoring method, but can only be used in consolidated rock formations where walls can remain vertical without support. Open wells do not help to determine the vertical distribution of contaminants, but can lead to an initial detection of contamination.

There are a few words of caution regarding the interpretation of results of analyses from this type of well because usually only water from the top of the surface is collected during sampling. Unfortunately, however, dense non-miscible liquids and extremely contaminated water sink to the bottom of wells. Where this is the case, water samples should be collected from the bottom of wells. Also, since water can filter in along the entire length of a borehole, in most cases there is a major dilution effect.

TABLE 2 - ADVANTAGES AND DISAVANTAGES OF OPEN WELLS

ADVANTAGES:	They are inexpensive;
	there is no contact between well material and groundwater;
	a wide range of drilling techniques can be used.
DISADVANTAGES:	They provide no information about the vertical distribution of contaminants;
	because it is a composite sample, contaminants may be diluted;
	because the entire length of the borehole is open, contaminants can migrate vertically.

FIGURE 1 - DIAGRAM OF AN OPEN WELL



2.1.2. Traditional well

The traditional well method consists of installing a strainer at a given depth to measure the degrees of contamination. The strainer zone is isolated from other horizons by a tight-fitting cap of bentonite. Installation of this type of cap requires an annular space between the tube and borehole wall. The usual construction of this type of installation is described in detail in section 2.3.

TABLE 3 - ADVANTAGES AND DISADVANTAGES OF TRADITIONAL WELLS

ADVANTAGES:	It minimizes vertical migration of contaminants;
	can be set up quickly and inexpensively;
	hydraulic conductivity tests can be conducted on site.
DISADVANTAGES:	Only one level can be sampled;
	can contribute to vertical migration of contaminants if the cap is not tight-fitting.

2.1.3. Multilevel well

Another type of setup is to introduce tubes fitted with strainers into different levels of a borehole (Figure 2a). Each level of sampling is separated by tight-fitting bentonite caps and each strainer is surrounded by a sand filter. The air tightness between each level is an important factor. Positioning airtight caps and sand lanterns may be difficult if the water table is near the ground surface. For practical purposes, usually no more than three to four monitoring wells can be inserted in each borehole.

In sand formations, another type of setup uses piezometer bundles (series of small tubes fitted with an open, screened or porous end point, attached to a rigid tube (Figure 2b). These systems do not require the installation of tight-fitting caps or sand lanterns because sandy material will enclose itself around the equipment.

These types of installations involve use of more sophisticated systems. They systems consist of sampling gates distributed along the length of the rigid tube (Figure 2c). Sampling gates are separated from one another by plugs. Each sampling gate is connected to a tube that allows sampling at the surface, using a suction technique if the water table is less than 8 metres deep, or using a gas displacement pump or manual piston pump. Most sampling gate systems are sold commercially. The most commonly used are Westbay and Solinst systems. These systems are particularly useful in fractured formations (one gate per intercepted fracture when fractures are properly located).

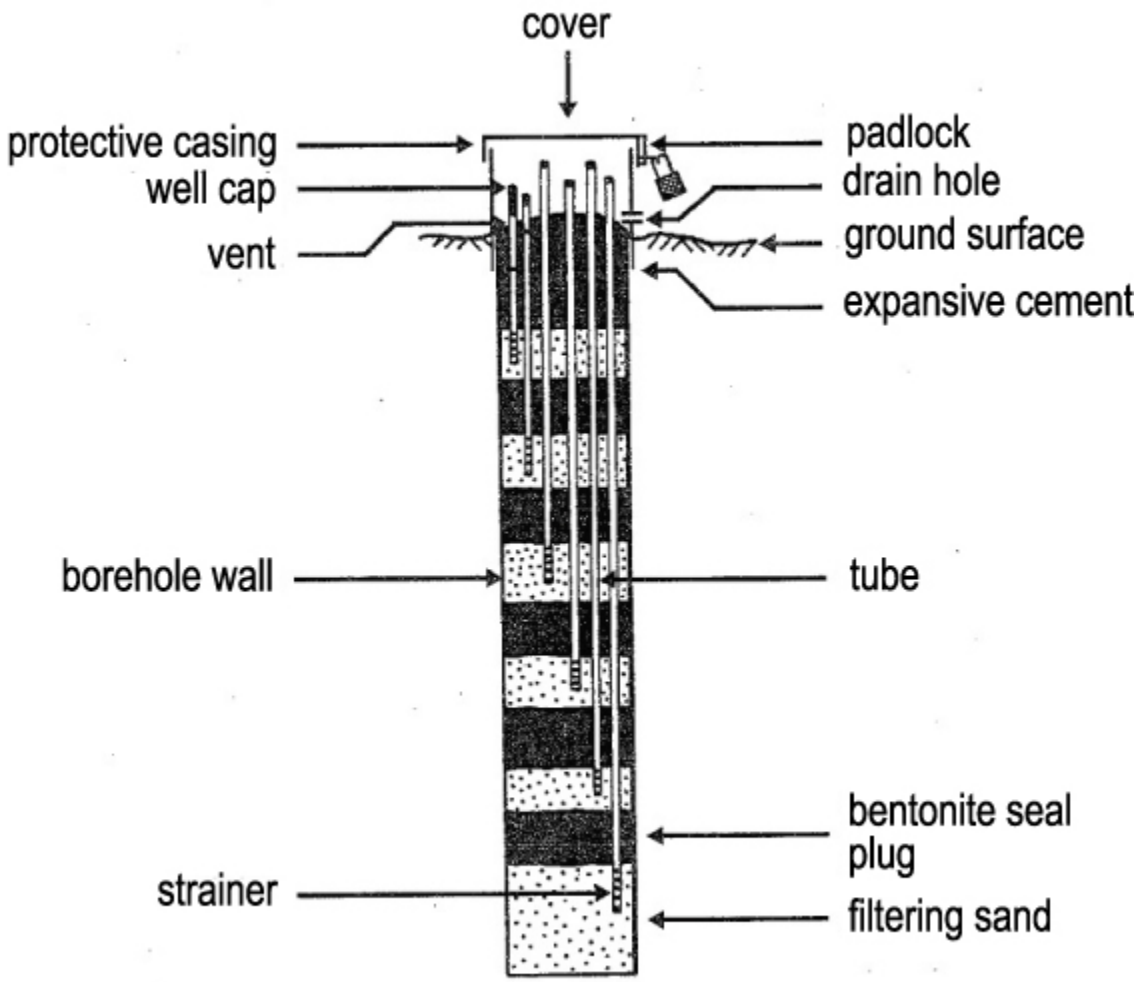
These types of installations are commonly used when deep boreholes are required and drilling a series of boreholes is not possible due to costs. Hydraulic conductivity tests must be performed before the devices are installed because of the small diameter of monitoring wells.

The advantages and disadvantages of single multilevel boreholes are shown in Table 4, on the page that follows.

TABLE 4 - ADVANTAGES AND DISADVANTAGES OF SINGLE MULTILEVEL WELLS

ADVANTAGES:	They provide information about the vertical distribution of contaminants;
	they can be installed quickly.
DISADVANTAGES:	They are usually expensive;
	sampling depths must be determined in advance;
	bentonite caps are hard to install;
	there is a risk of interconnection between one level and another during drilling and sampling;
	tubes can become plugged over time;
	some tube materials can warp and make water sampling difficult.

FIGURE 2A - DIAGRAM OF A MULTILEVEL WELL - SAMPLING LEVELS SEPARATED BY SEAL PLUGS



Source adapted from reference 7

FIGURE 2B - DIAGRAM OF A MULTILEVEL WELL - PIEZOMETER CLUSTER

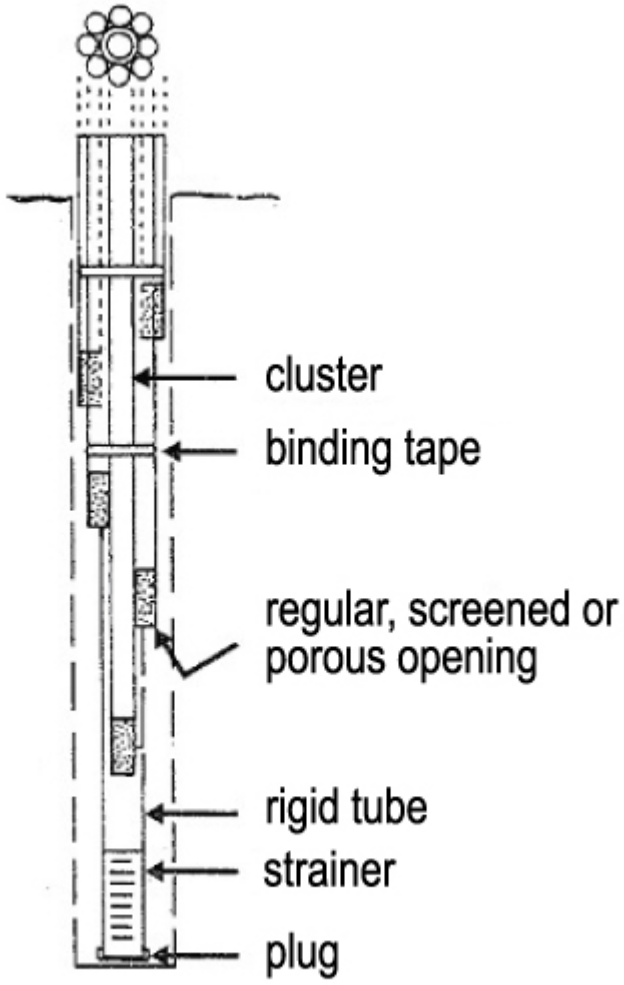
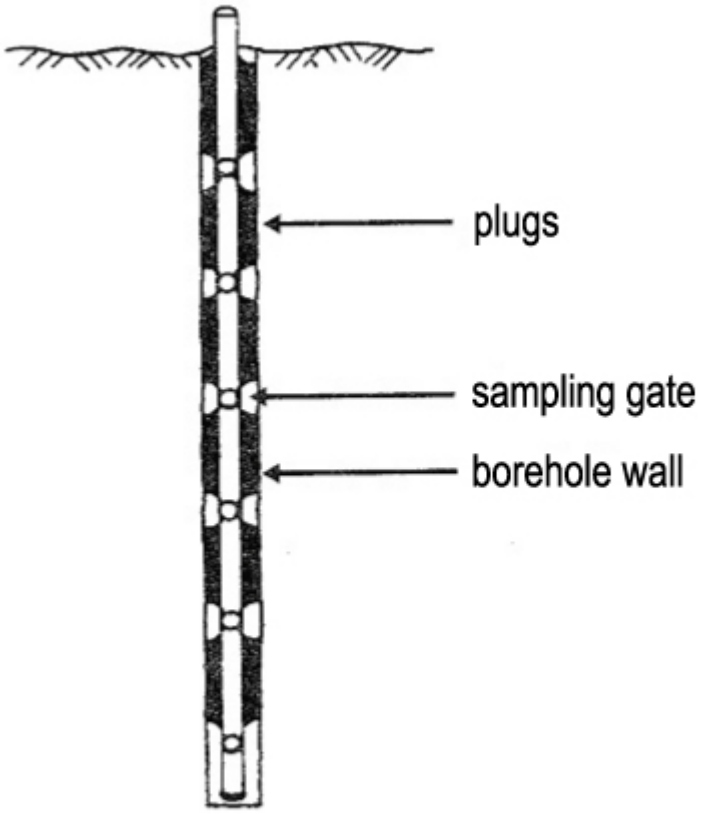


FIGURE 2C - DIAGRAM OF A MULTILEVEL WELL - SAMPLING GATE SYSTEM



Source: adapted from reference 7

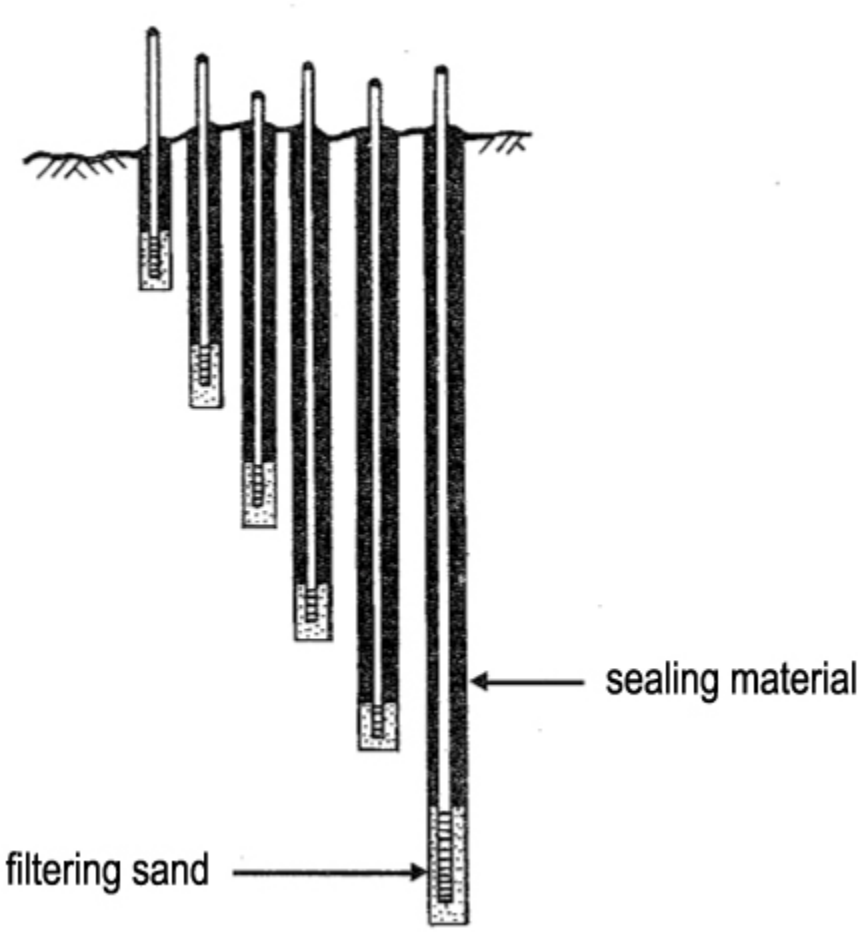
2.1.4. Monitoring well nest

Of all the different types of monitoring wells, the most reliable is the monitoring well nest if concentration profiles have to be determined according to depth (Figure 3). This involves a series of traditional monitoring wells drilled to different depths in individual boreholes that are in close proximity to one another. This type of setup provides effective vertical definition and minimizes the risk of cross contamination. **This monitoring system should be favoured over others**. Each well should be constructed according to the installation technique described in section 2.1.2.

TABLE 5 - ADVANTAGES AND DISADVANTAGES OF MONITORING WELL NESTS

ADVANTAGES:	They provide effective vertical definition of contamination;
	there is no risk of cross contamination;
	simple hydraulic tests can be carried out.
DISADVANTAGES:	They are long to install;
	they are relatively expensive.

FIGURE 3 - DIAGRAM OF A MONITORING WELL NEST



NB: A monitoring well should be built according to Figures 4a and 5

Source: adapted from reference 7

2.2. Drilling equipment

All drilling equipment, without exception, disturbs hydrogeological conditions in neighbouring surroundings[2]. The degree of disturbance depends on two main factors: the type of drilling equipment used and the type of geological formation. Given the vast array of drilling equipment and geological conditions available, all of the possible scenarios cannot be discussed in this document. Details for each item of equipment are presented in Driscoll (1986)[3] and Davis *et al.* (1991)[4].

The five main types of drilling equipment to install monitoring wells include:

- hollow and solid stem augers;
- rotary drills (mud, air and water);
- cable drills;
- diamond drills;
- portable drills.

In some cases, well construction may require use of more than one type of drilling equipment. The following factors determine which type of drilling equipment should be used:

- type of geological material;
- depth of boreholes;
- position of boreholes (access);
- availability of equipment;
- parameters to be analyzed.

2.2.1. Hollow and solid stem augers

A drilling method that uses auger drills is least likely to contaminate groundwater because it does not require use of drilling mud or liquid. **This method should therefore be preferred over other methods**. Auger drills, however, can only be used in loose material and maximum drilling depths vary from 6 to 45 m, depending on the equipment and type of geological materials present.

As augers penetrate the soil, drilling residues rise to the surface. Residues must be completely removed from the borehole because they can contaminate groundwater in uncontaminated areas.

All drilling residues must be stored in containers until soil analysis results become available. If results reveal that residues are not contaminated, according to the A-B-C criteria chart in the *Politique de réhabilitation des terrains contaminés* [Rehabilitation of Contaminated Sites Policy[5]], they can

be left at the site without treatment. If drilling residues are contaminated, they must remain at the site in containers until they can be rehabilitated, using an approved method, at the site. Residues must be managed in the same manner as contaminated soil[5].

There are two types of auger drills: hollow-stem augers and full-stem augers. The main advantage of hollow-stem augers over full-stem augers is the fact that monitoring wells can be installed without the need to remove augers from the ground. Full-stem augers can only be used in solid material because the walls of the borehole must remain vertical long enough to allow monitoring wells, a sand lantern and seal plug to be installed. Auger drilling is fast, inexpensive and the drilling machine can be put into service quickly.

During drilling operations, there may be upward and downward movement of groundwater alongside the auger. This vertical water movement, which shifts in the direction of hydraulic gradients, can cause an uncontaminated zone to appear contaminated and vice versa. Movement of contaminated soil to a higher level can also produce the same effect.

2.2.2. Rotary drills

In unconsolidated deposits, traditional rotary drills use drilling fluids. The purpose of fluids is to cool the drill, bring drilling residue to the surface and support the walls of the borehole. The fluids may be water, a mixture of water and bentonite, activated sludge or a mixture of water and synthetic organic polymers. The main difference between bentonite and organic sludge is the addition of organic polymers to change consistency, viscosity and liquid surface tension if necessary. These polymers include polyacrylamides, carboxymethyl cellulose, sodium acrylate, lignosulfonates and lignins.

These products are a potential source of contamination of groundwater samples and their use is recommended only where auger drilling is not possible. The advantage of rotary drills is that they can be used in all types of geological material and at extreme depths.

