Centre d'expertise
en analyse environnementale
du Québec

Sampling Guide for Environmental Analysis

Booklet 3

Groundwater sampling

English version of the french edition of February 28th 2012

Québec

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FOREWORD

Booklet 3, Groundwater Sampling, is a complete revision of the previous publication. It provides updated guidelines on sampling techniques and confirms their acceptance by the Ministère du Développement durable, de l'Environnement et des Parcs (MDDEP), within the limits of their application.

This booklet deals with the techniques and equipment used at every stage of sampling, from installing observation wells to sampling groundwater. Other guides from the Ministère provide guidelines on preparing sampling protocols and processing data, including well location, sampling frequency, *characterizing contaminated sites* and *monitoring groundwater quality*. Methods for conserving groundwater samples are detailed in *Modes de conservation pour l'échantillonnage des eaux souterraines – DR-09-09*, published by the Centre d'expertise en analyse environnementale du Québec (CEAEQ). As well, certain general principles for planning a campaign, cleaning equipment, quality control and safety procedures, are treated in *Cahier 1 – Généralités* of the Sampling Guide for Environmental Analysis. The present document (Booklet 3) deals specifically with aspects related to sampling groundwater in observation wells.

Designing a groundwater monitoring program is one of the tasks of the person responsible for the sampling campaign (hereafter the supervisor). Furthermore, one must be aware that following the methods presented here will not guarantee a successful operation in every possible hydrogeological setting. The supervisor must therefore ensure that the sampling methods used are appropriate to the setting and are applied in the appropriate manner.

About the Sampling Guide for Environmental Analysis

The Sampling Guide for Environmental Analysis is a series of booklets on the sampling of specific environmental compartments. For each, it describes best practices for the planning and execution of sampling, to ensure both the quality of samples and the validity of the scientific data garnered from them.

The Guide is a reference document that provides general information on recognized sampling practices. Numerous regulations, guidelines, policies and other documents published by the MDDEP require that sampling be performed in accordance with one or more booklets of the Guide (see appendix). Any sampling work using a method other than those mentioned in these booklets must be discussed with an analyst at the regional office concerned prior to proceeding.

As the authority responsible for sampling methods, the CEAEQ publishes the various booklets making up the Guide and coordinates their revision. It ensures that they are coherent with each other and consistent with regulatory requirements.

Important: In case of discrepancies between the English translation and the original French version, the French version prevails.

Note to the reader: References to specific commercial products are for information purposes only; equivalent products may be substituted.

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GLOSSARY AND ACRONYMS

Analyte: The substance determined in an analytical procedure.

Aquifer: A geological formation that is sufficiently permeable to allow a significant flow of groundwater and the extraction of appreciable quantities of water.

Aquitard: A geological formation of low permeability from which appreciable quantities of water cannot be extracted, but through which leakage can occur.

Bentonite: Clay composed primarily of monmorillonite, used to seal piezometers and observation wells due to its ability to swell in volume by 7 to 12 times in the presence of water.

Capillary fringe: Saturated or quasi-saturated zone above and continuous with the free surface of a groundwater body, where water pressure is less than atmospheric pressure.

CEAEQ: Centre d'expertise en analyse environnementale du Québec.

Cement-bentonite grout: A slurry made of cement, bentonite and water in the following proportions per 100 kg of cement: 70 to 75 litres of water and 3 to 5 kg of bentonite.

Cleaning blank[3]: Container filled with a sample of the last rinse liquid used in the cleaning of equipment. Must include preserving agents.

Conceptual hydrogeological model: Synthesis of the knowledge and data collected in order to prepare a set of figures and texts describing the hydrogeological setting, the cause (source) of groundwater contamination and the transport and attenuation (evolution) of dissolved contaminants.

Cross-contamination: Contamination of a sample by equipment that was contaminated by the previous sample or between sampling points.

Dedicated sampling equipment: Sampling equipment used exclusively for a specific observation well and generally left in place.

DNAPL (dense non aqueous phase liquid): Liquid that is immiscible with and denser than water (e.g. penetrating a groundwater body).

Exogenous: Arising from an external cause.

FID: Flame ionization detector.

Field blank[3]: Container prepared by the laboratory, filled with purified water and the appropriate preserving agents for the parameters represented by each blank. Must be taken to the sampling site, opened and handled during sampling, then returned to the laboratory as a sample.

[3] For complete definition, refer to cahier 1.

Gravel packing: A very fine gravel of uniform granulometry (containing no fine particles), placed in the annular space between a perforated casing (screen) and the borehole wall. Also called a “sand lantern”, “sand filter” or “filtering sand”.

Groundwater level: Water level measurable in an observation well or piezometer, the height of which indicates a hydraulic head.

Hydraulic head: Height of a water column above the point concerned (i.e. the equilibrium height of the water with atmospheric pressure).

Integrity (of a sample, a well, etc.): State of an object that has undergone no alteration.

Immiscible: Unable to mix with another body to form a homogeneous and stable mixture.

LNAPL (light non aqueous phase liquid): Liquid that is immiscible with and less dense than water (e.g. floating on a water table).

MSDS: Material safety data sheet.

Molecular diffusion: Movement of dissolved particles (ions, molecules, etc.) in water under the effect of a concentration gradient.

Organic mud: Bentonite to which organic polymers have been added to adjust the consistency, viscosity and surface tension of the slurry. Such polymers include polyacrylamides, carboxymethyl cellulose, sodium acrylate, lignosulfonates and lignins.

OVA: Organic vapour analyzer.

PAH: Polycyclic aromatic hydrocarbon.

Passive sampler: Sampling equipment that does not require purging of the well.

PDB: Polyethylene diffusion bag.

PID: Photoionization detector.

Piezometric level: Upper level of the static liquid column balancing the hydrostatic pressure at the reference point. Represented physically by the level of liquid in a tube, observation well or open piezometer at the point concerned.

Pit run: Fill of unspecified granulometry, installed in the form in which it was extracted (e.g. usually material brought to the surface by drilling the hole).

PVC: Polyvinyl chloride.

Representativeness of samples: Degree to which a sample is similar to the local quality of the groundwater body from which it was extracted.

Residual form: State of contaminants that remain in place after their more soluble constituents have been removed or biodegraded.

Supervisor of a sampling campaign: Person in charge of the campaign as a whole, of the fieldwork or of sampling activities.

Transportation blank[3]: Container prepared by the laboratory, filled with purified water and appropriate preserving agents for the parameters represented by each blank. Must be taken to the sampling site and be returned to the laboratory as a sample, without being opened.

Vadose zone: A subsurface zone between the surface of the ground and the surface of an unconfined groundwater body, where water pressure is less than atmospheric pressure.

VOC: Volatile organic compound.

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1. INTRODUCTION

Over the past two decades in Québec, increasing importance has been given to the legal and regulatory framework concerning the protection of groundwater this has lead to specific requirements for the characterization and monitoring of groundwater in various settings. Whether the project consists of characterizing the state of a site offered for sale, evaluating the quality of the resource, verifying the imperviousness of a waste burial cell or monitoring a contaminant plume, the success of a groundwater sampling campaign always depends on obtaining representative samples and maintaining their integrity from the sampling point to the laboratory.

Every step in sample collection, from well location and construction to delivering samples to the laboratory, is a potential source of deterioration and contamination. Throughout a sampling campaign, both supervisors and sample collectors must make decisions based on the hydrogeological setting as well as on the objectives of the campaign. Any of these decisions could compromise the campaign’s success in an obvious or subtle manner. Each sampling campaign is unique, and no document can replace experience, expertise, thoroughness and attention to detail. Expertise and professional judgment are the best safeguards of a successful sampling campaign.

To guide the supervisor in preparing a campaign, and to assist the sampler in accomplishing tasks in the field, this booklet presents the steps involved in collecting samples and provides general guidelines for choosing methods based on field conditions and campaign objectives. Certain deviations from the best practices presented here may be acceptable. It is up to the supervisor to determine their merit and justify their use. The principal methods of purging and sampling, and the most commonly used sampling and monitoring equipment, are examined briefly for their applicability in different contexts. The operations required for sample collection and transportation to the laboratory, and the precautions involved in quality assurance and control, are also described. Related aspects that are also discussed include the health and safety of the personnel doing the sampling, the daily and final reports requirements, the installation of monitoring instruments, sampling in the vadose zone and sampling of immiscible liquids.

2. PLANNING A SAMPLING CAMPAIGN

The supervisors of a campaign must make crucial decisions during the planning phase. The location of sampling points, the choice of parameters to analyze, the frequency of sampling, the design of observation wells and the choice of sampling methods will all have an impact on the representativeness of samples.

Above all, the choices to be made depend on the objectives of the campaign. These can be diverse and numerous: characterization of groundwater quality in an aquifer, evaluation of water quality in an intake structure, leak detection, temporal or spatial monitoring of a contaminant plume, etc. A good definition of goals will determine the degree of precision required and how much effort should go into preparing a conceptual hydrogeological model. A preliminary characterization campaign is not designed the same as a medium- or long-term monitoring campaign. The design and implementation of a groundwater monitoring program must necessarily begin with obtaining detailed knowledge of the hydrogeological conditions, to ensure for example a representative choice of sampling points.

The choice of parameters to analyze, the location of sampling or monitoring points, the number of samples and frequency of collection must all be directly based on the objectives, the conceptual hydrogeological model and the variability of the phenomena of interest (e.g. the spatial and temporal variability of the concentrations of different parameters).

The choice of parameters and the precision desired must also take into account the relevant regulations, guidelines and policies. The choice of the number, location and depth of sampling points must reflect the nature and location of contamination sources (if known), the site's hydrogeological characteristics and the physicochemical properties of the contaminants (e.g. their solubility and density). In some cases, such as long-term characterization or monitoring campaigns, the number and exact location of monitoring or sampling points can be decided as the campaign progresses.

For recurring campaigns, sampling frequency must be tailored to the site, objectives and expected results. When monitoring extends over more than one year, campaigns should be conducted at the same time each year to ensure that comparisons are meaningful. With certain configurations of unconfined groundwater, water quality can undergo more variations than confined and semi-confined groundwater bodies. Requirements and recommendations on sampling conditions are given in various documents issued by the MDDEP. The appendix provides an extensive list of regulations, depollution attestations, certificates of authorization and guides that can be consulted. Because the field is so vast and in constant evolution, the list is not complete.

Once campaign objectives have been established, the parameters selected and locations targeted, all that remains is to choose sampling methods and define the protocol.

2.1. Design of observation wells

An observation well is a structure that allows groundwater to be sampled so that its physicochemical or microbiological quality may be determined. Collecting representative samples requires the installation of a well, either in unconsolidated deposits or in the rock. The physical characteristics of the well (location, depth, perforated portion, etc.) will be crucial factors in the representativeness of samples.

Groundwater samples can also be collected from production wells (domestic, agricultural, municipal, industrial, etc.), the installation of which is not discussed here. The collection of samples from an intake structure is however examined in section 5.1.

An observation well may also be used for other purposes, such as:

- measuring piezometric level;
- measuring horizontal and vertical hydraulic gradients;
- identifying the presence of a layer of immiscible liquid, whether light (LNAPL) or dense (DNAPL), and evaluating its thickness;
- conducting permeability tests;
- conducting tracing tests;
- measuring and sampling biogas or volatile organic compounds (VOCs) in the vadose zone.

Since a well designed for some objectives will not necessarily be of use for others, the design of an observation well must be specifically based on campaign objectives. For example, with a well designed for detecting the presence of a floating phase (LNAPL), a variable head permeability test would give problematic results at best. This is because detecting the presence of LNAPL requires that the screen extend above and below the water table (which fluctuates in time), whereas a variable head permeability test requires that the screen be completely submerged.

Observation well or piezometer

The type of structure required for sampling groundwater is called an observation well. It is designed to allow the collection of water samples, the detection and sampling of immiscible liquids, and the measurement of water levels. In contrast, a piezometer is only used to measure hydraulic load at a given depth. Piezometers can be either hydraulic or equipped with a pressure sensor. A hydraulic piezometer is similar to an observation well but with a smaller diameter and a shorter screen. In a pressure sensor piezometer, the sensor is buried and sealed in the borehole, allowing no access to the groundwater.

The purpose of an observation well is to allow the collection of representative samples of groundwater at a specific point in a hydrogeological formation. Precautions are therefore taken to minimize the impact of construction and installation on the eventual representativeness of samples. For example, equipment and materials used must be thoroughly clean, completely free of substances targeted by laboratory analysis, and inert toward anything in the water.

The construction details of observation wells are of great importance in the interpretation of data with regard to hydraulic head, water quality and the hydraulic conductivity of a hydrogeological formation. Section 2.4 explains the principal categories of information to be recorded when installing an observation well.

2.1.1. Types of well used for sampling

The types of observation well[4] most commonly used are: simple observation wells (figures 1 and 2); multilevel wells (figure 3); well nests (figure 4); driven wells and open wells in rock (figure 5). The illustrations in this booklet indicate the basic elements of each. For more details and construction guidelines, see standard ASTM D5092 04.

Wells can be composed of different materials, the choice of which must be based on the contaminants to be monitored, the geological setting and the intended duration of use.

2.1.1.1. Simple observation well

A simple observation well (figure 1) is composed of a casing inserted into a borehole, with a screen placed between two given depths. This allows groundwater to be sampled from the geological setting intercepted by the screen. Usually, the screen is installed at the bottom end of the casing, just above the bottom of the well.

The screen and casing consist of sections placed end to end and connected by watertight joints. For this purpose, it is important to use threaded sections with O rings. Adhesives and other types of chemical binders must not be used, since the water quality could be altered (ASTM D5092-04).

The screen is isolated from overlying horizons by an annular seal of bentonite. If it is not at the bottom end of the casing it is also isolated from underlying horizons in the same manner. Installing such seals requires the presence of a space (called the annular space) between the casing and the borehole wall. At the level of the screen, gravel packing is inserted in this space to allow water to circulate while preventing the screen from clogging. The gravel packing must extend above and below the screen to prevent the bentonite and other materials from affecting it. The bentonite is installed in granular form, powdered, in pellets or as slurry.

The annular space remaining between the top of the annular seal and the surface of the ground must be filled with a cement/bentonite grout[5]. The upper part of the well must be stabilized by a protective casing filled with a plug of cement/bentonite grout inserted from the surface, ideally down to the frost line (at least 2 m). Besides physically supporting the protective casing, the plug serves to prevent runoff water from entering the well. A typical construction for such installations is presented in figures 1 and 2.

[4] Not to be confused with "exploratory well", the term often used for an exploratory trench.

[5] A cement/bentonite grout expands as it sets, forming a tight-fitting and relatively impermeable sheath. When technically feasible the grout must be installed with an injection tube. Prepared in a high-speed mixer, the cement, water and bentonite mix forms a viscous liquid that can be injected using a pump. Pouring such a grout from the surface, by gravity, can leave voids between the casing and borehole walls, potentially impairing the quality of samples.

With a permanent installation, if the ground surface permits, adding a cement/bentonite plug to a minimum depth of 30 cm and a radius of 15 cm around the well will make it virtually impervious to surface contamination. The whole should be completed with a mound of cement around the protective structure.

The length and location of the screen can have considerable impact on the characterization of the water. This is because the samples collected will be characteristic of the average concentration of contaminants over all horizons flowing through by the screen. A screen that is too short could be badly positioned, outside the cloud of contaminants. A screen that is too long could connect two layers, diluting the water from the contaminated zone or propagating the contamination. Either way, the samples would not be representative of the contamination present. To measure concentration gradients as a function of depth, the best solution is to construct a well nest (see section 2.1.1.3).

Generally, screens of 60 cm to 3 m in length are suitable for most cases. Where there are strong variations in the water table a longer screen may be necessary. Regardless of screen length, groundwater will primarily come from the most permeable horizons. In fractured rock, a longer screen can interconnect multiple fractures, increasing the probability of encountering the contaminant, though also causing a dilution effect.

When immiscible liquids are targeted, special attention must be paid to the position of the screen. For LNAPL the screen must extend above the capillary fringe to intercept the floating phase if present. For DNAPL the screen must be positioned to cover the horizon where the immiscible liquid has accumulated, without extending any significant distance below it. This will eliminate the risk of providing a channel for the contamination to penetrate below the impervious layer.

For practical reasons, the inner diameter of a well casing for groundwater sampling is typically 5 cm. This allows room for common sampling techniques. For construction materials to be installed (gravel packing, sealing plugs, cement/bentonite grout), the minimum annular space recommended between the casing and the borehole wall is another 5 cm. This implies a borehole with a total diameter of at least 15 cm. Centralizers can be used to keep the casing and screen properly centred in the borehole.

In geological formations of low permeability, gravel packing around the screen is imperative to prevent it from clogging. In formations composed of unconsolidated deposits that are coarser and more permeable, a filtering envelope of gravel or sand is also recommended. Besides facilitating circulation at the screen, the filtering material stabilizes the formation to prevent it from collapsing into the well. In formations with a large component of fine particles (e.g. very fine sand, silt), a fine-granulometry filtering sand can limit the turbidity of samples. Thus, the granulometry of the packing material must be appropriate for the physical context. It must be fine enough to filter out fine particles from the surrounding formation, but not so fine as to clog or enter the screen, and coarse enough to allow water to circulate.

Gravel packing must be inert, of uniform granulometry and composed of hard, rounded grains (e.g. of fluvial origin). Crushed material must never be used for filtering. An interesting option is to use a prepacked filter (see next section).