Use of water as a drilling fluid causes it to spread to permeable zones, which subsequently dilutes the water that may initially be contaminated. Water used during the drilling process must be removed from the well before sampling begins. A detailed discussion about drilling fluids and procedures to develop and empty monitoring wells appears in sections 2.2.6, 2.5 and 3.3 . Use of a water/bentonite and water/organic polymers mixture is a more serious problem because it is difficult to remove all these materials. Bentonite has the disadvantage of holding positively charged contaminants, which reduces the aqueous concentrations of these compounds. Organic polymer-based muds release large amounts of organic compounds into groundwater and encourage adsorption or organic and metal contaminants.

Drilling methods that require use of drilling fluids are therefore not recommended. If use of a drilling fluid is absolutely necessary, use purified water.

Rotary drills require use of air rather than water or drilling mud. Contamination can occur if water comes into contact with air because volatile organic compounds can be carried from extraneous material (dust, lubricating oil) and oxidize some chemical compounds such as nitrites, sulfides, etc. Special filters can therefore be installed on air compressors. Air contact with water can also cause volatile organic compounds to be released from the aqueous phase to the gaseous phase. A foaming agent is often mixed with air to help recover drilling residues. The foam, however, can enter the formation and contaminate groundwater. This drilling technique is not recommended in situations where organic compounds are analyzed.

2.2.3. Cable drills

Operation of cable drills consists of driving casings in under the weight of a hammer suspended from a steel cable. In unsaturated zones, water must be used to allow the casing to descend. Because this water is not pressurized, as it is with rotary drills, there is little risk of contamination. Small amounts of lubricating oil can be used to extend the life of the hammer. This type of drill can operate in all types of geological material to great depths and causes only a small redistribution of material along the walls. Drilling time is relatively long compared to other methods described above.

A monitoring well is installed when temporary steel casings are removed. The installation and withdrawal of temporary casings does not significantly affect water quality and does not promote contamination between zones. The cable drilling method should be used only where auger drilling cannot be used.

2.2.4. Diamond drills

Diamond drills are used mainly in crystalline rocks to enable core tests of rock and the installation of piezometers. A casing is driven in with the help of a diamond bit drill that must be cooled by water. Introduction of drill water into groundwater can cause contamination or can dilute the contaminants present.

The principal advantage of this technique is that is allows the degree of rock fracturing to be assessed on the basis of core samples that are taken. The risk of alteration of the chemical integrity of water samples is the same as risks associated with cable drill and rotary drill methods.

2.2.5. Portable drills

If drilling points cannot be accessed using drills mounted on trucks or caterpillar tractors, use of portable drills will be required. They are, however,

limited to small depths. The most common are hand-held gas-powered drills (vibration-percussion drills and solid stem augers). These methods do not require use of drilling fluids and there is minimal contamination risk. Use of petroleum lubricants, however, requires special precautionary measures to ensure that lubricants do not come into contact with water. The motors of these drills can be easily converted to natural gas.

2.2.6. Drilling precautions

During drilling operations, precautionary measures must be taken, regardless of which drilling method is in use. These include:

Careful supervision

The drilling supervisor assigned to installation of water quality monitoring instruments must closely monitor each phase and must never leave the site during the time drills are in operation. The supervisor must always bear in mind that an individual who has experience with water supply drilling methods, may not necessarily be familiar with contaminant hydrogeology methods.

Lubricating oils

Lubricating oils routinely used by drill operators to reduce corrosion and wear of equipment are a potential source of contamination because they can mix with water. In the case of some organic compounds, contamination and potability are measured in µg/L. Therefore, a very minute amount of oil is all that is required for these types of concentrations to be found in water. Remember also that lubricating oils contain high levels of heavy metals. Lubricants can also contain cadmium, cobalt, chromium, copper, iron, molybdenum, nickel, lead, zinc and other metals including barium, calcium, magnesium, potassium and sodium.

It is difficult to completely avoid use of lubricating oils and greases during drilling operations. It is possible, however, to urge operators to use these products sparingly to minimize the risk of contamination, particularly if heavy metals, organic compounds and major ions have to be analyzed.

Use of plant-based hydraulic oils and greases (Raisio Biosafe type) reduces the risk of water sample contamination.

Drilling fluids

To minimize risks related to use of water during certain drilling procedures, drill operators must use water that is as clean as possible and enquire about its

source. If the water composition is not known, it should be sampled for analysis. Remember that, regardless of its composition, water that is used during operations will inevitably cause a dilution of the concentration of certain parameters. Tracers can be added to the drilling water to verify if the effects attributed to the water have been completely mitigated. A list of tracers and their principal properties appears in Table 6, on the following page.

TABLE 6 - TYPES OF TRACERS AND THEIR PROPERTIES

DYES: uranin, rhodamine WT, sulforhodamine G

ADVANTAGES: easy to use;

safe;

concentrations can be measured at the site.

DISADVANTAGES: Some dyes are affected by the pH level and temperature or are adsorbed by clay particles and organic matter.

ELECTROLYTES: **sodium chloride, potassium chloride, ammonium chloride and lithium chloride**

ADVANTAGES: Concentrations can be measured at the site;

DISADVANTAGES: they require a large amount of electrolyte.

Adapted from Driscoll, G., (1986)[3].

Cleanliness of equipment

Drilling instruments should be checked for cleanliness before beginning a drilling program. It is important to ensure that rods and augers have been cleaned thoroughly because they may have been used previously at a contaminated site. Throughout the drilling program, equipment parts must be stored in locations that do not contain potential sources of contamination. Drilling should be carried out from the least contaminated area, to the most contaminated area, if the contamination source is known. Equipment may have to be decontaminated between two drilling sites, particularly if the last drilling operation was carried out in a visibly contaminated area. In these cases, decontamination using a steam-jet cleaner, or using the method described in section 2.3.1, is recommended.

Interception of a layer of non-miscible liquid

Drilling through layers of non-miscible liquids that have a higher density than water is usually not recommended to prevent the risk of spreading contamination. If, in order to protect public health and the environment, concentrations of a contaminant in the aqueous phase of water-bearing formations must be determined, drilling should take place downstream from the direction of groundwater flow and outside of the area where non-miscible liquids are located. To develop site rehabilitation programs, the thickness and properties of these products must be determined. To determine this information, a strainer should be positioned in the non-miscible phase and should extend slightly on either side of it. If non-miscible phases are denser than water, they migrate vertically until they encounter an impervious barrier. Their migration is governed mainly by the topography of this layer and to a lesser degree by the direction of groundwater flow. Information to sample and measure the density of these liquids is discussed in section 9.

If drilling is carried out through a zone contaminated by non-miscible liquids, a small amount of contaminants will adhere to augers and will contaminate water and soil that comes into contact with augers. The small amounts of contaminants that are carried in the borehole water along with augers will contribute to deterioration of groundwater quality.

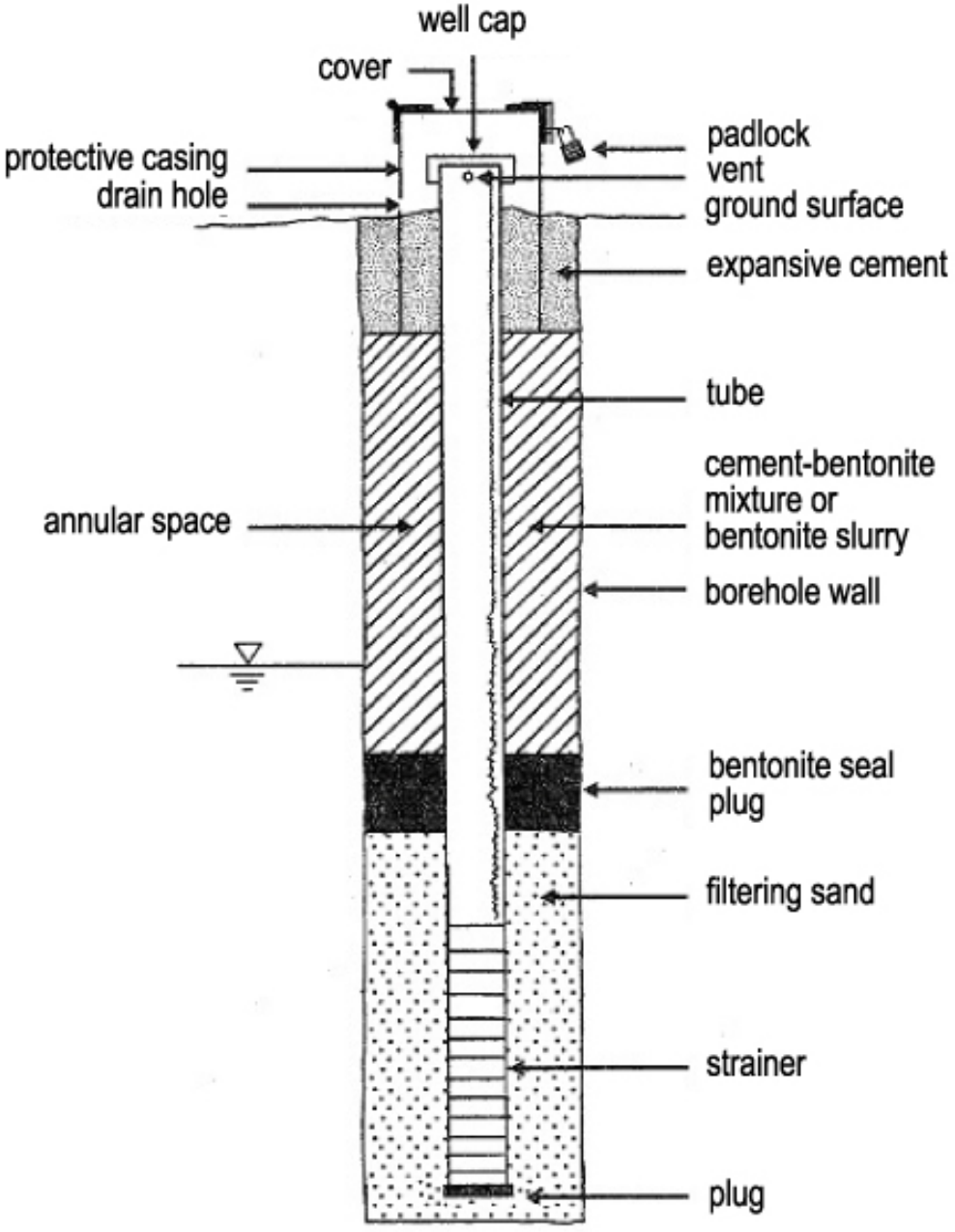
2.3. Material for construction of monitoring wells

A monitoring well consists of a number if components, which are shown in Figure 4a. A strainer attached to a tube is placed below the water level. An envelope of silica sand is placed around the strainer up to a slightly higher level (1 metre) to encourage the flow of water to this zone. A seal plug, more than one metre thick, consisting of bentonite (granular or powder) is then placed over the filtering material to isolate the strained water area from overlying layers and surface water. The space remaining between the tube and borehole wall must be filled with a cement/bentonite mixture or

bentonite slurry. Drilling residues must never fill the annular space. A cap of expansive cement slurry, extending from the surface to the frostline (at least 2 m), prevents runoff water from filtering in. To prevent rain water from accumulating, the cement slurry will form a small mound at the surface and cover only the diameter of the borehole (Figure 4a). A protective cover fitted with a padlock is anchored in the cement surface to protect the monitoring well from breakage or vandalism. Like the tube, the protective casing must be ventilated to prevent a potential accumulation of explosive gases and to allow the water level in the well to be subject to variations in atmospheric and hydraulic pressures. A drain hole must be installed in the protective casing at ground level (Figure 4a) to draw off water that might accumulate in this space. In some cases (streets, parking lots, service stations, etc.), the protective structure must installed below ground level and must be watertight (Figure 4b). This will require placing an O-ring or thick seal between the cover and protective casing. The monitoring well must be properly identified to avoid confusion with other underground installations.

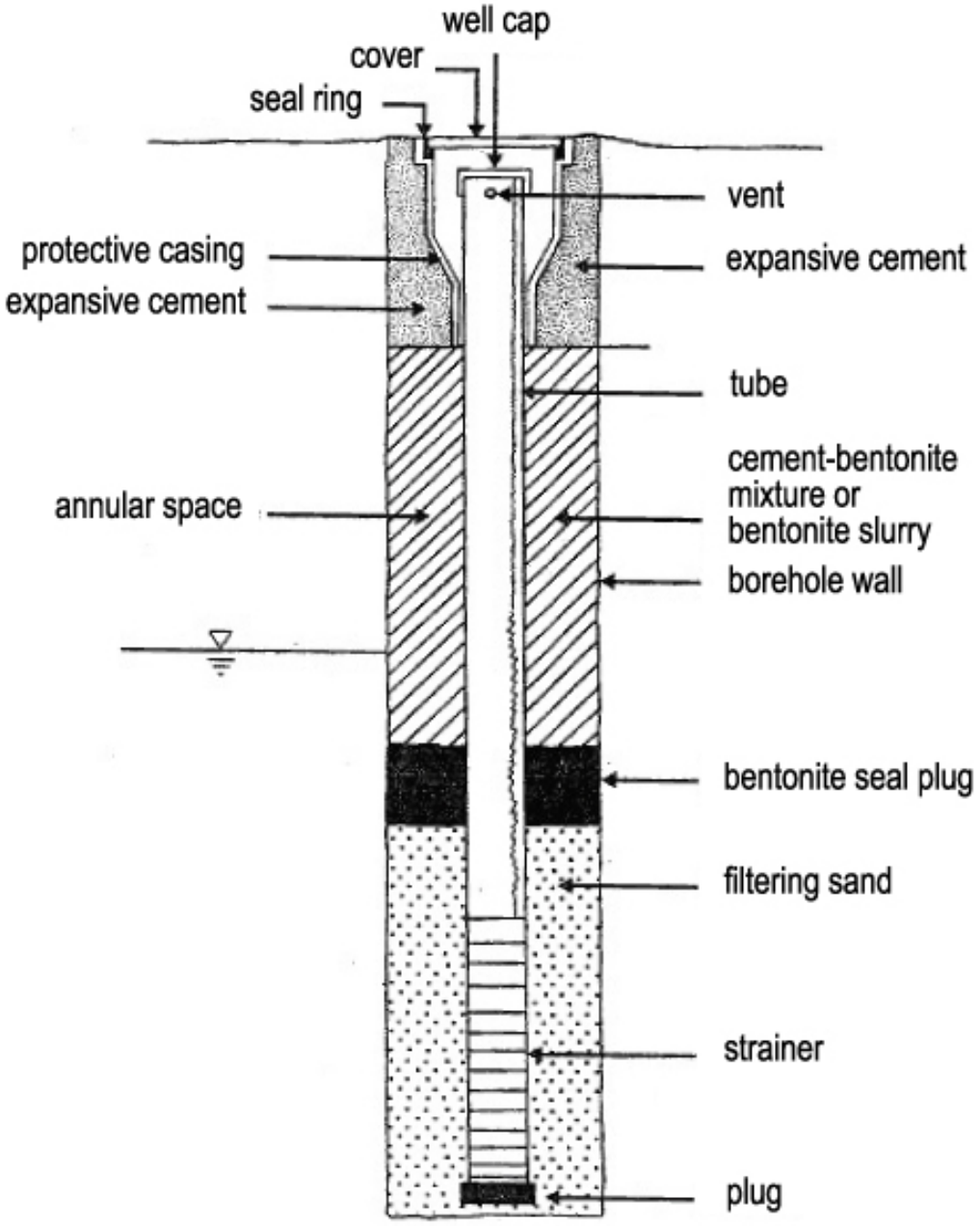
The proposed dimensions for components of a well are shown in Figure 5.

FIGURE 4A - COMPONENTS OF A MONITORING WELL



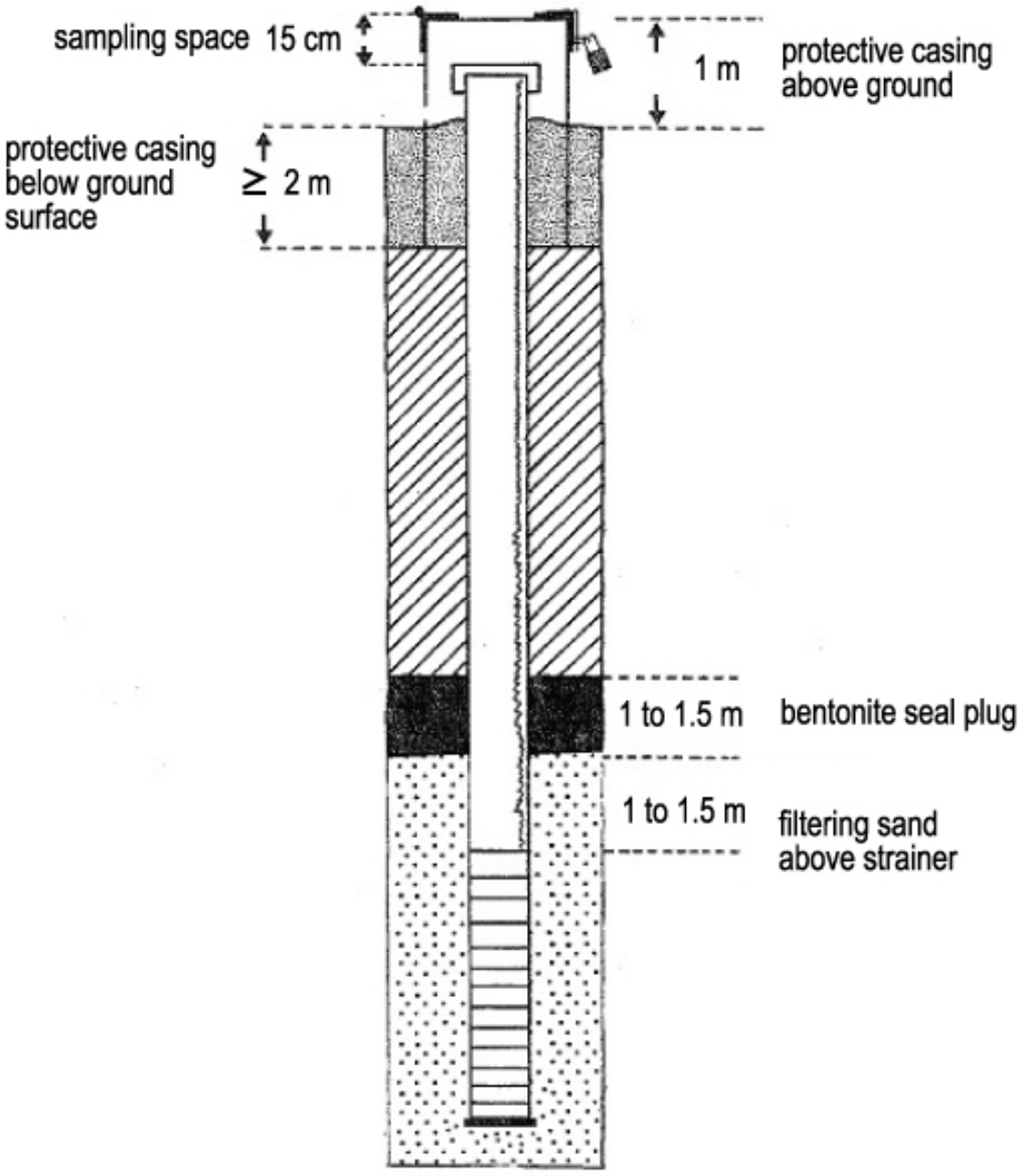
Source: adapted from reference 7

FIGURE 4B - COMPONENTS OF A MONITORING WELL - PROTECTIVE BELOW GROUND STRUCTURE



Source: adapted from reference 7

FIGURE 5 - DIMENSION OF COMPONENTS OF A MONITORING WELL



There are two ways to ensure that material has been installed correctly: by measuring the depth of material after each phase and by determining how much material will be required in advance. If there is a significant difference between the amount of material used and the original volume calculated, or if the depth of material is not consistent with calculations, this information must be noted. These differences may distort the representativeness of water samples and water levels.

Each monitoring well component must be carefully selected to minimize the risk of alteration of the chemical integrity of groundwater. Types of material and the effects they can have on the physical and chemical properties of water are discussed in the sections that follow.

2.3.1. Tubing and strainer

Tubing and strainers are most often manufactured from stainless steel and polyvinyl chloride (PVC). If stainless steel is used, it must be grade 304 and 316[6,7,8,9]. The high cost of stainless steel tubing and strainers, however, limits the degree to which stainless steel is used. Polyvinyl chlorides release traces of compounds, including phtalates and metals.

In most cases, PVC is an adequate substitute for stainless steel to construct a well for groundwater sampling purposes. When it comes to analysis of volatile organic compounds, there is not a significant difference between PVC and stainless steel for detection of contaminants in water at concentrations on the order of microgram per litre (see Tables 15a and 15b).

Homemade strainers made of other material such as galvanized steel and acrylonitrile-butadiene styrene copolymer (ABS) are not recommended. Manufacturer strainers are preferred because they have less surface contact with water. Using a saw to make homemade strainers dislodges fine particles of material that increase the specific area of the strainer and encourage interaction with water.

Obviously, particular care must be taken to ensure that the tubing and strainer remain clean. If they are not cleaned and wrapped separately, they should be cleaned according to the method described in section 2.3.1 of Cahier 1 – *Généralités* [Booklet 1 - General]. These parts should also not be left unprotected in locations where there are potential contamination risks (the back of a drilling truck, fouled ground surface, etc.). A protective box or plastic sheeting should be available for temporary storage at the drill site.

2.3.2. Filtering sand

Use of filtering sand will not be required if unconsolidated deposits are permeable. In a geological formation where there is poor permeability, the presence of a silica sand lantern around the area of the strainer is necessary and encourages a hydraulic connection between the geological formation and

the strainer. During sampling, water migrates through the sand ring. Filtering sand can therefore alter the chemical composition of water by adsorption/desorption. The contribution of filtering sand to the alteration of the chemical composition of water is greater in materials with little permeability because the flow is slower and water is in contact with sand for a longer period. The effect of filtering sand on water's chemical composition will be minimal if the proper particle size of clean silica sand is distributed around the opening of the strainer. Use of rounded or sub-rounded sand is recommended and use of silica chips is not recommended.

2.3.3. Sealing material

The purpose of a bentonite chips or granules plug is to prevent the cement/bentonite mixture or bentonite slurry, that is placed higher in the annular space, from intruding. If bentonite slurry is placed directly above filtering sand, a secondary filtering sand must be added between the filtering sand and bentonite slurry. Sodium bentonite has a high ion exchange capability. The principal outcome of these reactions is the release of sodium into water and the extraction of calcium. In carbonatized soil, use of calcium bentonite is recommended. Due to the alkaline properties of bentonite, it also causes the water's pH level to rise slightly[10].

Despite these inconveniences, use of a bentonite chips or granules plug is recommended because contamination due to bentonite has been established, whereas contamination due to infiltration of surface water has not.

The purpose of the cement/bentonite mixture is to minimize the inflow of surface water or the upper layers of the seal plug. The mixture should be prepared using clean water in a high-speed mixer. The amount of bentonite to be added to the cement must be approximately 3 to 8% of the weight of the cement[7].

The effectiveness of how well a monitoring well has been sealed can be tested using the method proposed by Chapuis (l987)[11].

2.3.4. Seals

Special attention must be given to connecting seals between sections of casing. The ideal connection is made using casing threaded according to standard ASTM F480. A threaded joint fitted with an O-ring provides a better seal than a simple threaded joint, to minimize the risk of water infiltration from layers above the strainer zone.

Use of plastic (PVC) glues should be avoided. These glues contain compounds that can leach into water and interfere with analyses of organic compounds. Most glues contain two or three of the following solvents[6]:

- methyl ethyl ketone;
- methyl butyl ketone;
- cyclohexanone;
- tetrahydrofuran;
- dimethyl formamide.

These solvents are not routinely analyzed but their presence in water interferes with main priority organic contaminants. Even a small amount of plastic glue can release solvents into groundwater at concentrations on the order of 100 µg/L, even after wells have been purged[6].

It is also important to remember that metal seals are often coated with a layer of oil that can also affect organic compound analyses.

2.3.5. Protective casing and cover

Technically, the cover and protective casing do not come into contact with water to be sampled. They do not therefore affect the water's chemical composition. The only restriction when selecting the right type of cover is when the casing head is installed at ground level. The cover must be tightly-sealed and rigid enough to prevent infiltration of ground water. The head of the monitoring well should be fitted with a protective casing that is padlocked to prevent vandalism.

2.4. Dimensions of sampling wells

The length of the strainer zone that is chosen may affect water composition. A strainer zone over too long a section can create a connection between two layers, which will result in a dilution of water from the contaminated zone. Strainers between 60 cm and 3 m are adequate in most cases. Regardless of the length of the strainer section, groundwater will originate mainly from more permeable layers and will very rarely represent the quality of water over the entire strainer section. In a fractured formation, the strainer zone should cover a longer section, which improves the chances of intercepting fractures, but can also cause a dilution effect.

Particular attention must be given to the strainer position in the case of non-miscible liquids. If hydrocarbons lighter than water are present, it is important to ensure that the strainer zone extends above the water table in order to intercept the supernatant phase. In the case of non-miscible liquids that are denser than water, the strainer must be long enough to reach the upper limit of the first impervious zone encountered below the non-miscible liquid phase. If multilevel wells are installed, openings should be located in the lower part of the sand filter[12].

For practical reasons, a monitoring well for groundwater sampling is usually 3.75 cm or 5.0 cm in diameter. Most of the usual sampling techniques can be carried out with

these diameters. In less permeable material, larger diameter wells result in longer stabilization times. The larger the diameter of a well, the larger the volume of water that has to be purged prior to sampling. The time and costs of sampling procedures will be higher for large wells. If material has to be added (filtering sand, seal plugs, expansive cement), the annular space between the borehole wall and tubing must be at least 5 cm.

In permeable geological formations consisting of unconsolidated deposits, naturally developed wells are recommended. The strainer opening should correspond to d_{20} (diameter of particles corresponding to 20% of the weight of the sample passing through the sieve during a gradation test) for the finest sample taken over the length of the strainer zone. In geological formations with low permeability, filtering sand is required.

The gradation curve for filtering sand is chosen by multiplying the d_{30} of the finest sample taken over the length of the strainer zone by three or four. The uniformity coefficient (d_{60}/d_{10}) for filters can vary between 2 and 3[3]. Where this is the case, the opening of the appropriate strainer should correspond to d_{10} of the filtering sand.

In both cases, the strainer opening should allow almost the entire natural formation and filtering sand to be held because a small diameter monitoring well (3.75 to 5.0 cm) is difficult to develop. The reader can refer to the recommendations of Driscoll (1986, Chapter 13)[3] for water supply wells when selecting the opening of strainers for large diameter monitoring wells.

2.5. Installing material

2.5.1. Tube and strainer

It is important to centre the tube and strainer in the borehole to ensure that sealing material and filtering sand (where necessary) are distributed evenly around the tube and strainer.

Adjustable diameter centralizers (polyvinyl chloride and stainless steel) can be secured prior to or when installing tubes in the well. Centralizers are placed on the tube at 3 to 6 metre intervals. If semi-circular centralizers are used, depth is easier to measure when filtering sand and sealing material are installed. Centralizers must have a smaller diameter than the borehole or temporary casing.

2.5.2. Filtering sand

Use of the hopper tube method is recommended when installing filtering sand. Filtering sand is introduced by gravity through a rigid hose or semi-flexible tube between the borehole wall and strainer. The annular space is filled while dry or simultaneously with clean water, from the bottom to the top of the strainer. The hopper should be at least 3.75 cm in diameter. If

filling is carried out in the presence of temporary casing (hollow auger, cable drilling) and in loose unconsolidated deposits, the casing must be removed gradually (30 to 60 cm at a time) as the filtering sand is being added.

In solid unconsolidated deposits (silt and clay), rock or hard formations, temporary casing or a hollow auger can be removed up to the sand's projected top level, before filtering sand is introduced.

The level of filtering sand must be measured as it is being added to ensure that it reaches the desired height.

2.5.3. Annular space sealing material

A) Bentonite cap (above the filtering sand):

Bentonite chips can be added by pouring, when a well is no more than 15 m deep and the annular space is at least 7.5 cm. Chips should be packed together with a rod.

In wells that are deeper than 15 m, bentonite chips can be mixed with clean water and poured in through a hopper in the annular space.

If bentonite slurry is used directly on top of filtering sand, a secondary filtering sand must be poured in to prevent the slurry from migrating to the first filter and into the strainer section[7]. The coarsest fraction for the secondary sand should be equal to d_{10} of the filtering sand. The d_{10} for the secondary filtering sand should be between one-third and one-fifth of the d_{10} for the filtering sand, to ensure that fine material from secondary filtering sand does not engulf the filtering sand. The finest particles should be no bigger than 0.7 mm and no smaller than 0.1 mm in diameter. This type of particle-size distribution is fine enough to prevent slurry from penetrating the secondary filtering sand, but coarse enough to be introduced in a reasonable time. The hydraulic conductivity of the secondary filtering sand should be greater than or equal to the hydraulic conductivity of the layer of the geological formation with which it is in contact. To prevent erosion of secondary filtering sand during filling, the hopper should be placed against the tube at an angle.

B) Above the bentonite cap:

The cement-bentonite mixture or bentonite slurry is introduced using a hopper hose at least 3.75 cm in diameter. A positive displacement pump should be used to continuously fill the annular space from the bottom to the top. The bottom of the hopper should remain immersed in the mixture at all times during filling. The hopper, however, should be removed as soon as filling is complete.

2.6. Development of monitoring wells

The purpose of developing a monitoring well is to remove fine particles that were introduced during drilling operations to restore the natural hydraulic conductivity of the water-bearing formation and to obtain water samples that have as little turbidity as possible.

The five main methods of developing monitoring wells are by plunger, pumping/overpumping, bailer, stream of water, stream of air. The first three methods can be used in combination. The last two are not recommended because introducing air or water into a geological formation can alter the chemical integrity of water samples collected.

Plunger

The plunger travels down as far as the top of the strainer and moves from top to bottom over a length of one metre. Fine particles and sand that move to the strainer must be pumped out periodically. The plunger is then gradually lowered towards the bottom of the strainer. The plunger should be slowly agitated at the beginning, then agitation should gradually increase during development. Too much agitation can cause the strainer or tube to break. This method is effective with a cable drill for a stainless steel monitoring well. If material other than steel is used, the tube and strainer may break.

Pumping/overpumping

The pumping/overpumping method consists of pumping water from a well faster than it can enter, until it is almost dry. The pump is then stopped and water rises to its initial level in the well. This cycle is repeated several times, until water is free of sediments. A siphon effect can also be produced inside the strainer if the pump does not have a one-way check valve. This can be produced by turning the pump on and off periodically.

Bailer

Development of a monitoring well using a bailer is carried out by allowing the bailer to fall into the well, which raises the water level to dislodge fine particles around the strainer. As the bailer fills with water, a drawdown effect is created and fine particles are drawn into the well. This operation should be repeated until the water is free of suspended particles. To speed up the process, the bailer can be shaken quickly near the base of the well.

These methods can usually be carried out in permeable material. In material with low permeability, none of these methods produces satisfactory results. Clean water should be circulated through the tube to the strainer and filtering sand before a seal plug is installed. The water flow should be controlled to prevent filtering sand from moving to

the surface. Once a seal plug has been installed, the well should be pumped to remove the small amount of water introduced into the formation during the development process.

The pumped water should be disposed of in accordance with the disposal criteria proposed in section 3.3.

For more information about development of monitoring wells, the reader can refer to Aller *et al.* (1988)[13].

3. SAMPLING PROCEDURES

3.1. Development of a sampling program

3.1.1. Determining which parameters to analyze

The purpose of groundwater sampling is to determine if there has been contamination and what type of contamination is present. Which parameters to analyze and the degree of precision desired, must be determined on the basis of established policies, guidelines and regulations. A review of the history and type of activities at the contaminated site or on neighbouring sites will sometimes provide clues about which contaminants might be present. A review of this information may also serve as a guide to planning the sampling program. Sometimes, however, the information available does not provide enough clues about the presence of certain contaminants when they are present. A screening analyses procedure should be used to detect as many parameters as possible during the first sampling session. The list of parameters can be significantly reduced during subsequent samplings.

3.1.2. Sampling frequency

A sampling program to characterize, restore or monitor groundwater quality after a contaminated site has been rehabilitated, should consist of at least four sampling sessions each year. One detailed session and three partial sessions should enable trends to be defined. During a detailed session, a scan is carried out for all suspected contaminants and only those parameters that are detected during this session are analyzed during a partial session. Ideally, monitoring wells should be sampled throughout the entire year, including at least one session per season to determine seasonal fluctuations in water quality.

3.1.3. Order of sampling

During a sampling program, monitoring wells that are located the furthest away from a source of contamination must be sampled first because they have a lower risk of being highly contaminated. This order of sampling minimizes the risk of cross contamination. Sometimes, the exact location of a

contamination source is unknown. It therefore becomes difficult to determine an order of sampling. The first session will help determine which monitoring wells are most contaminated and serve to establish the order of sampling. Sampling order is not important if a dedicated sampling system is in use. Dedicated systems consist of permanently setting up certain pieces of equipment for sampling at each monitoring well.

3.2. Water level analyses and hydraulic testing

Water sampling sessions are often include water level analyses and occasionally hydraulic testing. Hydraulic tests should be interpreted according to the Hvorslev[14] method or an equivalent method. Testing should not be conducted if the water level is dropping or if water or a foreign object has to be added. Testing should be carried out when the water level is rising (purging). Water level probes, preferably made of stainless steel, should be cleaned according to procedures recommended in section 3.6. If non-miscible phases are detected or if the density of a water column is >1 (ex. salt water), an equivalent load in water depth should be calculated.

3.3. Well purging

All wells, without exception, that are scheduled for sampling to verify groundwater quality must be purged before samples are collected. Purging is carried out to remove stagnant water in order to obtain a sample that is representative of the underground formation. Stagnant water in a well can be affected by the following processes: contact with well construction material, contact with the atmosphere, outgassing and biological activity. Well purging must allow enough water to be drained from the well. Too large an amount will interfere with the hydrogeological system. Ideally monitoring wells should be purged until the water's physical and chemical properties (temperature, electrical conductivity and pH) are stable[15,16,17,18].

For permeable material, a volume of water equivalent to 3 to 5 times the total volume of water in the monitoring well and in the filtering sand (depending on its porosity) should be removed. It is important to prevent drawdowns by avoiding overpumping when wells are purged. Excessive pumping will drawn water from overlying and underlying layers to the zone you would like to sample. Draining water from the strainer and filtering sand should be avoided because it may contribute to volatilization of volatile organic compounds.

In the case of material with low permeability, where large volumes of water cannot be purged over a reasonable period, stagnant water should be purged from the well at least once. Sampling must be carried out as soon as enough groundwater has reentered the well.

Purging should be carried out from the top of the water column to the bottom, to avoid disturbing the water unnecessarily[19]. Water that is purged must be collected and stored in containers, until the results of analysis are available. The water can then be emptied

at the site if concentrations are below criterion B of the *Politique de réhabilitation des terrains contaminés* [Rehabilitation of Contaminated Sites Policy[5]] or drained into the sewer system if concentrations comply with the sewer drainage standards of the municipality or water can be treated at the site, as the case may be.

3.4. Sampling equipment

A variety of equipment is available for groundwater sampling. Equipment ranges from simple to sophisticated. New instruments are constantly being developed and gradually introduced onto the market. The type of manufacturing material and operating methods for the instrument in question are the principal criteria to consider when selecting equipment. These two importants factors can affect a sample's chemical composition. This part of the guide contains a brief description of equipment and discusses advantages and disadvantages.

The types of material that go into constructing sampling systems are discussed in section 3.4.6.

Of all the different types of sampling systems, there are four large groups of systems that can be classified according to their operating procedure: direct sampling methods, suction methods, positive displacement methods and destructive methods.