When installing these materials (gravel packing, bentonite, grout, etc.), the volumes represented by the quantities used should be checked against the theoretical volumes calculated for the dimensions of the well. This will tell you whether collapsing, overexcavation or other construction problem has occurred during drilling or filling.

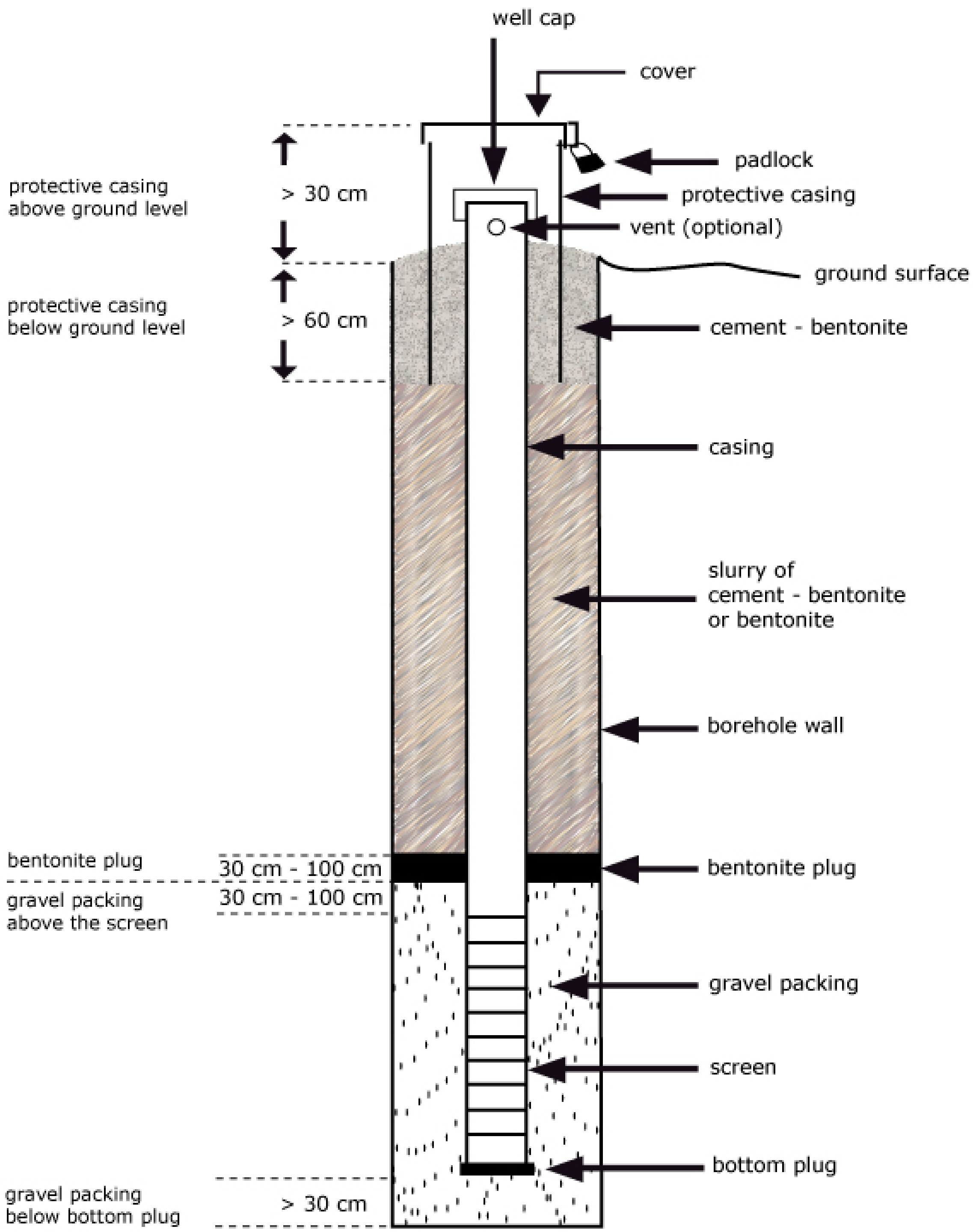

Figure 1. Components and dimensions of a simple observation well

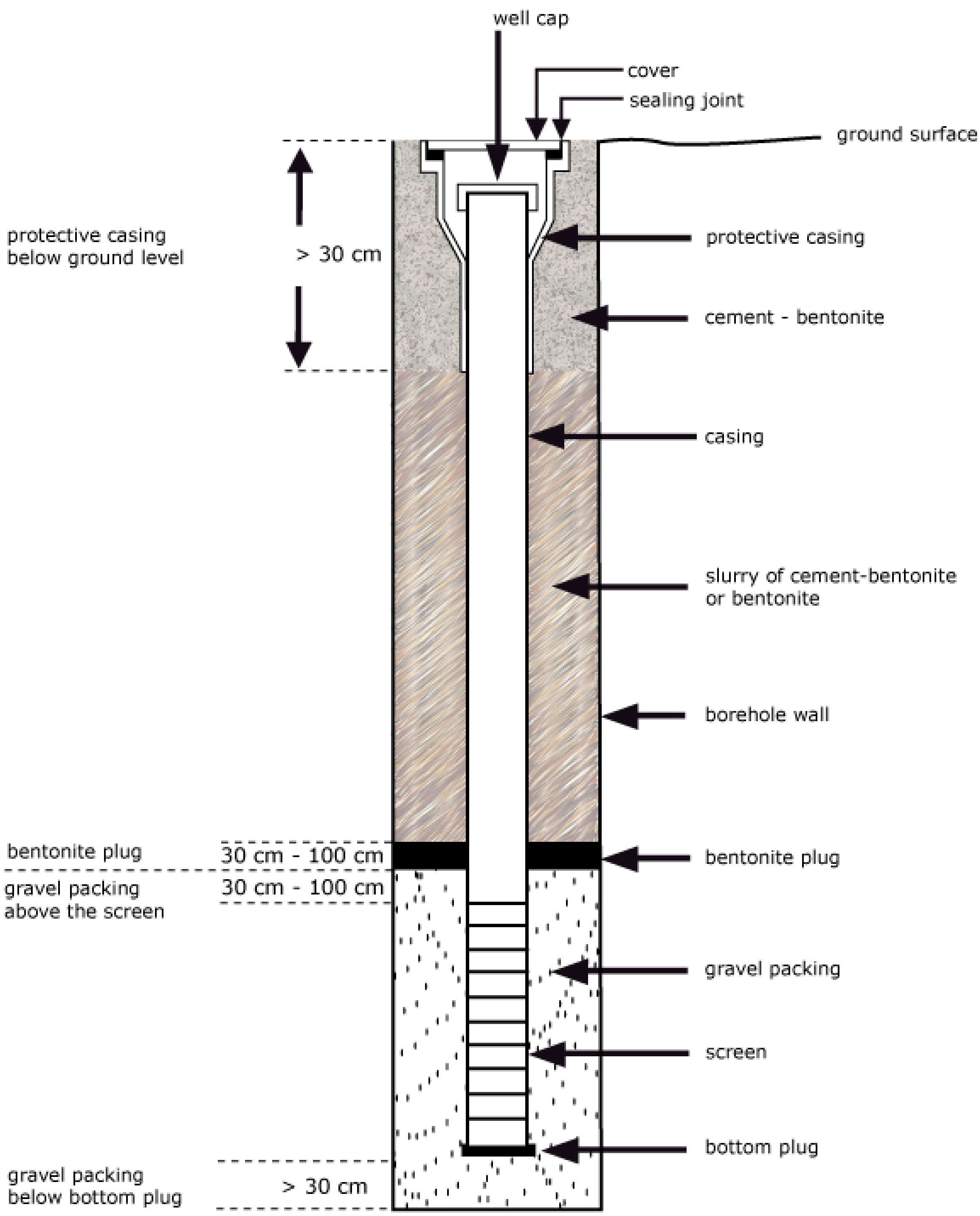

Figure 2. Simple observation well with protective structure below ground level

2.1.1.2. Observation well with prepacked gravel filter

Screens with prepacked filters are readily available on the market. The gravel packing, generally a sand, is held in place around the screen by either a second screen of larger diameter or a geotextile. In the latter case, it is important to make sure the geotextile is suitable for the sampling that will be done, i.e. that it does not give off any substance that could distort the analysis results nor impede the circulation of water and water-borne contaminants. Prepacked filters with geotextile must not be used when immiscible liquids are present.

Prepacked filters can be useful when the annular space is too narrow for packing to be poured satisfactorily from the surface. In this situation, using a prepacked filter ensures that the filtering sand is placed uniformly around the screen, and installation is generally quick and easy.

For more information about this type of system, refer to standards ASTM D6724 04 and D6725-04.

Remember that before building the well you must make sure the materials composing both screens and prepacked filters are inert and compatible with the well's purpose. In particular, they must not prevent the detection of immiscible phases (if present) or impair the representativeness of samples by releasing or reacting with contaminants.

2.1.1.3. Multilevel well and well nest

These are special types of well whose basic construction features are illustrated in figures 1 and 2.

Multilevel observation well

A multilevel observation well consists of multiple casings in the same borehole, each with its own screen. Each screen is positioned at a different depth (figure 3), surrounded by gravel packing and separated from the others by sealing plugs. The sampling depths must therefore be determined beforehand. This type of well allows sampling to be done at multiple levels (revealing the vertical distribution of contaminants), while also revealing the vertical hydraulic gradient. To ensure the representativeness of samples and the validity of the hydraulic gradient measurement, the seals between sampling levels must be tight. The bentonite sealing plugs should therefore be as thick as possible (over a metre).

Installing bentonite plugs and gravel packing can be difficult and time-consuming when significant depth is involved. In practice, installing more than three or four casings per borehole is generally unfeasible. Since these casings are generally less than 2.5 cm in diameter there is a greater risk of deformation occurring, which could make sample collection difficult.

Some of these installations are fairly sophisticated systems. They consist of sampling ports distributed along a rigid tube, each port being isolated from the others by packers, but connected to tubing that allows sampling from the surface. Several such systems are sold commercially, the most common being the Westbay™ and Solinst™ systems. They are useful in fractured formations where the fractures have been located precisely by core logging, allowing each fracture (or set of fractures) to be monitored by one port.

Multilevel observation wells are generally used to reduce the work of boring and installation when several deep wells are required. The drawbacks of this type of well include the difficulty of internal access, the complexity of installing them, and potential hydraulic short circuits between the multiple tubes inside the well. After a few years of use such wells may no longer be functional, so they are not the best solution.

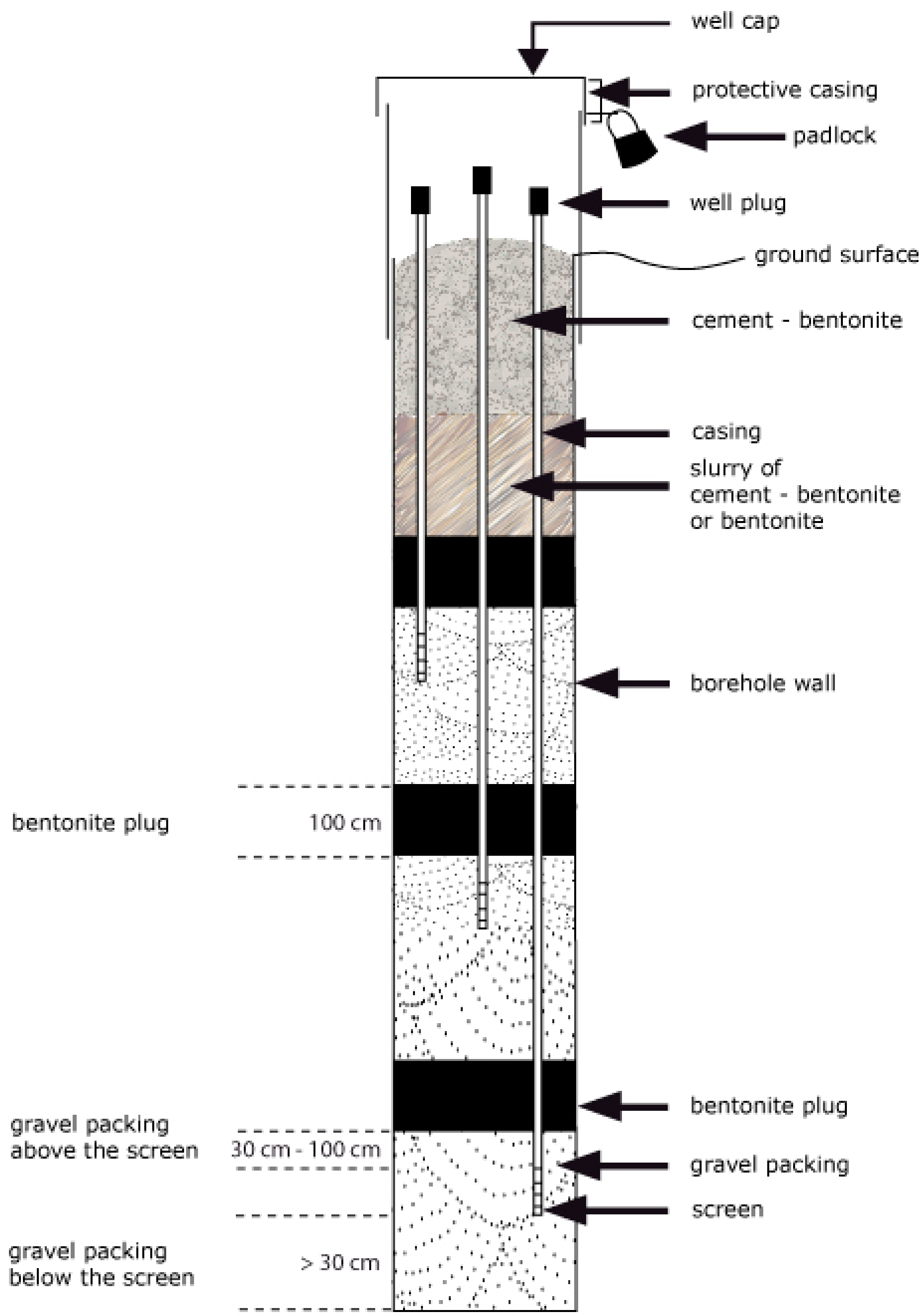

Figure 3. **Multilevel well (sampling levels separated by bentonite plugs)**

Nest of observation wells

A nest of observation wells consists of several wells of different depths installed in individual boreholes, generally 1.0 to 1.5 m apart (figure 4). The purpose is to be able to sample the groundwater, and measure the hydraulic head, at multiple levels. Ideally, the total diameter of the entire nest should be no more than three to five metres. This configuration allows a good determination of both the vertical distribution of contamination and the vertical hydraulic gradient, with minimal risk of contamination from one horizon to another. Well nests are therefore preferable over multilevel wells, since the construction difficulties associated with the latter put the integrity of samples at much greater risk.

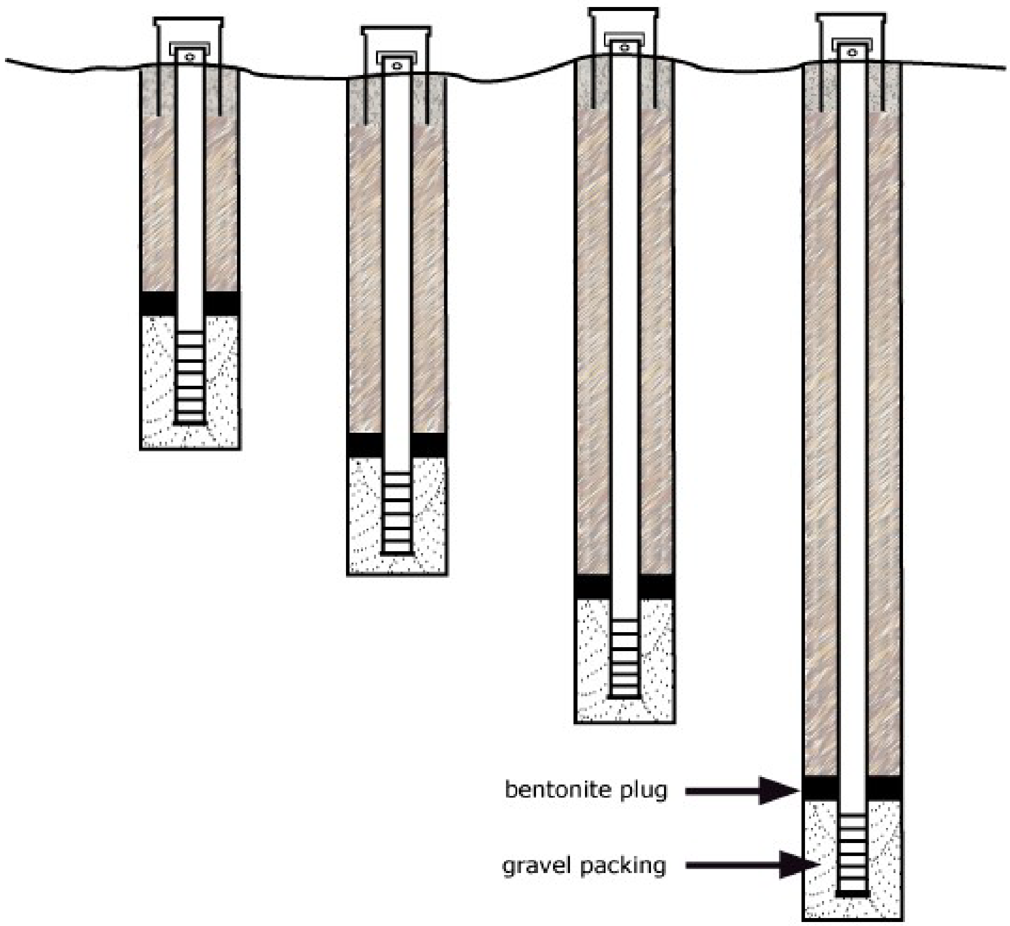

Figure 4. Nest of observation wells

Note: Each observation well must be constructed following the guidelines applied in figures 1 and 2.