3.4.1. Direct sampling methods

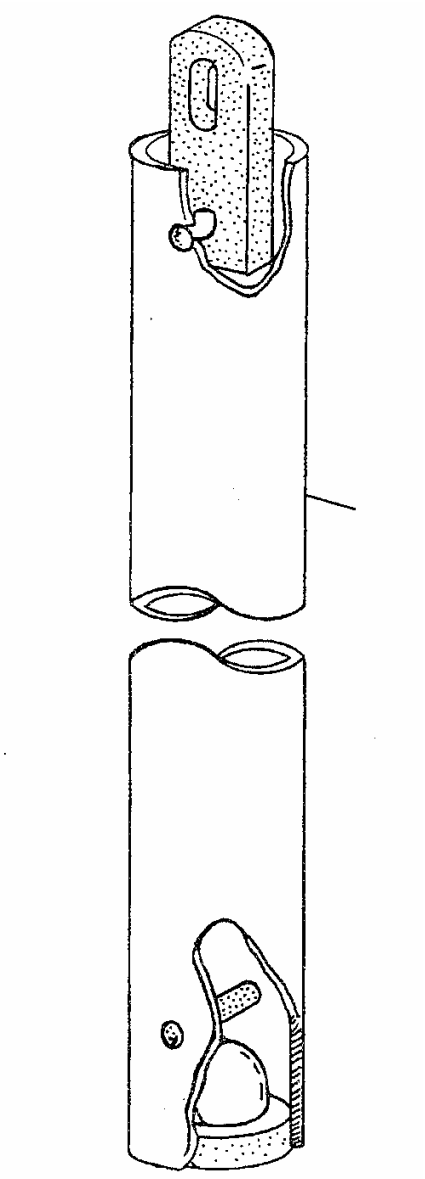
Direct sampling methods include sampling devices that are lowered into a well. This category includes bailers, syringes and hand piston pumps.

Bailer

A diagram of a bailer is shown in Figure 6 on the following page. It consists of a tube fitted with a check valve at the bottom. A bailer is lowered and raised by hand from the surface using a cable. The tube fills when it is lowered and water is trapped in the tube by the check valve when it is raised.

Because of its simple design, a bailer can be manufactured at a reasonable cost using a variety of material. It is also easy to clean. Bailer's, however, can only draw small volumes of water (maximum 1 L) and may therefore not be suitable for use in some instances. In some deep wells with a high water level, sampling can become labour-intensive. When a sample in a tube is decanted to a container, it is exposed to air. Bailers that allow a sample to be decanted from the bottom at a reduced capacity are now on the market. Use of this type of bailer is recommended where trace amounts of volatile organic compounds have to be sampled.

FIGURE 6 - BAILER



The most likely source of contamination during use of a bailer is the cable. Caution should be taken to prevent the cable from coming into contact with the ground or other possible sources of contamination. Prior to sampling, the cable should be rinsed with well water and the portion of the cable that was immerged should be cleaned, according to the procedure in section 3.6. Use of a new cable for each monitoring well prevents the risk of cross contamination.

During handling, the sample should be exposed to as little air as possible and the water should be agitated as little as possible. The advantages and disadvantages of bailers are detailed in Table 7, on the following page.

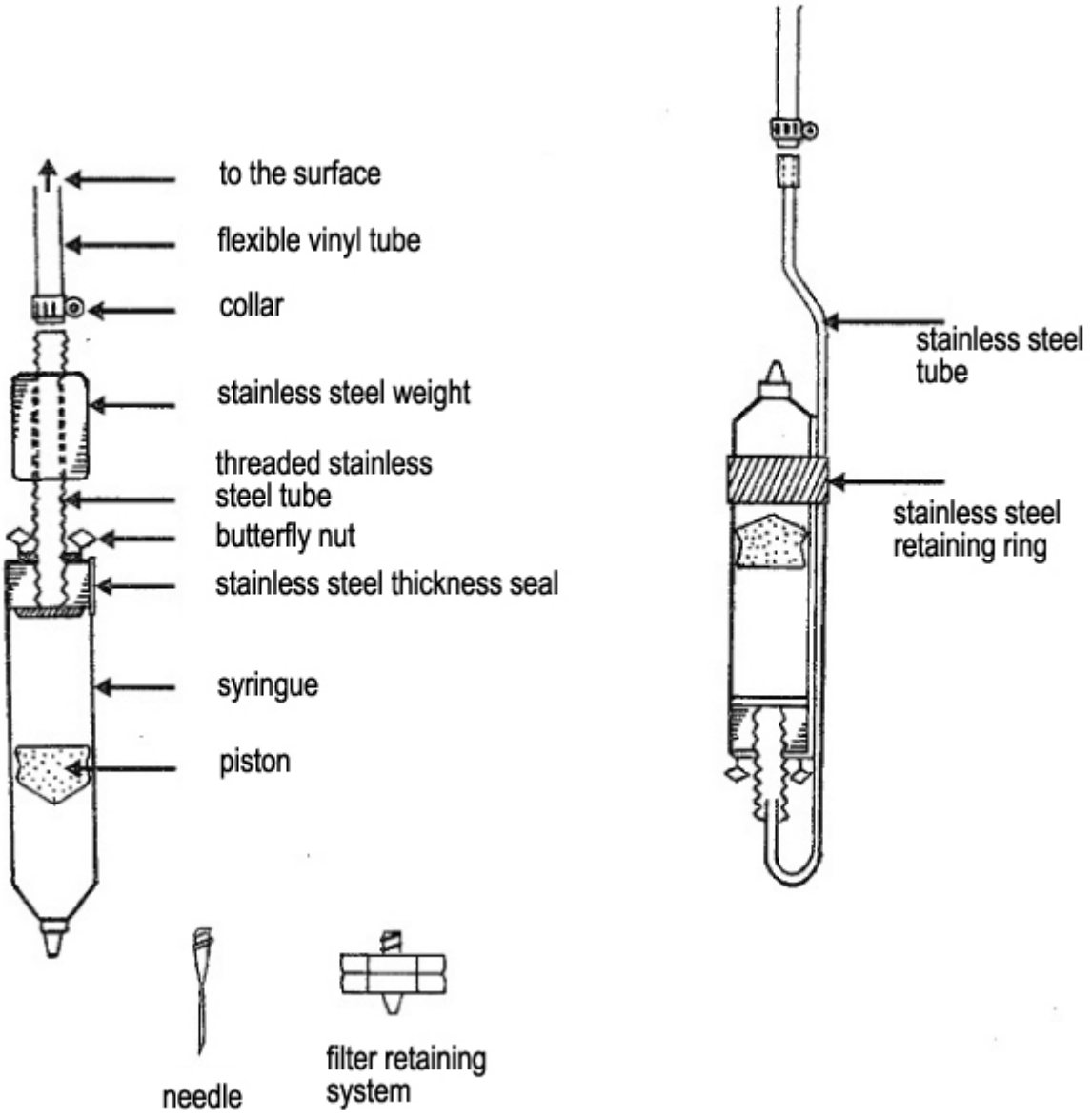
TABLE 7 - ADVANTAGES AND DISADVANTAGES OF A BAILER

ADVANTAGES:	It can be used as a dedicated sampling system;
	it is portable;
	no source of energy is required;
	it is made of a variety of material;
	easy to clean;
	it is inexpensive;
	it enables non-miscible liquids to be sampled;
	it is easy to use;
	it enables hydraulic conductivity testing and can be used to develop and purge wells.
DISADVANTAGES:	It has a small volume;
	it does not perform well in deep wells with high water levels;
	contact with air and degassing of the sample can occur when it is decanted to a container;
	valves can become blocked by suspended solids.

Syringes

Syringe systems have recently been developed for groundwater sampling procedures[2]. Figure 7 on the following page shows the principal components of this type of system. A water sample is taken at a desired depth from the surface.

FIGURE 7 - SYRINGE SAMPLING SYSTEM



To take samples at approximately 4 metres in depth, air pressure must be applied to prevent the plunger from rising. Pressure in the syringe is released when it reaches the desired depth. The main advantage of a syringe system is that water samples can be protected from exposure to air because the syringe serves as the sampling container. A filter can be added to the lower end of the syringe. The advantages and disadvantages of syringes are detailed in Table 8.

TABLE 8 - ADVANTAGES AND DISADVANTAGES OF SYRINGE SYSTEMS

ADVANTAGES:	Samples do not come into contact with air;
	the source of the sample is known;
	they are made of inert material;
	they can be used as a container;
	they are portable, inexpensive and easy to use.
DISADVANTAGES:	They have a small volume;
	they cannot be used to purge wells;
	their use is limited to samples that have few suspended solids;
	a source of compressed gas is required.

Inertia pump – "Waterra" type

An inertia pump operates according to the same principle as a bailer. When it is lowered, water enters the tubing and is trapped by a one-way check valve when pulled up. By continuously oscillating the tubing in an up-and-down motion connected, water rises to the surface.

Tubing often consists of a flexible polyethylene hose, which can also be made of Teflon® or aluminium. High-density polyethylene tubing is preferable to low-density tubing because low-density tubing is too flexible and tends crack easily.

Inertia pumps are available in a variety of materials and diameters. They can use tubes with a diameter as small as 2 cm and have a number of advantages. They are easy to use, reliable, portable and require no particular maintenance. They can be used manually to a depth of 40 metres. Because they are inexpensive, they can be used as a dedicated system to purge wells and for sampling. To minimize the disturbance of water when sampling volatile organic compounds, a smaller diameter device can be adjusted to fit the plastic tubing.

The main disadvantages of an inertia pump are the turbulence that is created when a pump is agitated in a well and wearing of the pump against a walls. If a well has not been developed correctly, valves may block.

The advantages and disadvantages of inertia pumps are detailed in Table 9, on the following page.

TABLE 9 - ADVANTAGES AND DISADVANTAGES OF MANUAL INERTIA PUMPS

ADVANTAGES:	They have a simple design;
	are lightweight and portable;
	are easy to operate;
	require little maintenance;
	are inexpensive;
	can be used in small diameter wells;
	are suited to sampling volatile organic compounds[20];
	can be used for purging and for sampling;
	can be used manually to a depth of 40 metres and with a motor, to a depth of 60 metres;
	can be used as a dedicated system.
DISADVANTAGES:	They are difficult to use in deep monitoring wells or large-diameter wells because they require a motor;
	the automated system is not portable;
	wearing of the pump occurs following prolonged use on a metal tube;
	they can cause turbulence in a well.

3.4.2. Suction methods

Suction sampling methods use negative pressure to draw water from a sampling well. These methods usually consist of lowering, a tube connected to a surface pump, to the desired depth. A vacuum can be applied at the surface using various methods: a manual vacuum pump or peristaltic pump. They are connected to an Erlenmeyer flask to limit potential contamination from flexible rubber tubing (ex. Tygon®), which are commonly used in combination with peristaltic pumps. The suction method principle is illustrated in Figure 8, on the following page.

Theoretically, suction methods cannot be used to collect samples at depths in excess of 9.7 m. In practice, however, samples cannot be collected at depths in excess of 7.5 m because there will not be enough vacuum pressure. These methods are therefore restricted to instances where the water level is less than 7 to 8 m from the ground surface. The strainer, however, can be positioned at much greater depths.

The vacuum can be applied to either the liquid phase or gaseous phase. These methods are usually not recommended for collecting samples that are submitted for analyses of volatile organic compounds. Where vacuum pressure is applied to water, degassing problems are less serious, but do still exist.

FIGURE 8 - SUCTION SAMPLING METHOD

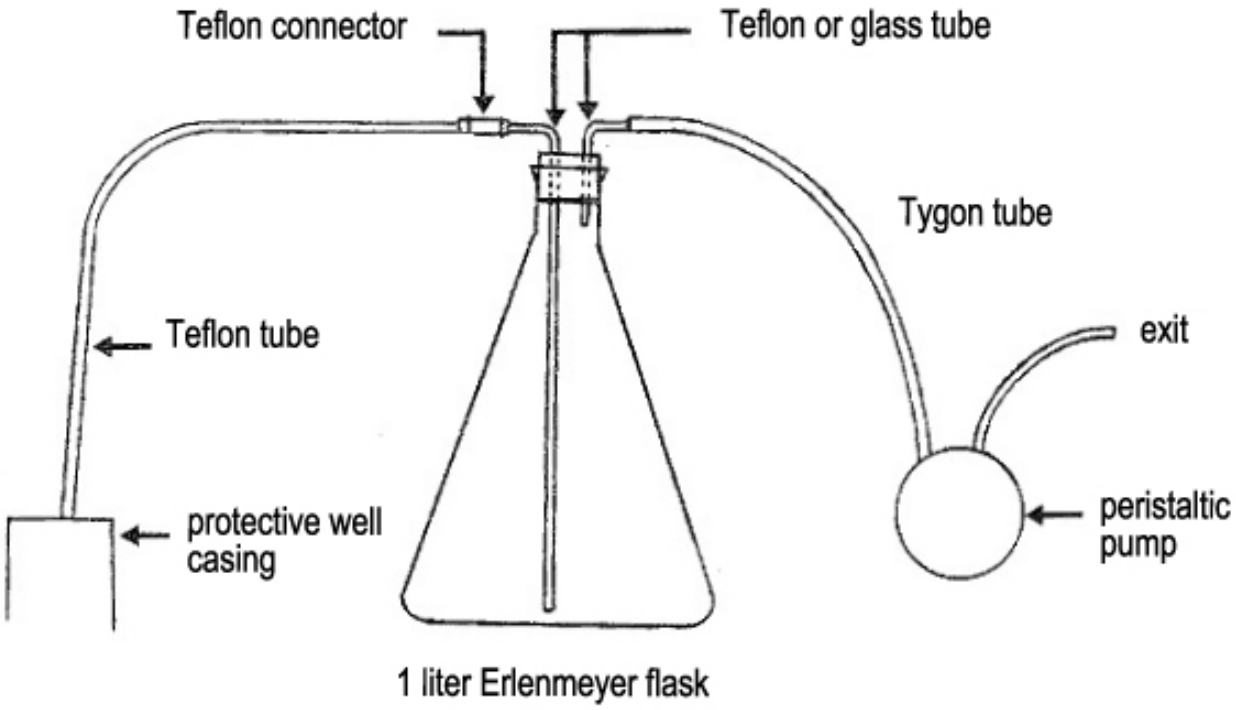


Table 10 lists the advantages and disadvantages of suction methods.

TABLE 10 - ADVANTAGES AND DISADVANTAGES OF SUCTION METHODS

ADVANTAGES:	They are easy to manufacture;
	are inexpensive;
	are portable;
	have a variable output capacity;
	components can be made of inert material.
DISADVANTAGES:	There is a chance of chemical alteration due to vacuum pressure;
	depth is limited.

3.4.3. Positive displacement methods

Positive displacement methods are based on mechanisms that exert direct pressure on water by using a gas, piston, turbine or bladder movement, to drive water. These methods allow samples to be collected at depths of 1,000 metres. The chance of chemical alteration of water due to exposure to positive pressure is small compared to the chance of chemical alteration due to use of suction methods[2]. Positive displacement methods are used when the water level is too deep and direct sampling methods are impractical. A sample undergoes significant changes in pressure as it is raised to the surface from extreme depths. A sample taken several hundred metres below the surface can undergo pressure changes equal to several thousand kilopascals, which changes steady-state conditions.

Gas-driven systems are included in positive displacement methods. They consist of applying pressurized gas to a water column, which forces water to rise in a collector tube up to the surface[21]. The details of these types of systems are shown in Figure 9, on the following page. In the case of gas-driven systems, contact of the water with gases may alter the water's chemical composition. Nitrogen is the gas that is recommended during use of these methods because it is relatively inert.

Positive displacement devices also include submersible piston pumps and bladder systems (bladder pump), shown in Figure 10.

Although expensive, bladder pumps provide samples that are more representative than gas-driven systems because the gases that are used do not come into contact with water. Unlike submersible pumps (piston or turbine), bladder pumps agitate water less, which makes them more reliable for sampling volatile compounds.

Of all positive displacement sampling methods, a bladder pump is the recommended system.