2.1.1.4. Driven well

A driven well consists of a casing or set of components driven straight into the ground, without drilling a hole and without any sealing. While installation is rapid, isolation from surface contamination is not guaranteed. This type of equipment can only be driven into unconsolidated deposits (fine gravel, sand, silt, clay), using the driller's hydraulic system or a penetrometer. Such wells should only be used if enough is known about the geology of the site. The most common driven wells are wellpoints. The points are made of stainless steel or Teflon™, and depending on the model are either recovered after sampling or left on-site. No drilling fluid is required, whether water, mud or air, etc. The point must penetrate the water table to a sufficient depth for groundwater to be sampled. One such device can be used for sampling LNAPL. For more information about these techniques, see standards ASTM D6001-05, D6724-04, D6725-04 and D7352-07.

2.1.1.5. Observation well with open hole in rock

An open well in the rock (figure 5) comprises no construction materials beyond, at most, a protective casing anchored in a watertight manner in the uppermost part of the rock. It can simply be a hole, bored into a formation that is sufficiently consolidated for the walls not to collapse, with the protective casing extending above the ground. It can also be a borehole that begins in unconsolidated deposits, with a protective casing to prevent collapse, and continues without casing into consolidated rock. Such wells must be constructed so that water from the surface cannot seep down along the casing. With this type of well, the groundwater sampled does not come into contact with construction materials. The producing interval consists of rock walls of more or less uniform profile, depending on the degree of fracturing and variations in consolidation. Theoretically, the water comes from fractures and pores throughout the intercepted section. In practice, the contribution of different fractures and degrees of porosity can vary considerably.

Open wells can provide an initial detection of contamination, but generally cannot indicate the vertical distribution of contaminants. The analysis results from this type of well should therefore be interpreted with caution. In the presence of heavy contaminants, water samples should be collected from the base of such wells. However, given that contamination may come from anywhere down the borehole, samples from such wells are only representative of the well as a whole, not a particular horizon.

Various types of packers can be used to isolate different sections for sampling in order to determine with some precision where contaminant-bearing fractures or horizons are located.

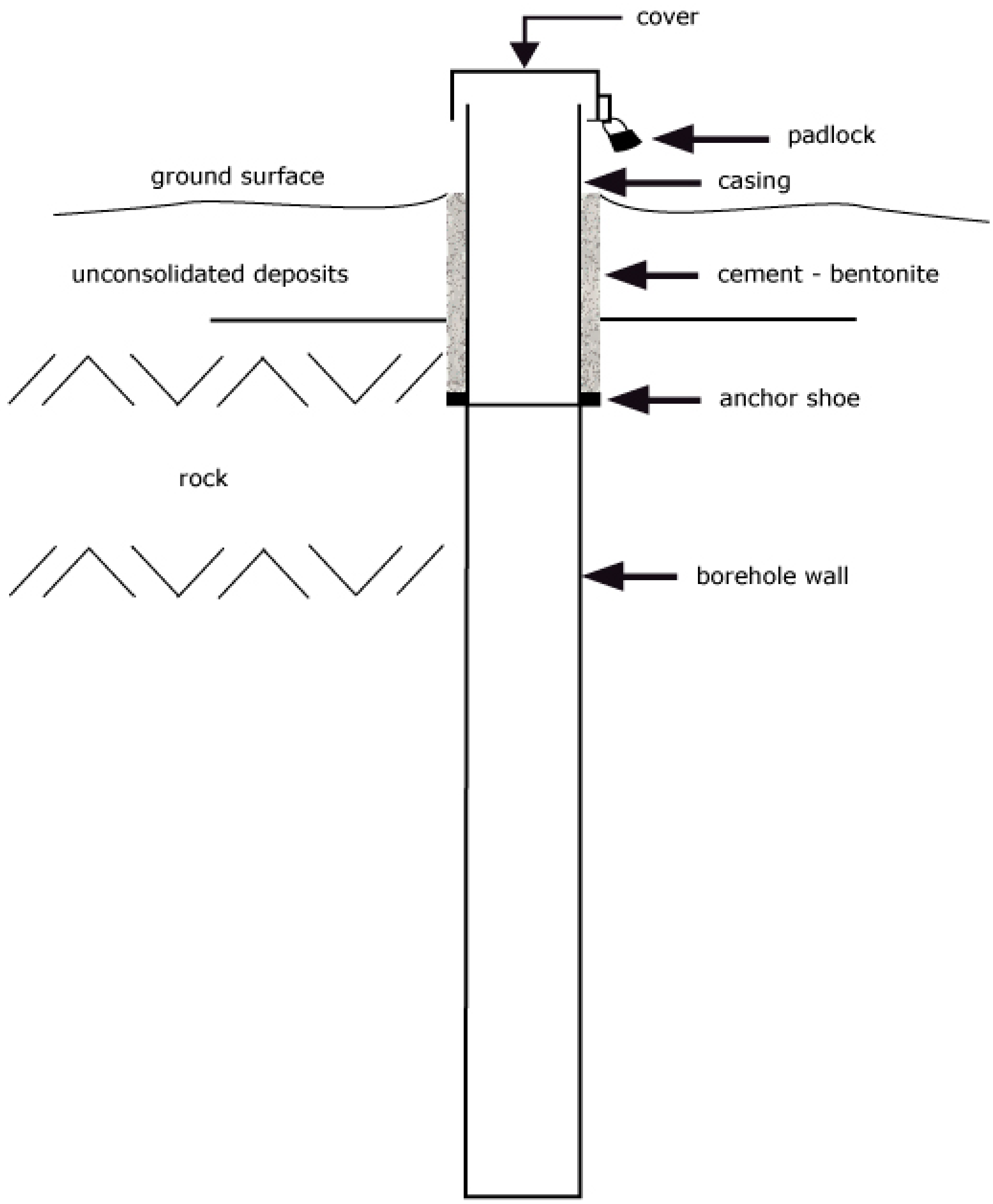

Figure 5. Observation well with open hole in rock

2.1.1.6. Exploratory well or trench

Collecting samples from the bottom of an excavation does not give a representative picture of groundwater conditions. For that reason, it is not an acceptable method for determining groundwater quality. It can however be used to see whether the quality of the excavation water meets effluent standards, e.g. during rehabilitation work. As for an observation well in the bottom of an excavation, it can only be used for measuring the depth of the water table.

2.1.2. Considerations for drilling

Drilling operations always disturb the hydrogeological conditions of the surrounding soil and/or rock, to a degree that varies with the type of equipment used (see *Cahier 5 – Échantillonnage des sols*) and the nature of the geological materials present. Therefore, whatever the method of drilling chosen, certain precautions should be taken to reduce the impact on hydraulic conditions and to avoid any physicochemical alteration of the water that will be sampled. The following sections present these precautions.

2.1.2.1. Compatibility of equipment materials

Depending on the material composing the casing, tubing and other equipment, there is a possibility that the chemistry of the water could be modified, e.g. by adsorption/desorption onto or from their surfaces, the release of substances from within their materials, or diffusion through them. To limit the adsorption/desorption of contaminants like aromatic and aliphatic hydrocarbons, hard (non-plasticized) PVC is recommended. Preference should also be given to high-density polyethylene (HDPE) rather than the low-density kind, which is softer. If the groundwater is corrosive, steel should be avoided because it would lead to increased concentrations of certain metals (Fe, Mn), reduced concentrations of nitrogen compounds (NO_2, NO_3), and increased pH and to degradation of chlorinated ethenes.

2.1.2.2. Careful supervision

Every step in the drilling of a borehole, the construction of an observation well and the installation of sampling equipment can impact the representativeness and integrity of samples. The person supervising drilling operations, construction and the installation of sampling instruments must oversee the work attentively and ensure that guidelines are respected.

2.1.2.3. Cleanliness of equipment

Before beginning a drilling campaign, it is important to ensure that the equipment is clean. To avoid cross-contamination, rods, casings and augers must be cleaned with either a pressure washer or a steam cleaner. Hot water with a phosphate-free soap is strongly recommended. Especially when cleaning is done on-site, the washwater must be recovered (see section 2.1.2.8 on the responsible management of residues). Care must also be taken, throughout the drilling campaign, to ensure that all items of equipment are protected from potential sources of contamination.

The order, in which holes are drilled, when the source of contamination is known, should proceed from the least-contaminated zone to the most-contaminated zone. Between two holes at the same site, drilling equipment must be washed, especially when the previous hole was drilled in an area whose degree of contamination is unknown. Equipment like corers, split-spoon samplers and so on must be cleaned before sampling from the next well. When in doubt, cleaning blanks should be made.

It cannot be over-emphasized that sampling equipment must be decontaminated as described in *Cahier 1 – Généralités*.

2.1.2.4. Hydraulic lubricants and petroleum products

The lubricating oils and greases commonly used by drillers to reduce corrosion and wear are a potential source of contamination, because they can get into the groundwater. For some organic compounds the criteria for contamination and potability are measured in µg/L. It therefore takes only a small amount of oil for such concentrations to appear in sampled water. Remember too that lubricating oils can contain not-insignificant amounts of trace metals and VOCs.

Completely avoiding the use of lubricating oils and greases during drilling is difficult. However operators can be reminded that a moderate and cautious use of such products is imperative to reduce the risks of contamination. Vegetable-based oils and greases, or detergent-based lubricants, can in some cases satisfactorily replace hydrocarbon-based lubricants. Nevertheless, if a replacement product is proposed one must ensure that it will not interact with the parameters of interest, and that it is biodegradable and phosphate-free. Also, the product's material safety data sheet (MSDS) must be attached to the report, or a chemical analysis performed if information is unavailable or incomplete.

In sensitive environments like lakes and rivers, vegetable-based hydraulic oils may be mandatory to limit the risk of environmental contamination in the event of equipment breakdown.

Drilling equipment requires fuel to power it. Precautions must be taken when handling such fuel to avoid introducing it into the environment and into samples. An emergency measures action plan should be prepared and presented to all stakeholders before work begins. Immediate action must be taken if an incident occurs, and all incidents must be documented. Depending on the gravity of an incident, analysis of the fuel and affected soil may be necessary. A possible replacement solution would be to use electric or propane-operated drillers.

2.1.2.5. Drilling fluids

All drilling fluids are potential sources of groundwater contamination. For this reason, whenever possible it is best to use methods that do not require the use of such fluids.

When there is no other choice, certain methods of drilling use fluids to cool moving parts, raise residues to the surface and retain the walls of the borehole. Drilling fluids include water, a mix of water and bentonite, organic mud, a mix of water and synthetic organic polymers, and water mixed with a biopolymer powder derived from bacteria[6]. If you must use a drilling fluid, a sample of it should be taken for analysis to verify that it does not interact with the parameters of interest (attach its MSDS to the report if necessary). Polymer-based organic muds are not recommended because they can release significant amounts of organic compounds and promote the adsorption of organic contaminants and metals.

Where the use of water as drilling fluid cannot be avoided, drill operators must use the cleanest water possible, after documenting its source and storing it in a clean tank. Remember that when water is used as a drilling fluid, regardless of composition, it propagates into permeable zones. This means that for an indeterminate period there will be a dilution of the concentrations of certain parameters in potentially contaminated water.

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[6] Bacteria-derived muds (e.g. Revert™) are broken down after drilling by adding an acid or chlorinated solution. Such muds may be used for special reasons, which must be documented.

Some drills require the use of air instead of water or drilling mud. Contact between groundwater and air can lead to contamination, or temporarily alter the physicochemical conditions of the groundwater. Air can transport VOCs and foreign substances (dust, droplets of lubricating oil) and can oxidize chemical compounds like nitrites and sulfides. The presence of air can also liberate any VOCs that may be in the groundwater. To limit the presence of foreign substances, special filters can be installed on the air compressors. You should therefore ensure that such filters are present and effective. Sometimes a foaming agent is mixed with the air to enhance the recovery of drilling residues. Such foam can however infiltrate into the formation, contaminating the groundwater.

2.1.2.6. Creation of preferential flow paths and vertical transfer of contamination

Vibrations caused by drilling operations can alter the structure of the soil, creating or expanding fissures and planes of weakness, thereby inducing preferential flow paths for groundwater. This modifies the hydraulic conditions around the well. As much as possible then, care should be taken to minimize vibrations, fracturing and the high-pressure insertion of fluids, to avoid altering the contamination profile near the well.

Also, during drilling there can occur ascending or descending movements of groundwater and liquid contaminants (DNAPL, LNAPL) along the drilling equipment. Such vertical movements of fluid can make an uncontaminated horizon appear to be contaminated, and vice versa. Developing the well (see section 2.1.4) will minimize these effects.

2.1.2.7. Interception of a layer of immiscible liquid

Immiscible (non aqueous phase) liquids are called either light (LNAPL) or dense (DNAPL) depending on whether their specific gravity is less or greater than that of water.

When the presence of immiscible liquids is suspected, detected or observed, special attention must be paid during drilling. Normally, when DNAPL is suspected, drilling should not be done in that zone. There is a very real risk of accidentally piercing a thin horizon on which DNAPL has accumulated. Before taking a chance, one should have an excellent knowledge of the geology of the site and exercise great prudence. It is absolutely critical to avoid precipitating any downward migration of DNAPL as a result of drilling.

Ill-advised drilling can propagate contamination by:

i) creating a preferential flow between naturally isolated layers, via the borehole;

ii) drawing contaminants more deeply into an aquifer by using equipment that has been soiled by drilling through a contaminated horizon;

iii) propagating contamination during development.

LNAPLs form a floating phase at the surface of the water table, with a plume of dissolved contaminants below that is transported by the flow of groundwater. To characterize this plume, the screen should be installed in the upper saturated part of the aquifer.

To determine the thickness of the floating phase (important when preparing a site restoration program), the screen must be sufficiently tall and suitably positioned to accommodate seasonal fluctuations in both the height of the water table and the thickness of the capillary fringe. The goal is to ensure that the LNAPL atop the water is always and entirely within the screen interval.

As for DNAPLs, they migrate downwards by spreading out in the form of immiscible droplets imprisoned within the geological formation. The downward flow of DNAPL continues until the emission either encounters a formation of lower permeability or is entirely converted to residual form. The topography of a layer of lower permeability has more impact on the migration of DNAPL than it does on the flow of groundwater. Migration of DNAPL can therefore occur at a different speed than the flow of water, and may even sometimes go in the opposite direction. The entire zone affected by DNAPL can be the long-term source of a plume of solubilized contaminants. The design of an observation well must take all this into account if its objectives include measuring the level or thickness of DNAPL. In particular, the bottom of the well must be at the level of the layer on which the DNAPL has accumulated (neither above, nor below) and there must be no gravel packing below the screen. When drilling in formations contaminated by DNAPL, every precaution must be taken to avoid creating a preferential flow path that could propagate contaminants further down.

Details on measuring the level and thickness of immiscible liquids are given in section 3.3, while sampling them is discussed in section 5.4.

2.1.2.8. Drilling residues

For proper control over factors that could impair the quality of samples, the use of drilling residues or other "pit run" material in construction of the well is to be avoided. Any deviation from this rule should be well documented. Among other things, such a practice could displace contaminants located on or below the surface toward the horizon of interest, thereby spreading the contamination and distorting the analysis results. Furthermore, the presence of pit run in the upper part of a borehole could promote the creation of preferential flow paths.

To avoid contaminating both the environment and samples, the drilling residues, water extracted during drilling, and water extracted during development and purging, must all be carefully managed.

The general procedure for managing residues must be adapted to each particular case and applied in accordance with the regulations in force (see Appendix 1 of the *Guide de caractérisation des terrains*). In particular, drilling residues, which must be assumed to be contaminated, must be safely stored until the soil analysis results are available. If the latter indicate no contamination, the residues can be left on-site without treatment. In the opposite case they must be managed in the same fashion as contaminated soils. If necessary, the water from drilling (settled sludge), development and purging should also be stored until analysis results are available. Water whose contaminants are all governed by municipal standards can be emptied into municipal sewers, but only if no concentration exceeds an emission standard. To be discharged untreated into the environment, such water must meet MDDEP criteria for surface water quality. In all other cases it must be treated or disposed of in an authorized location, unless some other mode of action is specifically authorized by the MDDEP.

2.1.3. Surface protection

For protection from debris, breakage and vandalism, the upper part of an observation well must be capped by a protective casing with a locked or sealed cover. Depending on the location (street, parking lot, service station, field, etc.), the protective casing can end either at or above the level of the ground. Where necessary, it should be further protected by one or more bollards (barrier posts) and have a flag or some other means of locating it quickly. Observation wells should be identified as such to avoid confusion with other underground facilities.

When the protective structure is installed below ground level, it must be watertight (figure 2). It is recommended in these cases to install a watertight well cap on the casing. As well, a sealing joint must be installed between the cover and the protective casing.

When the protective structure extends above the ground, a small mound should be built around it to prevent any accumulation and infiltration of runoff water.