FIGURE 9 - GAS DISPLACEMENT SAMPLING METHOD

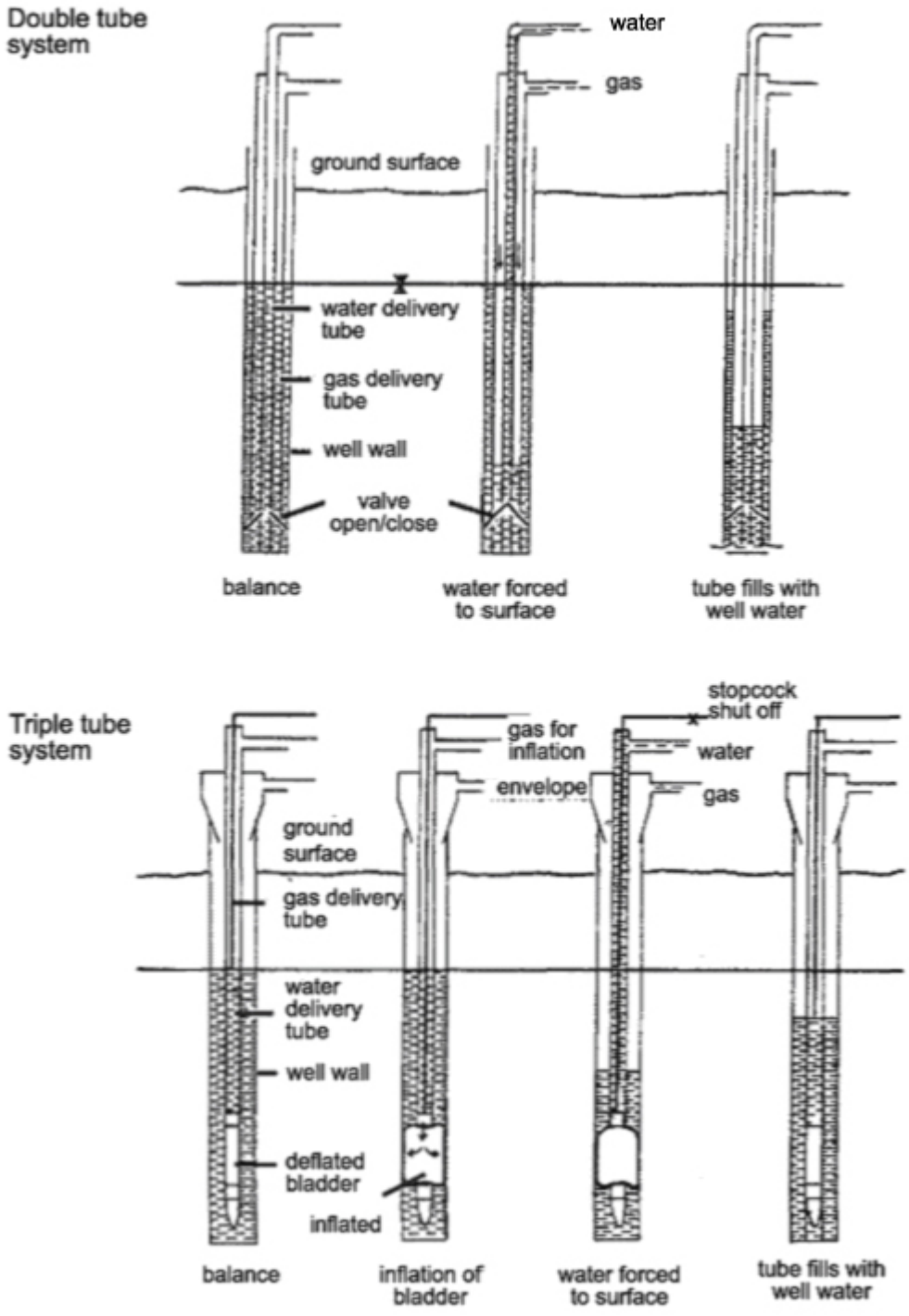


FIGURE 10 - POSITIVE DISPLACEMENT SAMPLING METHOD – BLADDER

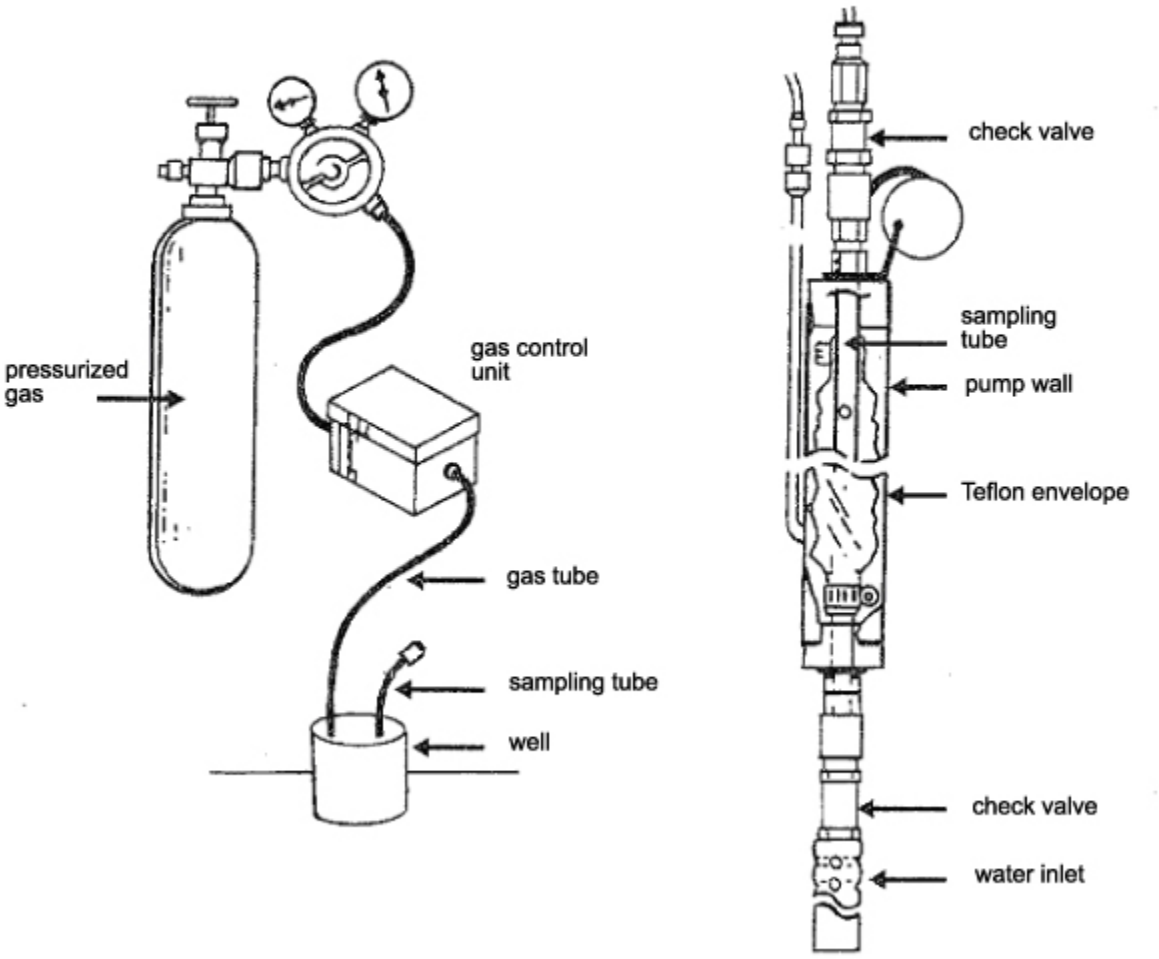


TABLE 11 - ADVANTAGES AND DISADVANTAGES OF POSITIVE DISPLACEMENT METHODS

ADVANTAGES:	Reduced chance of degassing and volatilization;
	the piezometer purges quickly;
	can be used at extreme depths;
	they accommodate a variable flow.
DISADVANTAGES:	They are expensive;
	require a power supply;
	are difficult to clean;
	require a large diameter;
	water comes into contact with pump components.

3.4.4. Destructive methods

Destructive sampling techniques are methods that require a very different approach than the methods discussed earlier in this guide. Destructive methods do not require use of permanently installed monitoring instruments. They therefore cannot be used for long-term monitoring of groundwater quality. The most common method consists of extracting water from soil samples collected during drilling operations. Destructive methods are used in clay deposits with low permeability or where the inlet of water into piezometers is very slow and where, as a result, traditional methods do not produce satisfactory results.

Water can be extracted from soil samples by centrifugation or compressing the sample. Since only very small amounts of water can be extracted using these methods, it is important to carefully choose which parameters are analyzed.

TABLE 12 - ADVANTAGES AND DISADVANTAGES OF DESTRUCTIVE METHODS

ADVANTAGES:	Sampling can be carried out in material with low permeability.
DISADVANTAGES:	Only small volumes of water are extracted; they do not allow long-term monitoring.

3.4.5. Special samplers

Resins

An alternative to groundwater sampling for analysis of volatile organic compounds is the use of tubes containing an adsorbent resin. The sample is forced through the tube by a pump. Organic compounds are trapped and resins are taken to the laboratory for desorption and analysis.

Large volume samples are required to detect very small levels of organic compounds. Resins help minimize the amount of space required to carry regular samples. They also prevent a sample from coming into contact air because it remains in the collector tube.

Well point – "HydroPunch" type

Well points are samplers that can be driven into unconsolidated deposits (fine gravel, sand, silt and clay), to a depth of 5 to 8 metres, using a drilling machine hydraulic system or penetrometer. Points are made of stainless steel and Teflon® and can be recovered after water sampling and left at the site, depending on the model. Use of a drilling fluid (water, mud, air, ...) is not required. The point must penetrate at least 2 metres below the water table to enable groundwater sampling. A device has also been developed for sampling light non-miscible liquids.

Tables 13a to 13d, show a summary of the types of samplers that can be used, depending on which parameters are analyzed.

TABLE 13A - RELIABILITY OF DIRECT SAMPLING METHODS[2]

PARAMETRE	BAILER	SYRINGE	INERTIA PUMP
INORGANIC CHEMISTRY			
Ammonium	(r)	r	r
Silver	(r)	r	r
Arsenic	(r)	r	r
Barium	(r)	r	r
Cadmium	(r)	r	r
Calcium	r	r	r
Chlorides	r	r	r
Chromium	(r)	r	r
Conductivity	r	r	r
Iron	(r)	r	r
Fluorides	r	r	r
Magnesium	r	r	r
Manganese	(r)	r	r
Mercury	(r)	r	r
Nitrates	r	r	r
pH	(r)	r	r
Lead	(r)	r	r
Redox potential (E_h)	(r)	r	r
Selenium	(r)	r	r
Sodium	r	r	r
Sulfates	(r)	r	r
			r
ORGANIC CHEMISTRY			r
Phenolic compounds	(r)	r	r
Volatile compounds	(r)	r	r
Pesticides	(r)	r	r
RADIOACTIVITY			
Alpha and beta	(r)	r	r
Radium	r	r	r
MICROBIOLOGY			
Heterotrophic plate count	r	r	r
Total and fecal coliforms	r	r	r
Fecal streptococcus	r	r	r

r: reliable (r): limited reliability n: unreliable

TABLE 13B - RELIABILITY OF SUCTION SAMPLING METHODS ON THE BASIS OF PARAMETERS[2]

PARAMETRES	SUCTION LIFT APPLIED TO WATER	SUCTION LIFT APPLIED TO GAS
INORGANIC CHEMISTRY		
Ammonium	r	n
Silver	(r)	n
Arsenic	(r)	n
Barium	(r)	n
Cadmium	(r)	n
Calcium	r	(r)
Chlorides	r	r
Chromium	(r)	n
Conductivity	r	r
Iron	(r)	n
Fluorides	r	r
Magnesium	r	(r)
Manganese	(r)	n
Mercury	(r)	n
Nitrates	r	r
pH	r	n
Lead	(r)	n
Redox potential (E_h)	(r)	n
Selenium	(r)	n
Sodium	r	r
Sulfates	(r)	(r)
ORGANIC CHEMISTRY		
Phenolic compounds	n	n
Volatile compounds	n	n
Pesticides	r	(r)
RADIOACTIVITY		
Alpha and beta	(r)	n
Radium	r	(r)
MICROBIOLOGY		
Heterotrophic plate count	r	(r)
Total and fecal coliforms	r	(r)
Fecal streptococcus	r	(r)

r: reliable (r): limited reliability n: unreliable

TABLE 13C - RELIABILITY OF POSITIVE DISPLACEMENT SAMPLING METHODS[2]

PARAMETRE	CENTRIFUGAL PUMP	PISTON PUMP	BLADDER PUMP	GAS DISPLACEMENT
INORGANIC CHEMISTRY				
Ammonium	r	r	r	r
Silver	r	r	r	(r)
Arsenic	r	r	r	(r)
Barium	r	r	r	(r)
Cadmium	r	r	r	(r)
Calcium	r	r	r	r
Chlorides	r	r	r	r
Chromium	r	r	r	(r)
Conductivity	r	r	r	r
Iron	r	r	r	(r)
Fluorides	r	r	r	r
Magnesium	r	r	r	r
Manganese	r	r	r	(r)
Mercury	r	r	r	(r)
Nitrates	r	r	r	r
pH	r	r	r	(r)
Lead	r	r	r	(r)
Redox potential(E_h)	(r)	r	r	(r)
Selenium	r	r	r	(r)
Sodium	r	r	r	r
Sulfates	r	r	r	(r)
ORGANIC CHEMISTRY				
Phenolic compounds	(r)	(r)	r	(r)
Volatile compounds	(r)	(r)	r	(r)
Pesticides	(r)	r	r	r
RADIOACTIVITY				
Alpha and beta	r	r	r	r
Radium	r	r	r	r
MICROBIOLOGY				
Heterotrophic plate count	(r)	(r)	r	(r)
Total and fecal coliforms	(r)	(r)	r	(r)
Fecal streptococcus	(r)	(r)	r	(r)

r: reliable (r): limited reliability n: unreliable

TABLE 13D - RELIABILITY OF DESTRUCTIVE SAMPLING METHODS[2]

PARAMETER	EXTRACTION OF INTERSTITIAL WATER FROM SOIL SAMPLES
INORGANIC CHEMISTRY	
Ammonium	(r)
Silver	(r)
Arsenic	(r)
Barium	(r)
Cadmium	(r)
Calcium	(r)
Chlorides	r
Chromium	(r)
Conductivity	r
Iron	(r)
Fluorides	r
Magnesium	(r)
Manganese	(r)
Mercury	(r)
Nitrates	r
pH	(r)
Lead	(r)
Redox potential(E_h)	n
Selenium	(r)
Sodium	r
Sulfates	(r)
ORGANIC CHEMISTRY	
Phenolic compounds	n
Volatile compounds	n
Pesticides	r
RADIOACTIVITY	(r)
Alpha and beta	r
Radium	
MICROBIOLOGY	
Heterotrophic plate count	r
Total and fecal coliforms	r
Fecal streptococcus	r

r: reliable (r): limited reliability n: unreliable

3.4.6. Choice of materials

Chemical contamination as a result of samples coming into contact with certain materials can have negative consequences. Sampling system components (tubing, pumps, valves, sampling containers, etc.) are manufactured of a variety of materials that can contribute, to varying degrees, to the chemical alteration of a sample. Metals, plastics, glass and rubber are the most common materials in use. Two reactions, which are the result of water coming into contact with these materials, can affect the water's chemical composition: the release of compounds into water and adsorption of contaminants on the surface of materials. If small concentrations of metals or organic compounds are anticipated in groundwater, precautions should be taken when choosing the material that will come into contact with water.

Plastics

The most common plastics for sampling groundwater include[22]:

- Teflon®
- PVC = polyvinyl chloride
- PE = high-density and low-density polyethylene (HDPE and LDPE)
- PP = polypropylene
- ABS = acrylonitrile-butadiene-styrene copolymer
- SR = styrene rubber

Some of these plastics release considerable amounts of compounds into water. For example, PVC, commonly used in well construction, releases compounds such as phtalates, ortho-cresol, naphtalene, butyloctylfumarate and butylchloracetate[2]. The elements that are most affected by adsorption on PVC, PE and PP are lead and organic compounds. The processes of adsorption and release of organic compounds occur quickly in the case of PE, moderately slowly in the case of PP and slowly in the case of PVC. Adsorption of organic compounds in water on PVC is significant (over 10%) if compounds are hydrophobic (solubility < 1 millimole/cubic metre), and not significant where solubility is less than 10 millimoles per cubic metre[23]. Of all the plastics mentioned at the beginning of this section, ABS and SR are those that have pose the highest risk for alteration of a water's chemical composition. Teflon® poses the smallest risk. Teflon® is currently the highest recommended plastic for sampling trace amounts of organic compounds because it is the most inert. Use of Teflon® should therefore be favoured over other plastics. Tables 14a to 14c, show the adsorption and desorption risks of six organic compounds commonly detected in groundwater that comes into contact with PVC, PE and PP surfaces[2].

Some plastics allow gas to diffuse through their walls. The loss of gas (volatile organic compounds) as a result of this process, however, is not well documented. Plastics that are relatively gas-permeable (from most permeable to least permeable) include: LDPE, Teflon®, PP, HDPE and PVC.

For long-term sampling programs, a plastic's degree of resistance and durability on contact with chemical compounds present in water should be verified with manufacturers.

TABLE 14A - ADSORPTION AND RELEASE OF ORGANIC COMPOUNDS BY PVC (ADAPTED FROM REFERENCE[2])

COMPOUND	ADSORPTION	RELEASE
Bromoform	None	None
Tetrachloroethylene	Moderate	Marginal
1,1,1-Trichloroethane	None	None
1,1,2-Trichloroethane	None	None
Trichloroethylene	None	None
Trichlorofluoromethane	None	None

TABLE 14B - ADSORPTION AND RELEASE OF ORGANIC COMPOUNDS BY PE (ADAPTED FROM REFERENCE[2])

COMPOUND	ADSORPTION	RELEASE
Bromoform	Moderate	Moderate
Tetrachloroethylene	Very strong	None
1,1,1-Trichloroethane	Substantial	Marginal
1,1,2-Trichloroethane	Moderate	Marginal
Trichloroethylene	Substantial	None
Trichlorofluoromethane	Substantial	Marginal

TABLE 14C - ADSORPTION AND RELEASE OF ORGANIC COMPOUNDS BY PP (ADAPTED FROM REFERENCE[2])

COMPOUND	ADSORPTION	RELEASE
Bromoform	Marginal	Very strong
Tetrachloroethylene	Very strong	None
1,1,1-Trichloroethane	Moderate	Marginal
1,1,2-Trichloroethane	Marginal	Marginal
Trichloroethylene	Substantial	Marginal
Trichlorofluoromethane	Moderate	Marginal

Metals

Metals are resistant, rigid and unaffected by changes in temperature. A number of alloys, however, can release metals into water. Cases of water contamination by zinc and copper from brass have been documented. Oxidization products and corrosion of metal components can also find their way into water. Metal components are usually made of iron, aluminum and copper. In addition to the release of metal ions in water, metal components act as adsorbent surfaces on which a variety of organic compounds can become trapped. Of all the metal components that might be used, only those made of 304 and 306 grade stainless steel show the least degree of risk of contamination. According to Driscoll (1986)[3], however, use of these steels is not recommended to detect heavy metals in groundwater because they can release chromium and other metals. Galvanized steel can release iron, manganese, zinc and cadmium in water. It is also important to note that metal parts that have not been washed are often coated with a protective film of oil that can release organic compounds into water.

Glass

Like Teflon® and stainless steel, glass is considered a relatively inert material. For organic compounds, glass is the preferred material. Glass surfaces, however, can adsorb positive ions such as metals and release negative ions such as silicates and borates.

Rubber

Rubber is sometimes used to manufacture a variety of sampling system components (sealing rings, tubing). Rubber, however, is able to adsorb a wide variety of organic compounds. Rubber is also a major source of organic and inorganic compounds that can find their way into water. **The use of rubber should therefore be avoided, regardless of which parameter is analyzed**.

Recommended material

Materials that are recommended for sampling organic compounds include, in order of preference:

- glass;
- Teflon®;
- stainless steel;
- polyvinyl chloride;
- polyethylene;
- polypropylene.

Tables 15a to 15c, on the pages that follow, serve as a guide to selecting construction material on the basis of which parameters are analyzed.