2.1.4. Development

The first purpose of well development is to remove fine particles from the vicinity of the well screen, gravel pack and within the adjacent formation. It also serves to flush out any fluids that may have been introduced during drilling, so they will not interfere with water quality analysis. Particularly thorough development is needed if a significant amount of drilling fluid was injected. Finally, development serves to restore, partially or entirely, the hydraulic properties of the formation (which were altered during drilling), and to improve those of the gravel pack, thus optimizing the circulation of water between the geological formation and the well.

If sealing plugs were installed within the groundwater interval, it is recommended to wait at least 24 hours before starting development to allow the bentonite and cement/bentonite grout enough time to set solid. Development must then continue until the water removed is visually free of particles in suspension (photo 1) or at least stable in degree of turbidity. The duration of development will depend on various factors, including the method chosen. The water pumped out must be managed with the assumption that it may be contaminated (see section 2.1.2.8).

In formations with a high proportion of clay, silt or very fine sand, development must be done carefully. If it is too vigorous, turbidity could be increased with no improvement in water flow toward the well.

Overly vigorous development can also impair the integrity of sealing elements. If no gravel packing was installed around the screen, strong development could pull material around the screen.

Throughout the development process, it is important to record the drawdown and recovery characteristics observed. This information will guide the choice of the most suitable methods of purging and sampling (see section 3). Return to equilibrium (the static level, initial natural flow and geochemical equilibrium) must be achieved before any sampling is done. This can take several days or longer, depending on the characteristics of the geological formation intercepted (porosity, permeability, hydraulic gradient, fracturing, etc.). The supervisor of the sampling campaign must decide how long to wait before sampling.

The main methods of development for observation wells are pumping and surging. Using a bailer increases the risk of development being incomplete if not continued long enough, though it lessens the risk to sealing integrity. Development methods that require the introduction of chemical substances must be ruled out entirely.

Photo 1. Visual observation of the absence of particles in suspension (MDDEP, 2006)

2.1.4.1. Surging

This operation consists of moving a surge block up and down in the well to push and pull water through the screen. For short screens that are completely submerged (less than 1.5 m long), there is no need to operate the surge block in the screen interval; surging just above it should be sufficient. For longer screens or those that are only partly submerged, the surge block is lowered to the top of the screen (or of the water, in the case of partial submersion) and pumped up and down while gradually moving the action interval further down. Surging should be alternated with bouts of overpumping to remove any particles drawn through the screen. This will prevent the surge block from jamming, improving its effectiveness and avoiding the risk of breakage caused by an accumulation of sediments.

Surging movements must be slow at first, increasingly gradually as development proceeds. If too vigorous, the screen or casing could be broken. Manual or mechanical agitation of the surge block is workable for most observation wells whose casing is no more than 100 mm in diameter. The method is similar to that used for developing steel wells with a cable drill.

2.1.4.2. Overpumping

Overpumping consists of pumping out water at a higher rate than the well can supply. The pump is then stopped until the water returns to its initial level. The cycle is repeated several times until the water is free of sediments. To avoid jamming the pump with particles (or altering the characteristics of the well), the exercise must begin with a reduced flow that is gradually increased. If the pump has no check valve, a surging effect can be produced in the screen interval by repeatedly starting and stopping the pump.

2.1.4.3. Combination of overpumping and surging

It may be possible to surge and overpump the well simultaneously. Development will then be more effective, because sediments are evacuated as fast as they are drawn into the well by the action of the surge block. Inertia pumps, with or without a development ring, are often used for this purpose.

2.1.4.4. Air-lift

Systems that use a jet of filtered air should not be used, as they can alter the physicochemical properties of the groundwater around the well. An air-lift system with double tubing could be considered, however. The system must be properly set up to prevent any air circulating outside of the tubes, especially at the screen. An explanatory diagram of such a system may be found in standard ASTM D5521-05.

2.1.4.5. Hydraulic jetting

Hydraulic jetting systems are not recommended, because they can modify the physicochemical properties of the groundwater around the well, especially if the screen intersects a horizon of low permeability. If the method is used anyway, all water added to the well during drilling or development must be thoroughly evacuated before sampling begins.

2.1.5. Abandonment

As a precautionary measure, when an observation well will no longer be used it should be closed – filled and sealed. If this is not done, the well could provide an entry for surface contamination, or allow water to migrate between horizons that previously were hydraulically independent. Either occurrence would make the well a threat to groundwater quality. A diagram of the closure of a cased well is provided in the *Guide d'interprétation technique du règlement sur le captage des eaux souterraines*.

2.2. Preparation for sampling

This section describes precautions that should be taken before and during sampling to ensure the quality of samples and facilitate the interpretation of analysis results.

Generally, if only one set of equipment will be used, sampling should begin where the least amount of contamination is expected, progressing to where the most is expected. This approach will reduce the risk of cross-contamination from one point to another.

Sometimes the location of the source of contamination is unknown, making it hard to determine the best sampling order. Analysis results from the first sampling campaign will reveal which wells have the most contaminated water, and from this, the optimal sequence for subsequent campaigns can be deduced.

Sampling order is of less importance when dedicated equipment is used. Also, when the same equipment is used for purging and sampling just one well, the risk of cross-contamination is much less.

2.2.1. Cleaning equipment

Cleaning procedures depend directly on the nature of the parameters being monitored. Equipment must be sufficiently clean that samples can be analyzed at the relevant concentrations without any risk of false positives. In that sense, though the procedures can vary they must reduce exogenous contamination to below detection limits for the analytes of interest. If cleaning blanks or field blanks turn out to give positive analysis results, the protocols should be adjusted for subsequent campaigns, and analysis interpretations must take this into account. The supervisor will have to decide whether to continue the current campaign or start over, a matter of professional judgment and the possible impact on objectives. Inadequate cleaning procedures can compromise the representativeness of samples. Refer to *Cahier 1 – Généralités* for the basic principles that must be respected when cleaning sampling equipment.

While cleaning can be done in the field, periodically a complete cleaning should be done in the laboratory. It is easier in the laboratory to completely disassemble the equipment, let it soak as long as needed, and manage the cleaning water. Since non-dedicated equipment will be cleaned frequently in the field, it must be easy to disassemble and clean.

Equipment that is not dedicated should be easy to disassemble and to clean. Sampling equipment must be inspected before each campaign. It must be free of damage, stains, mold and encrusted sediments. If any such imperfections are found the offending item must be replaced. All seals and couplings must be in good condition, with no missing parts. Before going into the field, make sure everything is working properly.

Sample collectors will not have to wash or rinse containers if the laboratory provides them, in which case they are expected to be contaminant-free. However, when communicating with the laboratory the supervisor should take care to specify needs clearly, particularly for anything requiring special treatment.

For example, a composite or filtered sample may require the use of intermediate containers, in which case the latter should ideally be provided for each sampling point (if not, they will have to be cleaned following the recommendations in *Cahier 1 – Généralités*).

2.2.2. Preservation agents in sampling containers

Depending on the laboratory and the specifications on the order, sample containers will be provided with or without preserving agents. In the latter case they may have to be added in the field. See *Modes de conservation pour l'échantillonnage des eaux souterraines* for the quantities to use. Adding preserving agents in the field requires extra care due to the risk of spills, broken bottles, wrong doses, omissions, etc. Also, care must be taken to avoid contaminating equipment with preserving agents in the bottles. Containers without preserving agents should always be filled first[7], keeping the tube outside the container. If preserving agent touches the tube, the part that came into contact should either be cut off or decontaminated. Subsequently, if unexpected results are returned the procedural review should include considering whether the tube must be replaced.

If the containers already have preserving agents, care must be taken when sampling to avoid overfilling, since any spillage would lose some of the preserving agent. If preserving agents were added in the field, the pH must be checked after filling in case adjustment is needed to the amount of preserving agent. All of these details should be documented and sent to the laboratory with the samples. If sampling for VOCs, since the container stoppers are semi-permeable the containers should not be stored where VOCs are present, and a transportation blank is required to validate that aspect.

As a precaution, sample containers should never be placed on a contaminated surface, in a contaminated environment or on the ground. Even preserving agents can be a potential source of contamination, since they may contain certain analytes sought. A complete list of preserving agents is given in *Modes de conservation pour l'échantillonnage des eaux souterraines*.

2.2.3. Planning the preservation and transportation of samples

Once they have been collected, groundwater samples must be conserved following the guidelines in *Modes de conservation pour l'échantillonnage des eaux souterraines*. They must be properly packed to avoid breakage during transport, then shipped to the laboratory as soon as possible and within the time limit given in the guidelines. The equipment required and provisions to be taken must therefore be planned accordingly.

2.2.4. Seasonal considerations

Sampling protocols often plan for several campaigns per year, ideally taking into account seasonal variations in hydrogeological conditions, such as minimum flow and recharge conditions, or seasonal contamination (e.g. from agriculture).

Well design and sampling protocols must therefore be suitable for all parts of the year that will be targeted by the campaign.

[7] When multiple containers are provided with preserving agents, the laboratory should be asked if they must be filled in a specific order.