TABLE 15A - RELIABILITY OF PLASTICS ON THE BASIS OF TYPES OF PARAMETERS TO BE ANALYZED[2]

PARAMETER	TEFLON®	PVC	SR	PE	PP	ABS
INORGANIC CHEMISTRY						
Ammonium	r	r	r	r	r	r
Silver	r	r	r	r	r	r
Arsenic	r	r	r	r	r	r
Barium	r	r	r	r	r	r
Cadmium	r	r	r	r	r	r
Calcium	r	r	r	r	r	r
Chlorides	r	r	r	r	r	r
Chromium	r	r	r	r	r	r
Conductivity	r	r	r	r	r	r
Iron	r	r	r	r	r	r
Fluorides	r	r	r	r	r	r
Magnesium	r	r	r	r	r	r
Manganese	r	r	r	r	r	r
Mercury	r	r	r	r	r	r
Nitrates	r	r	r	r	r	r
pH	r	r	r	r	r	r
Lead	r	n	r	n	n	r
Redox potential(E_h)	r	r	r	(r)	r	r
Selenium	r	r	r	r	r	r
Sodium	r	r	r	r	r	r
Sulfates	r	r	r	r	r	r
ORGANIC CHEMISTRY						
Phenolic compounds	r	(r)	n	(r)	n	n
Volatile compounds	r	(r)	n	(r)	n	n
Pesticides	r	(r)	n	(r)	n	n
RADIOACTIVITY						
Alpha and beta	r	r	r	r	r	r
Radium	r	r	r	r	r	r
MICROBIOLOGY						
Heterotrophic plate count	r	(r)	(r)	(r)	(r)	(r)
Total and fecal coliforms	r	(r)	(r)	(r)	(r)	(r)
Fecal streptococcus	r	(r)	(r)	(r)	(r)	(r)

r: reliable (r): limited reliability n: unreliable

TABLE 15B - RELIABILITY OF METAL MATERIAL ON THE BASIS OF TYPE OF PARAMETERS ANALYZED[2]

PARAMETER	STAINLESS STEEL	GALVANIZED STEEL	COPPER BRASS	ALUMINIUM
INORGANIC CHEMISTRY				
Ammonium	r	r	r	r
Silver	(r)	(r)	(r)	(r)
Arsenic	(r)	(r)	(r)	(r)
Barium	(r)	(r)	(r)	(r)
Cadmium	(r)	(r)	(r)	(r)
Calcium	r	r	r	r
Chlorides	r	r	r	r
Chromium	(r)	(r)	(r)	(r)
Conductivity	r	r	r	r
Iron	r	r	r	r
Fluorides	r	r	r	r
Magnesium	r	r	r	r
Manganese	r	r	r	r
Mercury	(r)	(r)	(r)	(r)
Nitrates	r	r	r	r
pH	r	r	r	r
Lead	(r)	(r)	(r)	(r)
Redox potential(E_h)	r	r	r	r
Selenium	(r)	(r)	(r)	(r)
Sodium	r	r	r	r
Sulfates	r	r	r	r
ORGANIC CHEMISTRY				
Phenolic compounds	r	(r)	(r)	(r)
Volatile compounds	r	(r)	(r)	(r)
Pesticides	r	(r)	(r)	(r)
RADIOACTIVITY				
Alpha and beta	r	r	r	r
Radium	r	r	r	r
MICROBIOLOGY				
Heterotrophic plate count	r	(r)	(r)	(r)
Total and fecal coliforms	r	(r)	(r)	(r)
Fecal streptococcus	r	(r)	(r)	(r)

r: reliable (r): limited reliability n: unreliable

TABLE 15C - RELIABILITY OF GLASS AND RUBBER ON THE BASIS OF TYPE OF PARAMETERS ANALYZED[2]

PARAMETER	GLASS	RUBBER
INORGANIC CHEMISTRY		
Ammonium	r	r
Silver	(r)	r
Arsenic	(r)	r
Barium	(r)	r
Cadmium	(r)	r
Calcium	r	r
Chlorides	r	r
Chromium	(r)	r
Conductivity	r	r
Iron	r	r
Fluorides	r	r
Magnesium	r	r
Manganese	r	r
Mercury	(r)	r
Nitrates	r	r
pH	r	r
Lead	r	r
Redox potential(E_h)	r	r
Selenium	(r)	r
Sodium	(r)	r
Sulfates	r	r
ORGANIC CHEMISTRY		
Phenolic compounds	r	n
Volatile compounds	r	n
Pesticides	r	n
RADIOACTIVITY		
Alpha and beta	(r)	r
Radium	(r)	r
MICROBIOLOGY		
Heterotrophic plate count	r	(r)
Total and fecal coliforms	r	(r)
Fecal streptococcus	r	(r)

r: reliable (r): limited reliability n: unreliable

3.5. Sample filtration

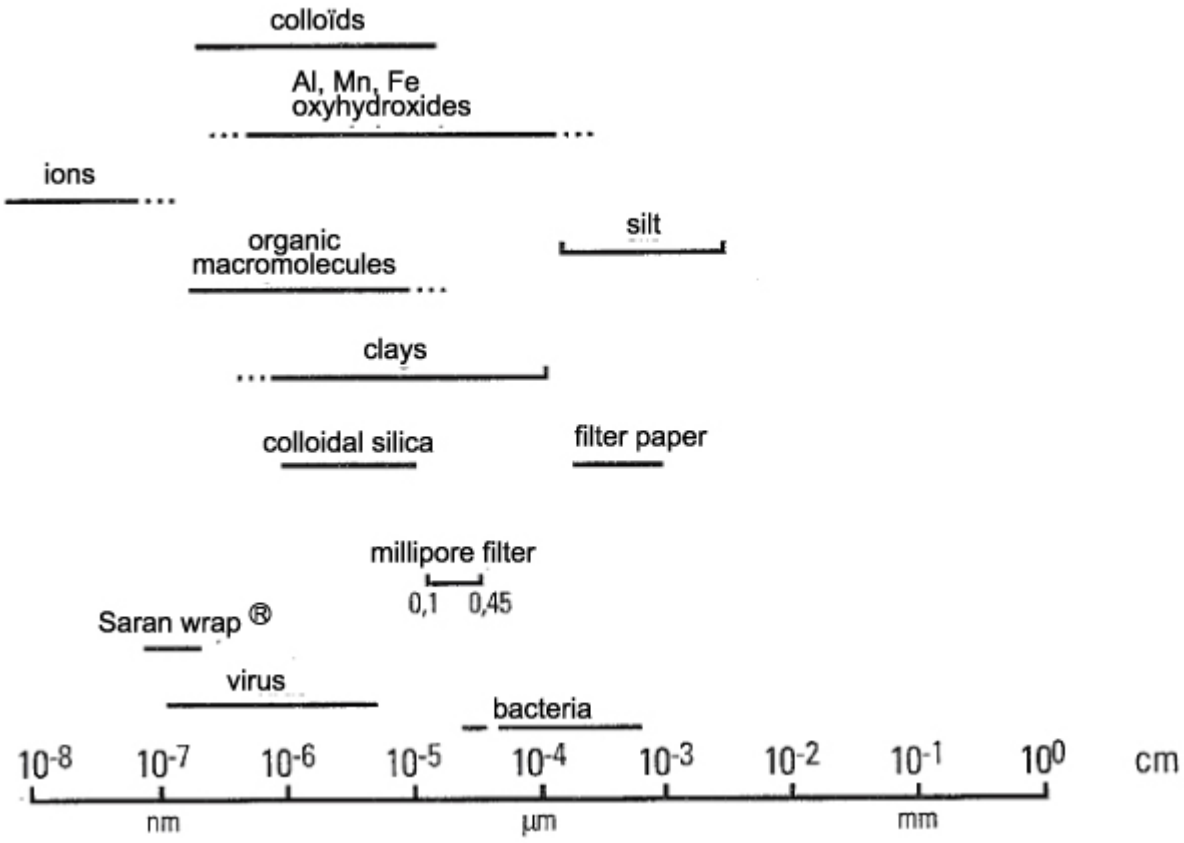
Despite best efforts to obtain water samples with as little turbidity as possible, they usually contain some suspended silty/argillaceous particles. The reaction between suspended particles in water and preservative agents can alter the water's composition, particularly the content of metals.

Filtering at the sampling site is recommended for water samples that are scheduled to be analyzed for dissolved metals[24,25]. Filtering should be carried out immediately after sample collection to prevent precipitation and adsorption of metals. Preservatives are added after filtering. Filtering should be carried out using 0.45 micron filters. These types of filters trap all silt particles, most argillaceous particles, most bacteria and a portion of iron and manganese hydroxides. Viruses and organic macromolecules (humic and fulvic acids) will not be trapped (see Figure 11, following page). Samples that are to be submitted to analyses for volatile and non-volatile organic compounds, negative ions and total metals (dissolved and suspended) must not be filtered.

The two most common types of filters are organic filters (cellulose nitrate) and inorganic filters (polycarbonate membrane). Cellulose nitrate filters can adsorb some organic constituents and release nitrogen, phosphorus, zinc and molybdenum; whereas polycarbonate filters do not appear to cause contamination.

Filters should be handled using stainless steel or Teflon® tongs to prevent contamination. Care should be taken to prevent damage to filters.

FIGURE 11 - DIAMETER OF PORES OF MATERIAL AND SIZES OF PARTICLES, ORGANISMS AND CHEMICAL COMPOUNDS THAT MAY BE PRESENT IN GROUNDWATER



Large-diameter filters speed up filtering because filters have to be replaced less often. However, only one filter can be used to filter one water sample. Filtering equipment should be washed thoroughly after each sample, according to the method described in section 3.6.

If the purpose of sampling is to determine if water from a well is potable, samples should not be filtered. If groundwater quality is being analyzed to determine the how effective drainage to a sewer system is, samples should not be filtered.

If water is turbid and samples are submitted to organic chemical analyses, it may be appropriate to analyze organic compounds that have high distribution constants (water-suspended solids) in a filtered sample and in an unfiltered sample. Major differences may occur in some instances.

3.6. Method of cleaning equipment

Cross contamination between sampling points depends on the type of sampling method that is used and cleaning procedures. The representativeness of samples collected using sophisticated methods may be jeopardized if proper cleaning procedures are not followed. The reader should refer to section 2 of Cahier 1 – *Généralités* [Booklet 1 - General] for information about the fundamental principles of washing sampling equipment. Specific details pertaining to groundwater are listed below.

All parameters (organic and inorganic)

For this section, refer to Cahier 1 – *Généralités* [Booklet 1 - General], section 2.3.2 method A.

Organic parameters only

For this section, refer to Cahier 1 – *Généralités* [Booklet 1 - General], section 2.3.2 method B.

Inorganic parameters only

For this section, refer to Cahier 1 – *Généralités* [Booklet 1 - General], section 2.3.2 method C. If samples are submitted to analysis of nitrates, nitric acid (HNO_3) should be replaced by 10% hydrochloric acid (HCl).

3.7. Identifying samples

The details for identification of groundwater samples are the same as those for other sectors of activity. The reader should therefore refer to section 2.5 of Cahier 1 – *Généralités* [Booklet 1 - General].

3.8. Safety precautions

The safety precautions that must be observed during groundwater sampling are detailed in section 5 of Cahier 1 – *Généralités* [Booklet 1 - General]. It is important to read this section before beginning any sampling work.

4. PRESERVING, STORING AND TRANSPORTING SAMPLES

The reader should refer to section 2.6 of Cahier 1 – *Généralités* [Booklet 1 - General] to learn the fundamentals for preservation, storage and transport of samples. Details relating specifically to groundwater are listed in Table 16[26,27,28], on the pages that follow.

TABLE 16 - PRESERVATION OF GROUNDWATER, SURFACE WATER AND POTABLE WATER SAMPLES

PARAMETERS	CONS.	CONTAINER	VOLUME	PERIOD
BIOLOGY				
ALGAE (COUNT)	LUGOL	P	0.25 L	1 yr
ALGAE (IDENTIFICATION)	LUGOL	P	0.25 L	1 yr
OTHER	LAB	LAB	LAB	LAB
INORGANIC CHEMISTRY				
ACIDITY	N	P,T,G;(B)	0.1 L	14 days
ALKALINITY	N	P,T,G;(B)	0.1 L	14 days
ARSENIC	AN	P,T,G	0.2 L	6 months
AMMONIACAL NITROGEN	AS	P,T,G;(B)	0.1 L	28 days
TOTAL KJELDAHL NITROGEN	AS	P,T,G;(B)	0.1 L	28 days
BORON[a]	AN	P,T	0.1 L	6 months
BROMIDES	N	P,T,G	0.1 L	28 days
CARBONATES/BICARBONATES	N	P,T,G;(B)	0.2 L	14 days
DISSOLVED INORGANIC CARBON	N	P,T,G;(B)	0.1 L	48 hours
TOTAL INORGANIC CARBON	N	P,T,G;(B)	0.1 L	48 hours
DISSOLVED ORGANIC CARBON	N	T,G	0.1 L	28 days
TOTAL ORGANIC CARBON	AS	T,G	0.1 L	28 days
CHLORATES	N	P,T,G	0.1 L	7 days
CHLORINE (RESIDUAL)	N	P,T,G;(B)	0.1 L	SITE
CHLORITES	N	P,T,G	0.1 L	7 days
CHLORIDES	N	P,T,G	0.2 L	28 days
HEXAVALENT CHROMIUM (VI)	N	P,T,G	0.2 L	24 hours
CONDUCTIVITY	N	P,T,G	0.1 L	28 days
COLOUR	N	P,T,G	0.1 L	48 hours
CYANATES	NaOH	P,T,G	0.5 L	14 days
CYANIDES	NaOH	P,T,G	0.5 L	14 days
BOD_5	N	P,T,G	1 L	48 hours
COD	AS	P,T,G	0.1 L	28 days

PARAMETERS	CONS.	CONTAINER	VOLUME	PERIOD
HARDNESS	AN	P,T,G;(B)	0.1 L	6 months
FLUORIDES	N	P,T	0.2 L	28 days
IODIDES	N	P,T,G	0.1 L	28 days
MERCURY (DECONTAMINATED BOTTLE)	DICR	T,VT	0.2 L	28 days
METALS (OTHER THAN THOSE INDICATED)	AN	P,T,G	0.1 L	6 months
NITRATE	N	P,T,G	0.2 L	48 hours
NITRITES	N	P,T,G	0.2 L	48 hours
NITRITES & NITRATES	AS	P,T,G	0.1 L	28 days
DISSOLVED OXYGEN	LAB	V(B)	0.3 L	1 days
o-PHOSPHATES	N	P,T,G	0.2 L	48 hours
pH	N	P,T,G;(B)	0.1 L	SITE
HYDROLYSABLE PHOSPHORUS	AS	P,T,G	0.1 L	28 days
TOTAL PHOSPHORUS	AS	P,T,G	0.1 L	28 days
TOTAL SUSPENDED PHOSPHORUS	N	P,T,G	0.5 L	28 days
REDOX POTENTIAL (E_h)	N	P,T,G	0.1 L	48 hours
SALINITY	N	P,T,G	0.1 L	28 days
SELENIUM	AN	P,T,G	0.2 L	28 days
SILICATES	N	P,T	0.2 L	28 days
SILICONE[a]	AN	P,T	0.1 L	6 months
SETTING SOLIDS	N	P,T,G	0.5 L	48 hours
DISSOLVED SOLIDS[b]	N	P,T,G	0.5 L	7 days
SUSPENDED SOLIDS[b]	N	P,T,G	0.5 L	7 days
TOTAL SOLIDS[b]	N	P,T,G	0.5 L	7 days
SULFATES	N	P,T,G	0.1 L	28 days
SULFITES	N	P,T,G	0.2 L	SITE
SULFIDES	AcZn	P,T,G;(B)	0.2 L	7 days
TANNINS & LIGNINS	N	P,T,G	0.2 L	7 days
TURBIDITY	N	P,T,G	0.1 L	48 hours
URANIUM	AN	P,T,G	0.5 L	28 days
ORGANIC CHEMISTRY				

PARAMETERS	CONS.	CONTAINER	VOLUME	PERIOD
HALOGENOUS ACETIC ACIDS	N	VA (A)	1.0 L	14 days
AMINOMETHYL PHOSPHONIC ACID (AMPA)	N	P,T	0.25 L	24h[c]
TRICHLOROACETIC ACID	TS	P,T	0.25 L	7 days/40 days
RESIN AND FATTY ACIDS	AS	GA,GT	1.0 L	7 days
POLYCHLORINATED BIPHENYLS	N	GA,GT	2 X 1.0 L	7 days/40 days
CAPTAN/CAPTAFOL	N	GA,GT	1.0 L	7 days/40 days
SEMI-VOLATILE OGANIC COMPOUNDS	N/T	GA	1.0 L	7 days
VOLATILE ORGANIC COMPOUNDS	N/T	F(B)	3 X 0.04 L	7 days
PHENOLIC COMPOUNDS (chromatography)	AS	GA,GT;(A)	1.0 L	14 days/40 days
PHENOLIC COMPOUNDS (colorimetry)	AS	GA,GT;(A)	0.125 L	28 days
DETERGENTS (L.A.S)	N	GA,GT	1.0 L	48 hours
DIOXINS & FURANS	N	LAB	4.0 L	7 days/40 days
DIQUAT/PARAQUAT	N	P,T	0.25 L	7 days[c]
ETHYLENE THIOUREA	N	GA,GT	1.0 L	14 days/40 days
GLYPHOSATE	N	P,T	0.25 L	24h[c]
HEXAZINONE	N	GA,GT	1.0 L	14 days/40 days
OILS & FATS	AS	GA,GT	1.0 L	28 days
POLYCYCLIC AROMATIC HYDROCARBONS	AS	GA,GT;(A)	2 X 1.0 L	7 days/40 days
PERMETHRINS	N	GA,GT	1.0 L	7 days/40 days
PESTICIDES (ARYLOXYACIDS)	AS	GA,GT; (A)	1.0 L	21 days/40 days
PESTICIDES (CARBAMATES)	TS2	P,T	0.25 L	7 days[c]
PESTICIDES (ORGANOCHLORINES)	N	GA,GT;(A)	1.0 L	7 days/40 days
PESTICIDES (ORGANOPHOSPHOROUS)	N	GA,GT;(A)	1.0 L	7 days/40

PARAMETERS	CONS.	CONTAINER	VOLUME	PERIOD
				days
PESTICIDES (TRIAZINES)	N	GA,GT;(A)	1.0 L	14 days/40 days
PETROLEUM PRODUCTS (identification)	N	GA,GT	1.0 L	14 days/28 days
ROTENONE	AS	GA,GT	1.0 L	7 days/40 days
CHLORINATION BY-PRODUCTS	TP	F (B)	4 X 0.04 L	2 days
TRIHALOMETHANES (THM)	T	F(B)	0.04 L	7 days
OTHER	LAB	LAB	LAB	LAB
MICROBIOLOGY[d]				
ACTINOMYCETES	TS,E	PPS	0.1 L	48 hours
AEROMONAS HYDROPHILA	TS,E	PPS	0.1 L	48 hours
IRON BACTERIA	TS,E	PPS	1.0 L	48 hours
SULFUR BACTERIA	TS,E	PPS	1.0 L	48 hours
HETEROTROPHIC PLATE COUNT (COUNT)	TS,E	PPS	0.1 L	48 hours
HETEROTROPHIC PLATE COUNT (IDENTIFICATION)	TS,E	PPS	4.0 L	48 hours
CAMPYLOBACTER	TS,E	PPS	4.0 L	48 hours
CLOSTRIDIUM	TS,E	PPS	4.0 L	48 hours
FECAL COLIFORMS	TS,E	PPS	0.1 L	48 hours
TOTAL COLIFORMS	TS,E	PPS	0.1 L	48 hours
KLEBSIELLA	TS,E	PPS	0.1 L	48 hours
LEGIONELLA	TS,E	PPS	1.0 L	48 hours
YEASTS AND MOLDS	TS,E	PPS	0.1 L	48 hours
PARASITES	LAB	LAB	300 L	48 hours
PSEUDOMONAS	TS,E	PPS	0.1 L	48 hours
SALMONELLA	TS,E	PPS	4.0 L	48 hours
SHIGELLA	TS,E	PPS	4.0 L	48 hours
STAPHYLOCOCCI	TS,E	PPS	0.1 L	48 hours
FECAL STREPTOCOCCI	TS,E	PPS	0.1 L	48 hours
YERSINIA	TS,E	PPS	0.1 L	48 hours

PARAMETERS	CONS.	CONTAINER	VOLUME	PERIOD
OTHER	LAB	LAB	LAB	LAB
TOXICITY AND GÉNOTOXICITY				
ALGAE BIOTEST[e]	N	P(B)	1.0 L	96 hours
DAPHNIA BIOTEST[e]	N	P(B)	1.0 L	96 hours
MICROTOX BIOTEST[e]	N	P(B)	0.1 L	96 hours
AMES TEST	LAB	PO,V;(A)	10 L	24 hours
OTHER	LAB	LAB	LAB	LAB

REFERENCE NOTES

[a]: THESE PARAMETERS MAY BE COMBINED WITH METALS, DEPENDING ON THE LABORATORY

[b]: AND/OR VOLATILE SOLIDS

[c]: CAN BE STORED AT -20°C FOR 28 DAYS

[d]: A SPACE OF APPROXIMATELY 3 cm BETWEEN THE SAMPLE AND THE CONTAINER LID IS REQUIRED

[e]: A VOLUME OF 2.0 L IS ENOUGH FOR 3 BIOTESTS

TABLE 16 (LEGEND)	
PRESERVATION = PRESERVATIVES	
AcZn	4 DROPS OF ZINC ACETATE 2N PER 100mL OF SAMPLE AND NaOH 10N UP TO pH >12
AN	HNO_3 8N UP TO pH < 2
AS	H_2SO_4 9N UP TO pH < 2
CONG	FREEZE THE SAMPLE, LEAVE A SPACE OF APPROXIMATELY 5 CM FOR A 1 LITRE BOTTLE
DICR	1 mL OF POTASSIUM DICHROMATE 5% IN HNO_3 8N PER 100 mL OF SAMPLE
E	6.2 mL OF ETHYLENEDIAMINE TETRAACETATE SODIUM 1.5% IF A HIGH CONCENTRATION OF HEAVY METALS IS SUSPECTED IN THE SAMPLE
LAB	CONTACT THE LABORATORY IN QUESTION BEFORE SAMPLING
LUGOL	0.3 mL OF LUGOL'S SOLUTION PER 100 mL OF SAMPLE
N	NO PRESERVATIVE (STORE AT 4°C)
N/T	IN THE CASE OF CHLORINATED WATER, ADD APPROXIMATELY 10 mg OF SODIUM THIOSULFATE
NaOH	NaOH 10N UP TO pH > 12
T	APPROXIMATELY 10 mg OF SODIUM THIOSULFATE
TP	APPROXIMATELY 4 mg OF THIOSULFATE AND BUFFER pH 4.5
TS	2.5 mL OF A SOLUTION OF 1% SODIUM THIOSULFATE
TS2	0.25 mL OF A SOLUTION OF 1% SODIUM THIOSULFATE
CONTAINER	
(A)	ABSOLUTELY AMBER GLASS, OTHERWISE WRAP OUTSIDE OF BOTTLE WITH ALUMINUM FOIL
(B)	FILL TO TOP
F	TRANSPARENT OR AMBER GLASS BOTTLE WITH SCREW TOP LID

TABLE 16 (LEGEND)	
	AND SILICON SEPTUM
LAB	CONTACT THE LABORATORY IN QUESTION PRIOR TO SAMPLE COLLECTION
P	BOTTLES AND LID LININGS CONSIST OF THE FOLLOWING PLASTICS: LOW OR HIGH DENSITY POLYETHYLENE, POLYPROPYLENE, POLYSTYRENE AND POLYVINYL CHLORIDE
PO	PLASTIC BOTTLE (SEE P) OPAQUE OR BROWN
PP	POLYPROPYLENE BOTTLE
PPS	STERILE POLYPROPYLENE BOTTLE
T	BOTTLES AND LID LININGS CONSIST OF THE FOLLOWING TYPES OF TEFLON®: POLYTETRAFLUOROETHYLENE (PTFE), FLUORINATED ETHYLENE-PROPYLENE RESIN (FEP), PERFLUOROALKOXY (PFA), CHLOROTRIFLUOROETHYLENE (CTFE), ETHYLENE COPOLYMER WITH TETRAFLUOROETHYLENE (ETFE) OR WITH CHLORO-TRIFLUOROETHYLENE (ECTFE)
G	TRANSPARENT OR AMBER GLASS BOTTLE
GA	TRANSPARENT OR AMBER GLASS BOTTLE WITH ALUMINUM FOIL SEAL
GT	TRANSPARENT OR AMBER GLASS BOTTLE WITH TEFLON® SEAL
VOLUME= MINIMUM VOLUME OF SAMPLE FOR ANALYSIS	
LAB	CONTACT THE LABORATORY IN QUESTION PRIOR TO SAMPLE COLLECTION
PERIOD= MAXIMUM STORAGE PERIOD BEFORE ANALYSIS	
LAB	CONTACT THE LABORATORY IN QUESTION PRIOR TO SAMPLE COLLECTION
SITE	IMMEDIATELY MEASURE AT THE SAMPLING SITE
/	PERIOD BEFORE EXTRACTION/PERIOD BEFORE MEASUREMENT

5. PARAMETERS MEASURED IN THE FIELD

Some parameters must be measured as soon as possible at the sample collection site (on samples or directly in wells) because they are sensitive to changes in temperature and pressure. These include temperature, pH and electrical conductivity[16]. Although not routine, on-site measurement of organic vapours also has obvious advantages.

5.1. Temperature

Temperature should preferably be measured in the well or as soon as a sample is collected in a container, other than containers sent to the laboratory. Measurements are taken ideally with a temperature probe or thermometer that is precise to within ± 0.2°C.

5.2. pH

pH is one of the parameters that is most sensitive to changes in temperature and pressure. pH differences of up to two units can be observed between values measured in the field and those measured in the laboratory. A wide variety of probes are designed specifically to measure the pH of water, depending on the degree of precision required. Electrodes that provide a precision of ± 0.1 pH unit are adequate for most applications. Greater precision is required when geochemical models must be used. These instruments consist essentially of an electrode bathing in a solution of KCl, accompanied by solutions that are required for calibration. The recommendations that follow are general in nature and apply to all types of instruments that are sold commercially: regardless of model, the electrode must be calibrated before measurements are taken. Calibration must be checked regularly with pH 4, 7 and 10 buffer solutions;

- groundwater and the electrode should be approximately the same temperature, ideally the temperature of groundwater. This can be accomplished with the help of a closed cell;
- the electrode must be rinsed in purified water prior to and after each time it is immersed in a water sample;
- samples that have been used for pH measurements cannot be reused for analysis of electrical conductivity, potassium (K^+) or chloride (Cl^-), due to the possible transfer of KC1 from the electrode to the sample;
- the pH-metre must be stored is a dry location away from sources of moisture. It should also not be exposed to direct sunlight. It must remain at a constant temperature when measurements are taken;
- the level of the KCI solution in which the electrode is bathed must be monitored constantly. The electrode must <u>always</u> bath in this solution when it is not in use.

5.3. Electrical conductivity

Electrical conductivity is an indicator of the charge of ions in a solution. For a site where conductivity is monitored, an increase in conductivity may indicate contamination. Electrical conductivity in the field are used to gauge, although only a very general assessment, the degree of contamination and, if necessary, to change the drilling program to adapt it to conditions at the site.

Electrical conductivity is relatively easy to gauge in the field. Conductivity is measured using a conductivity meter. The value obtained must be multiplied by a constant for each cell to obtain the real conductivity of the calibration solution and samples. Calibration can be carried out using a KCl 0.01 M solution, which has an electrical conductivity of 1,400 µmhos/cm (µS/cm) at 25°C. Some conductivity meters have a 2% compensator per degree Celsius, which brings values to 25°C. If a compensator is not present, the calculation must be carried out manually according to method 2510 B of the *Standard Method for the Examination of Water and Wastewater*[26].

5.4. Organic vapours – explosive gases

As a safety precaution and to guide drilling operations, estimates of concentrations of explosive gases (methane), hydrogen sulfide and organic vapours can be made as work progresses. Mixtures of explosive gases can be detected with the use of explosimeters (see Cahier 1 – *Généralités* [Booklet 1 - General], section 5.2.3). Concentrations of total organic vapours can also be measured using Hnu and OVA (Organic Vapor Analyzer) instruments. Field measurements of organic compounds require use of a portable gaseous phase chromatograph[29]. These instruments are extremely sensitive and difficult to calibrate. They must be used by skilled individuals to produce conclusive results.

5.5. Keeping a field log book

In addition to information described in section 2.7 of Cahier 1 – *Généralités* [Booklet 1 - General], a groundwater sample field log book should detail the volume of water purged, methods of sample collection and the washing agents used.

6. SAMPLING IN AN UNSATURATED ZONE

An unsaturated zone is that portion of the subsurface that is located above the saturation line. This portion of the ground consists of solid, liquid and gas phases. The liquid phase is found in conditions of negative pressure and therefore cannot be sampled using traditional monitoring methods (monitoring wells). There are, however, sampling methods to collect water and gases in the unsaturated zone. These methods are often more complicated and expensive than sampling techniques in the saturated zone.

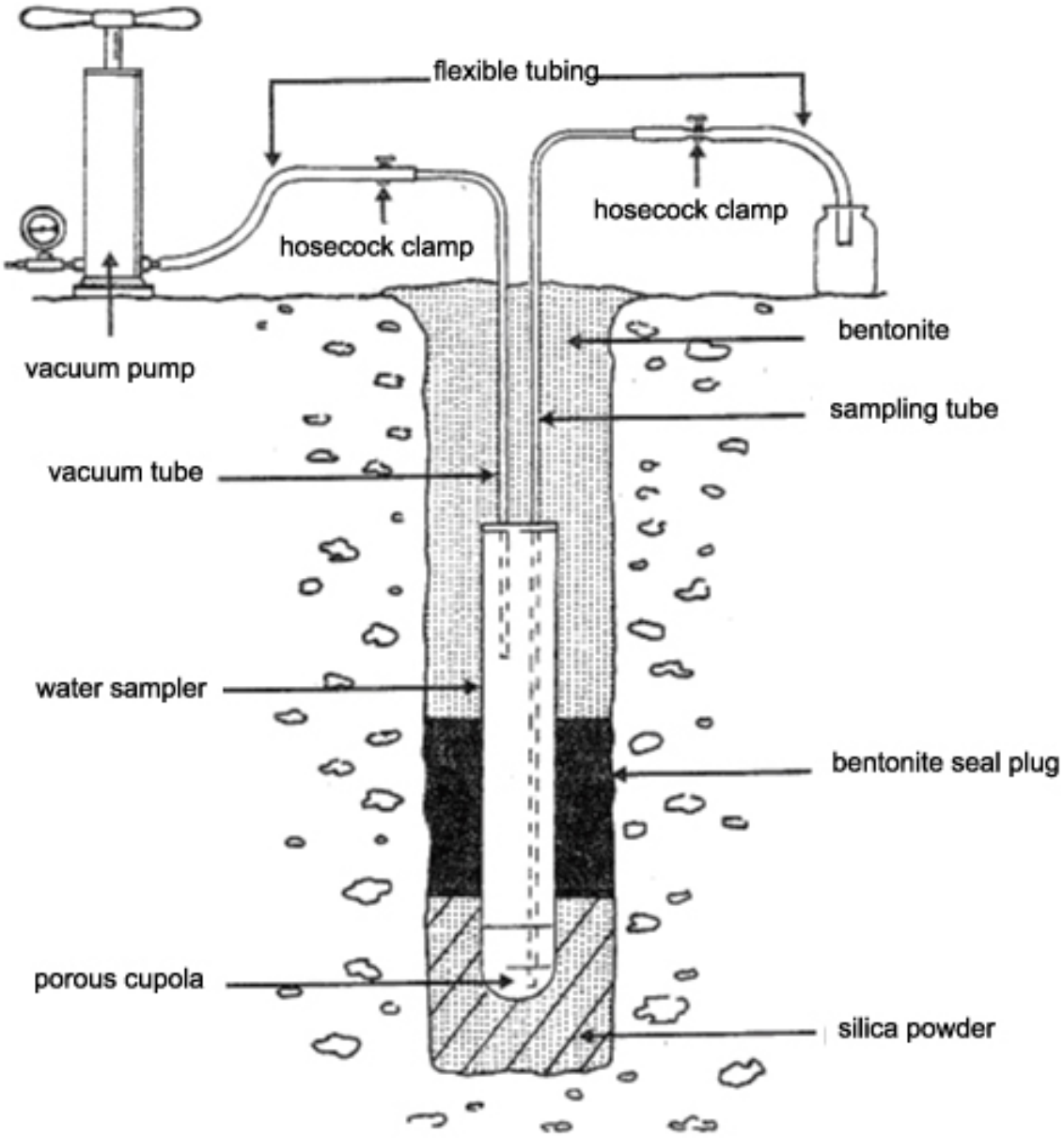
The paragraphs that follow discuss the most common methods for sampling interstitial water and gases in the unsaturated zone.

6.1. Sampling interstitial water

By sampling interstitial water in an unsaturated zone, you can follow the advancement of a periphery of contamination that originated from a point-specific source or hard to pinpoint source on the surface, in order to predict when it will arrive at the water table.

Interstitial water in an unsaturated zone can be sampled using devices called lysimeters. A lysimeter is a small porous ceramic container fastened to a PVC pipe that is capable of maintaining a vacuum (Figure 12, following page). The vacuum is applied from the surface and forces water into the porous container. A vacuum must be maintained between samples. During a sampling session, the vacuum is increased using a suction device to recover water in the cup at the surface.

FIGURE 12 - DIAGRAM OF A LYSIMETER



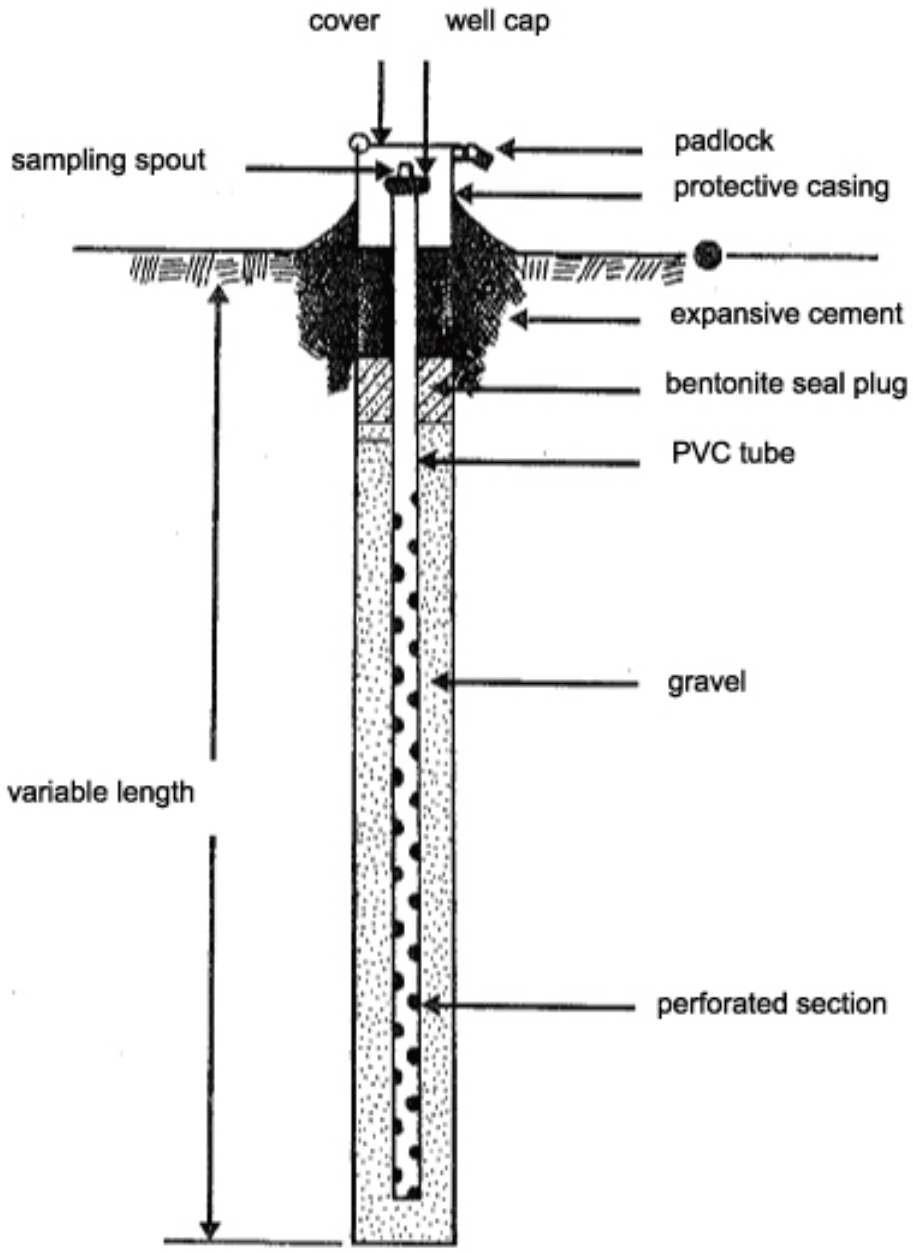
Before a lysimeter is installed, it must be checked to ensure that is it completely watertight. The hole in which the lysimeter is installed must have a minimum diameter to enable the neighbouring soil to enclose around the cup. A bentonite cap near the surface minimizes infiltration of surface water. The ability of this instrument to operate correctly, depends on its ability to maintain a vacuum. Only a small volume of water can be recovered, which limits the number of analyses that can be performed. The choice of which parameters to measure must be made carefully. By adding a layer of silica powder around the ceramic cup, this will prevent the cup from becoming clogged by colloidal particles.

6.2. Sampling of the gaseous phase

Sampling of the gaseous phase that is part of the unsaturated zone can serve as an indicator of groundwater and soil contamination. Therefore, setting up monitoring wells and establishing soil sampling points can be optimized. Preventive decontamination measures can be taken if gas is detected using special sensors. These methods have applications that are particularly interesting for detection of volatile organic compounds due to leaks from underground tanks. Only volatile compounds can be measured for this type of analysis; the most common include benzene, toluene, xylene, ethylbenzene, trichloroethylene, chloroform, tetrachloroethylene and trichloroethanes.

The most effective way to sample these gases is to install a biogas well and to collect samples using tubes that contain an absorbent substance or an expandable bag. Details for installing a biogas well are listed in Figure 13 (following page). Construction is very similar to that of a monitoring well, except for the strainer, which is positioned above the water table and the sampling spout that is hermetically secured to the PVC cover. Samples of gases that have accumulated in the biogas well are collected by means of a manual pump.

FIGURE 13 - STANDARD CONSTRUCTION OF A BIOGAS SAMPLING WELL



The two main tubes that contain an adsorbent substance are tubes of activated carbon and “Drager” tubes. Activated carbon tubes trap organic compounds and are taken to the laboratory for desorption and analysis. “Drager” tubes enable a semi-quantitative on-site assessment of gas concentrations. As gas circulates through the tube, the adsorbent substance loses colour. The length that has lost coloration indicates the concentration of the compound. A manual pump circulates gas in the tube. “Drager” tubes are available for a wide variety of organic compounds and for gases such as carbon dioxide, hydrogen sulfide and methane. Drager tubes are of particular interest for areas that neighbour sanitary landfill sites. These tubes are available on the market for a number of other compounds and for a wide range of concentrations.

7. QUALITY CONTROL

In addition to the quality controls listed in section 3 of Cahier 1 – *Généralités* [Booklet 1 - General], a groundwater sampling program should include inter-laboratory inspections, such as those described in the quality assurance and control procedures document entitled: *Procédures d'assurance et de contrôle de la qualité pour les travaux analytiques contractuels*[30].

8. SAMPLING SPRING WATER AND WELLS FOR DRINKING WATER

8.1. Spring water

The sampling of points where water resurfaces (spring) is less tedious than sampling monitoring wells because no pumping or purging is required, and no special sampling equipment is necessary. To sample a spring, simply place a container as close as possible to the groundwater discharge point. The type of container, type of preservatives and volumes to collect are identical to those recommended for monitoring wells in Table 16.

8.2. Sampling a drinking water well

Testing the quality of drinking water in a rural community is carried out by collecting samples from domestic wells. It is important to remember that drinking water wells are designed for the purpose of water supply, not for sampling the quality of groundwater. Results must therefore be interpreted with caution. Results should be interpreted on the basis of drinkability of the water. The following recommendations are suggested:

- obtain all possible information about the well’s construction (depth, type of pump, treatment unit), type of piping system and potential sources of contamination around the well;
- if there is no treatment unit, water can be sampled from the tap. If there is a treatment unit (filter, water softener, reverse osmosis system), samples should be collected at the intake of the treatment unit;

- similar to sampling a monitoring well, a drinking water well must be purged before sampling can begin. Purging can be carried out by allowing the tap to run until the water's physical and chemical properties are stable. If a well is used routinely, the stabilization period is 5 to 10 minutes. Since the stabilization period will vary from one well to another, depending on diameter and depth, indicator parameters such as conductivity and temperature should be measured before samples are collected;
- containers, preservatives and the volumes required should be determined according to Table 16;
- if volatile compounds are being sampled, water should be allowed to flow slowly into containers and bottles must be tilted slightly to minimize agitation. A sample must be collected once indicator parameters are stable.

9. SAMPLING AND MEASUREMENT OF THE THICKNESS OF NON-MISCIBLE LIQUIDS

Non-miscible liquids are liquids that do not mix together. Depending on their density compared to water, lighter liquids float on the surface of the water table and denser liquids move through the water table until they reach an impenetrable barrier. Sampling of non-miscible liquids should be carried out before wells are purged, because sampling after purging may result in fluid mixing.

The thickness of petroleum products in a monitoring well can be estimated using a transparent bailer, a strip coated with an indicator compound and an interface probe. An interface probe, which is very similar to a water level probe, changes resonance when it moves from the floating layer to the underlying water area. The thickness measured in the well always exceeds the actual thickness of the non-miscible liquid in a water-bearing formation[31,32,33]. There is no simple relationship to connect the thickness of non-miscible liquids measured in a well to the actual thickness of non-miscible liquids in a water-bearing formation[34,35]. However, the thickness of light non-miscible liquids in a water-bearing formation can be linked approximately using the CONCAWE[36] equation:

$$h \approx \frac{H}{r_{LNML}} (r_{water} - r_{LNML})$$

where

h = average thickness of light non-miscible liquid in the water-bearing formation near a well

H = thickness of light non-miscible liquid measured in a well

r_{water} = water density

r_{LNML} = density of light non-miscible liquid

9.1. Light non-miscible liquids

This category of contaminants includes a variety of petroleum products, in particular gasoline, diesel, oils and tar. Soil and groundwater contamination by these liquids is usually attributed to underground tanks containing petroleum products. These products are relatively easy to find and sample because their migration during the non-miscible phase is limited to the top of the water table.

The two systems used to collect a floating phase sample in a well are bailers and check valve hand pumps. Ideally, dedicated systems should be used because sampling instruments will not be able to be decontaminated at the site. The same equipment should not be used to sample the aqueous phase.

9.2. Dense non-miscible liquids

Dense non-miscible liquids include chlorinated organic solvents, such as trichloro-ethylene, tetrachloroethylene, trichloroethanes and dichloromethane or a mixture of petroleum products such as creosotes and tars, polychlorinated biphenyls (PCB) and some pesticides. If these products are accidentally introduced into the subsurface, they migrate vertically through the water table until they come across an impermeable barrier. They become extremely difficult to trace in complex geological formations, particularly in fractured formations.

Sampling of the dense liquid phase is carried out in the same manner as the floating phase, using a bailer and a check valve hand pump connected to a polyethylene tube. These two systems have the advantage of being able to be dedicated.

CONCLUSION

Success of a groundwater sampling program depends on the representativeness of the samples collected. Project managers and sample collectors must make decisions when a sampling program is drawn up and when it is in operation. Each decision may alter the chemical and microbiological integrity of samples. The selection of sampling points, drilling method, well dimensions, sampling method, selection of well construction materials and sampling equipment are all factors that require careful decisions.

An understanding of the factors and processes that can alter the chemical composition of water when samples are collected, requires knowledge and efforts that are devoted to chemical analyses and interpretation of results. An accurate definition of which objectives are targeted in the characterization study will determine the precision that will be required and the safety precautions that be required during the sampling program. Precautions that result in cost overruns may not be justified if they are part of a preliminary characterization study, but may become essential as characterization work takes shape or rehabilitation work progresses.

We hope that this booklet will help users who are involved in implementing sampling programs and that it will guide their work.

REFERENCES

1- LIARD, A, *et al*. Caractérisation environnementale des sites contaminés, École Polytechnique de Montréal en collaboration avec l'Association of Engineering Geologists, Section de Montréal, avril 1989.

2- GILHAM, R.W., M.J.L. ROBIN, J.F. BARKER and J.A. CHERRY. Groundwater Monitoring and Sample Bias, Department of Earth Sciences, University of Waterloo, Waterloo, Ontario, June 1983, 206 p.

3- DRISCOLL, F.G., Groundwater and Wells, 1986, Second edition, Johnson Division Publishers, 1089 p.

4- DAVIS, H., J.L. JEHN and S. SMITH. Monitoring Well Drilling Soil Sampling, Rock Coring and Borehole Logging, in Practical Handbook of Groundwater Monitoring, 1991, Lewis Publishers, p. 239-333.

5- MINISTÈRE DE L'ENVIRONNEMENT DU QUÉBEC, Direction des substances dangereuses, Gestion des lieux contaminés. Politique de réhabilitation des terrains contaminés, février 1988, SD-5.

6- BARCELONA, M.J., J.P. GIBB and R.A. MILLER. A Guide to the Selection of Materials for Monitoring Well Construction and Groundwater Sampling, Illinois State Water Survey, Champaign, Illinois, 1983, 78 p.

7- NIELSON, D.M. and R. SCHALLA. Design and Installation of Ground Water Monitoring Wells, in Practical Handbook of Groundwater Monitoring, 1991, Lewis Publishers, p. 209-333.

8- PARKER, L.V., A.D. HEWITT and T.F. JENKINS. «Influence of Casing Materials on Trace-Level Chemicals in Well Water», Groundwater Monitoring Review, Spring 1990, p. 146-156.

9- RIGGS, C.O. and A.W. HATEWAY. Groundwater Monitoring Field Practice-An Overview, dans: Groundwater Contamination: Field Methods, ASTM STP 963, A.G. Collins and A.I. Johnson, Eds., American Society for Testing and Materials, Philadelphia, 1988, p. 121-136.

10- GIBB, J.P. «How Drilling Fluids and Grouting Materials Affect the Integrity of Groundwater Samples from Monitoring Wells», Groundwater Monitoring Review, Winter 1987, p. 33-42.

11- CHAPUIS, R.P. Piézomètre hydraulique et risques d'erreur associés, Séminaire sur les barrières géologiques pour le contrôle de la contamination des eaux aux sites d'enfouissement, mars 1987, 165 p.

12- GARRETT, P. How to Sample Groundwater and Soils, National Water Well Association Publishers, 1988, 37 p.

13- ALLER, L., T.W. BENNETT, G. HACKETT, R.J. PETTY, J.H. LEHR, H. SEDORIS, D.M. NIELSEN and J.E. DENNE. Monitoring Well Developpement, in: Handbook of Suggested Practices for the Design and Installation of Groundwater Monitoring Wells, 1988, p. 228-245.

14. HVORSLEV, M.J. «Time lag and soil permeability in groundwater observations», in U.S. Army Corps Engrs. Waterways Exp. Sta. Bull. 36, Vicksburg, Miss.

15- BARCELONA, M.J., J.A. HELFRICH, and E.E. GARSKE. Verification of Sampling Methods and Selection of Materials for Groundwater Contamination Studies, in Groundwater Contamination: Field Methods, ASTM STP 963, A.G. Collins and A.I. Johnson, Eds., American Society for Testing and Materials, Philadelphia, 1988, p. 221-231.

16- CHERRY, J.A. *et al*. Field Guide for Sampling and Chemical Analysis of Groundwater, Field course, Department of Earth Sciences, University of Waterloo, Waterloo, Ontario, 1984.

17- HERZOG, B.L., J.D. PENNINO, and G.L. NIELSON. Groundwater Sampling, in Practical Handbook of Groundwater Monitoring, 1991, Lewis Publishers, p. 449-501.

18- PANKO, A.W. and P. BARTH. Chemical Stability Prior to Ground Water Sampling: A Review of Current Well Purging Methods, in Groundwater Contamination: Field Methods, ASTM STP 963, A.G. Collins and A.I. Johnson, Eds., American Society for Testing and Materials, Philadelphia, 1988, p. 232-239.

19- ROBIN, M.J.L. and R.W. GILHAM. «Field Evaluation of Well Purging Procedures», Groundwater Monitoring Review, Fall 1987, p. 85-93.

20- BARKER, J.F. and R. DICKOUT. «An Evaluation of Some Systems for Sampling Gas-Charged Groundwater for Volatile Organic Analysis», Groundwater Monitoring Review, Fall 1988, p. 112-120.

21- ROBIN, M.J.L., D.J. DYTYNYSHYN, and S.J. SWEENEY. «Two Gas-Drive Sampling Devices», Groundwater Monitoring Review, Winter 1982, p. 63-66.

22- JONES, J.N. and G.D. MILLER. Adsorption of Selected Organic Contaminants onto Possible Well Casing Materials, in Groundwater Contamination: Field Methods, ASTM STP 963, A.G. Collins and A.I.Johnson Eds., American Society for Testing and Materials, Philadelphia, 1988, p.185-198.

23. BARKER, J.F., R.V. NICHOLSON, D. SMYTH, D.L. RUDOLPH, J.P. GREENHOUSE, P. GUDJURGIS, J. MOLSON, E.O. FRIND, E.A. SUDICKY. Subsurface assessment for contaminated sites - Handbook, *DRAFT, For review,* Waterloo Centre for Groundwater Research, University of Waterloo, Ontario, Canada, October 1992.

24- BARCELONA, M.J. and J.P. GIBB. Development of Effective Groundwater Sampling Protocols, in Groundwater Contamination: Field Methods, ASTM STP 963, A.G. Collins and A.I. Johnson Eds., American Society for Testing and Materials, Philadelphia, 1988, p. 17-26.

25- STUART Garner, P.E. «Making the Most of Field-Measurable Groundwater Quality Parameters», Groundwater Monitoring Review, Summer 1988, p. 60-66.

26- AMERICAN PUBLIC HEALTH ASSOCIATION, American Water Works Association and Water Pollution Control Federation. Standard Method for the Examination of Water and Wastewater, 17th edition 1989. Method 2510B.

27. U.S. ENVIRONMENTAL PROTECTION AGENCY. Handbook for Sampling and Sample Preservation of Water and Wastewater, U.S. Government Printing Office, Washington, DC, 1982, EPA-600/4-82-029.

28. MINISTRY OF THE ENVIRONNEMENT OF THE ONTARIO. Protocol for the Sampling and Analysis of Industrial/Municipal Wastewater, Municipal and Industrial System for Abattement, June 1991.

29- BUCHMILLER, R.C. «Screening of Groundwater Samples for Volatile Organic Compounds Using a Portable Gas Chromatograph», Groundwater Monitoring Review, Spring 1990, p. 126-130.

30- MINISTÈRE DE L'ENVIRONNEMENT DU QUÉBEC, Direction des laboratoires, Procédure d'assurance et de contrôle de la qualité pour les travaux analytiques contractuels, avril 1992.

31- HAMPTON, D.R. Laboratory investigation of the relationship between actual and apparent product thickness in sands, in Environmental concerns in the petroleum industry, S.M. testa (ED), Pacific section, AAPG, 1989.

32. HAMPTON, D.R. *et al.* «A New Tool to Measure Petroleum Thickness in Shallow Aquifers», in Proceedings of the fourth national outdoor action conference on aquifer restoration, ground water monitoring and geophysical methods, Las Vegas, Nv, May 14-17, 1990.

33. HUGHES, John P., *et al.* «Two Techniques for Determining the True Hydrocarbon Thickness in an Unconfined Sandy Aquifer» in Proceedings of the Conference on Petroleum Hydrocarbons and Organic Chemicals in Ground Water: Prevention, Detection and Restoration, Houston, Tx, November 9-11, 1988.

34. LENHARD, R.J., J.C. PARKER. «Estimation of free hydrocarbon volume from fluid levels in observation wells» in Ground Water, 1990, vol. 28, p. 57-67.

35. MERCER, J.W., R.M. COHEN. «Review of non-miscible fluids in the subsurface: Properties models characterization and remediation» in Journal of contaminant hydrogeology, 1990, 6, p. 107-163.

36. de PASTROVICH, T.L., Y. BARADAT, R. BARTHEL, A. CHIARELLI, D.R. FUSSELL. Protection of groundwater from oil pollution, The Hague, Netherlands, CONCAWE, report, 3/79, 1979.

37. BALLASTERO, T., B.L. HERZOG and O.D. EVANS. Monitoring and Sampling the Vadose Zone, in Practical Handbook of Groundwater Monitoring, 1991, Lewis Publishers, p. 97-143.

38. O'LEARY, P. and P. WALSH. 1991, Lesson 3, Landfill Gas Movement, Control and Uses, Waste Age, June 1991, p. 114-124

BIBLIOGRAPHY

BARCELONA, M.J., J.P. GIBB, J.A. HELFRICH and E.E. GARSKE. Practical Guide for Groundwater Sampling, Illinois State Water Survey, Champaign, Illinois, 1985, ISWS Contract Report 374.

BARCELONA, M.J., J.F. KEELY, W.A. PETTYJOHN and A. WEHRMANN. Handbook of Groundwater Protection, Hemisphere Publishing Corporation, 1988, 212 p.

FETTER, C.W. «Potential Sources of Contamination in Groundwater Monitoring», Groundwater Monitoring Review, Spring 1983, p. 60- 64.

GÉLINAS, P.J., J. LOCAT, P. THERRIEN, et A. MASSON. Hydrogéologie des contaminants; Instrumentation et surveillance, Département de Géologie, Faculté des Sciences et de Génie, Université Laval, GGL-A0406, 1987.

GIBB, J.P. and M.J.BARCELONA. «Sampling for Organic Contaminants in Groundwater», Journal AWW, May 1984, p. 48-51.

GIBB, J.P., R.M. SCHULLER, and R.A. GRIFFIN. Procedures for the Collection of Representative Water Quality Data from Monitoring Wells, Illinois State Water Survey, Champaign, Illinois 61820, 1981, 61 p.

KEELY, J.F. and K. BOATENG. Monitoring Well Installation, Purging and Sampling Techniques-Part I: Conceptualization, Groundwater, vol. 25, no. 3, May-June 1987, p. 300-313.

PETTYJOHN, W.A. et al., «Sampling Groundwater for Organic Contaminants», Groundwater, 19:2:180, 1981, p. 48-51.

PICKENS, J.F., R.M. CHERRY, R.M. COUPLAND, G.E. GRISAK, W.F. MERRITT and B.A. RISTO, «A Multiple Device for Groundwater Sampling», Groundwater Monitoring Review, Spring 1981, p. 48-51.

RCRA. Groundwater Monitoring Technical Enforcement Guidance Document, NWWA-EPA Series, September 1986.

REYNOLDS, Glenn W. et al. Environ. Sci. Technol. 1990, 24(1), 135.

SCALF, M.R., J.F. McNABB, W.J. DUNLAP, R.L. COSBY and J.S. FRYBERGER. Manual of Groundwater Quality Sampling Procedures, Robert S. Kerr Environmental Research Laboratory, Office of Research and Developpement, U.S. Environmental Protection Agency, Oklahoma, 1981, 93 p.

SWANSON, Gloria J. Well Water Journal 1989, May, 76.

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