In particular, one should bear in mind that wells may be hard to access in certain parts of the year. In winter, wells could be covered by snow or ice, or water in the wells could partially freeze. In wetlands or areas prone to flooding, wells may be difficult to access in spring or summer.

Certain sampling methods are also less suitable in hard weather; for example, intense cold would make low-flow purging and sampling very tough indeed unless a heated shelter was used. The point is to avoid having to change sampling methods once monitoring is underway (see section 4.1).

2.2.5. Possible alterations of the sample

The representativeness of a sample can be altered both during collection and during shipping.

First, fine particles in suspension not only increase turbidity but can impact a sample's integrity. For example, some contaminants may be adsorbed onto particles or part of their crystalline structure, without necessarily being mobile. Also, certain preserving agents can dissolve fine particles. The analysis results on contaminant concentrations would then be unrepresentative of the real quality of the groundwater (section 3.7).

Certain parameters can vary with changes in temperature and pressure. For example, when a sample is recovered from great depth the change in pressure is substantial enough to change the equilibrium conditions. In all cases, it is important to take strict precautions when collecting, conserving and shipping samples. As explained in *Modes de conservation pour l'échantillonnage des eaux souterraines*, samples should be kept at around 4 °C until they reach the laboratory.

Careless handling magnifies the risk of contamination (contact with dust, hands, a reactive product in another sample, polluted air, etc.). For example, the least soiling of the neck of a sample bottle will lead to false results if microbiological analysis is done.

For the analysis of volatile compounds, contact with the air is to be avoided as much as possible, to prevent both atmospheric contaminants from getting in and dissolved contaminants from getting out. The sampling method used must therefore be one that minimizes drawdown and contact between the air and samples.

Another cause of contamination can be the ill-advised choice of sampling or shipping equipment. The wrong sampling equipment can give rise to adsorption (e.g. of organic substances onto PVC) or alternately desorption (e.g. through the corrosion of metallic materials). It is therefore essential to choose the right equipment for both the parameters of interest and the environment in which it will be used (see *Modes de conservation pour l'échantillonnage des eaux souterraines*).

Note that when the parameters of interest are photo-sensitive (especially PAHs and fluorescent tracers) it is critical that the samples be protected from light.

2.3. Health and safety

This section focuses on two aspects of health and safety: the presence of gas when drilling and in completed wells, and the responsible management of drilling residues. General guidelines on safety measures are described in detail in *Cahier 1 – Généralités*. Reading the health and safety section is recommended before any sampling work is done.

Remember that whenever the presence of VOCs is suspected, care must be taken to limit respiratory tract exposure to volatilized compounds.

2.3.1. Presence of gas in an observation well

This section does not concern gas sampling, but rather the problem of the presence of gas in an observation well devoted to sampling groundwater.

If the presence of gas is suspected, the well must be ventilated to prevent any potential accumulation of gas and allow the water level to follow atmospheric and hydraulic pressure variations. To prevent surface water from entering the well through a vent, the protective casing must extend above the ground (see section 2.1.1.1). Keep in mind that in winter, ice formation due to condensation or other phenomena could obstruct the vent, allowing gas to accumulate.

2.3.2. Organic vapours – explosive gases

As a safety measure, as well as to guide drilling operations and assess the environmental conditions in the aquifer, concentrations of explosive gases (methane), hydrogen sulfide and organic vapours can be estimated as work progresses. Such measurements could also be taken before purging, as a precaution. Explosive gases can be detected using an explosimeter (see *Cahier 1 – Généralités*). As well, concentrations of total organic vapours can be measured with several types of devices, including FID, PID (e.g. MiniRae™, Hnu™, Photovac™) and OVA detectors. If concentrations of specific organic compounds must be measured in the field, this can be done using a portable gas chromatograph.

These devices are sensitive and hard to calibrate however; they must be used by qualified, experienced people for results to be conclusive.

2.4. Planning field documentation

Every step in a sampling campaign must be documented in the appropriate manner. Negligence in reporting certain information could significantly hamper the interpretation of results, diminishing their credibility.

The field data compiled during each stage of a sampling project must give a precise reflection of the field conditions, both to enable correct interpretation of the data and so that a representative environmental portrait can be drawn.

The supervisor of the campaign must carefully plan the fieldwork to be done, indicating the work methods to be used and the data to be collected and interpreted. It is his responsibility to determine the level of detail to provide at each stage of a project.

2.4.1. Work program

Regardless of the type and scale of the project, the campaign supervisor should produce a detailed work program for the fieldwork to be done, including a description of project objectives and any other information relevant to conducting the work. This program should be given to the person in charge of fieldwork. It will also serve as a reference document when the final report is written.

2.4.2. Field notes

On the work site, it is best to use forms or a field notebook, since this allows all the data to be compiled subsequently in a complete and organized manner. The medium chosen can be customized to the needs of the project at hand.

2.4.2.1. Daily report

Fieldwork is carried out according to the work program. A detailed daily report should be written so that every step in the work accomplished can be followed chronologically.

2.4.2.2. Drilling report and installation plan for an observation well

The drilling method, stratigraphic description and details on each installation (in particular the elevation at ground level and at the top of the casing, the quantities of materials used and the calculations of corresponding volumes) must be provided in a drilling report. When all this information is put together, it will facilitate interpretation of the data. Information in the drilling logs will also be used later in writing the report. An undocumented observation well is not a reliable source of data.

2.4.2.3. Documentation of well development

After installation and before the first samples are collected, observation wells must be developed. Since the data collected during development (drawdown levels, recovery speed, etc.) is subsequently used to plan the sampling, every step in development should be properly documented and included in the final report.

2.4.2.4. Documentation of preparatory tasks

Prior to sampling groundwater, various preparatory tasks must be accomplished to decontaminate equipment and material, calibrate instruments and inspect the condition of each well. Each of these tasks should be documented, since failure to perform any one could impair the quality and credibility of the analysis results.

3. SAMPLING

This chapter presents the methods considered by the MDDEP to be suitable for collecting samples that are as representative as possible of their environment. No one method is favoured over another, since which is best will always depend on the context.

The supervisor of the sampling campaign should carefully consider the particular features of each technique, to choose the one most suitable for the context in which samples will be taken. Factors to consider include the type of equipment required, the analytes targeted, their sensitivity to turbidity, degassing and the presence of air, the duration of monitoring, the seasons in which sampling will be done, the geographical remoteness of the sampling site, the management of purge water, the handling required, and the calibration sensitivity of any measuring instruments used.

Choosing the wrong method could result in having to change in midstream, when monitoring is already underway (see section 4.1). This is to be avoided as much as possible; because different methods are not equivalent, and the analysis results for samples collected using one could be different from those using another.

Depending on the sampling method chosen, greater or lesser volumes will be drawn from the aquifer. Also, a sample is not always taken instantaneously. The sample will therefore be representative of a certain combination of values for a greater or lesser volume of the aquifer, or of the quality of the water right at the sampling point, or of a combination of concentrations over a given period, or of an instantaneous measurement. Thus, only double sampling over successive campaigns, using two methods in parallel, can indicate whether they give different results, and if so, how constant the differences are (see section 4.1).

3.1. Inspecting the well

Before sampling begins, the well must be inspected. This is done to ensure the following in particular is checked:

- the structural integrity of the well (good condition of the internal casing: no cracking, deterioration or breakage; accuracy of the elevation given for the measuring point) and the well's protective equipment (no signs of vandalism);
- the integrity of the well's surface seal (no indications that surface water might have entered) and the absence of water around the well (especially for wells installed at ground level).

If the well is in poor condition, if its protective cap or surface seal is defective, if particles have accumulated at the bottom of the well or microbial growth is observed, the decision to proceed must be questioned.

Clogging of the screen due to precipitation, sanding-up or microbial growth can impede the circulation of water between the aquifer and the well. Water in the well would then be less representative of the water in the aquifer. In this situation, development methods (section 2.1.4) should be used to attempt to clean the well.

If fresh development is not effective, the best solution may be to replace the well instead of trying to rehabilitate it, which might only be temporarily effective. In any well with a tendency to become clogged, cleaning should be performed regularly. As with the initial development, after cleaning is done the well must be allowed to return to equilibrium before samples are collected.

3.2. Measuring water levels

On arriving in the field, it is good practice to record the water level in each well (Photo 2), doing so for all wells within as short a time as possible to reduce the effect of potential barometric or tidal variations. The knowledge, precision and reliability of the elevation of the measuring point (usually the top of the casing leading to the screen, not the protective casing) are crucial for the interpretation of hydrogeological conditions.

For unvented wells and wells installed at ground level, a stabilization period must be left before recording water level, depending on the permeability of the formation concerned. Also, when there is tubing inside the casing that has to be removed first, a stabilization period must be left before measuring the water level.

Sampling campaigns are often accompanied by permeability tests. For performing and interpreting such tests, see the *Guide des essais de pompage et leurs interprétations* and standard CAN/BNQ 2501-135. As much as possible however, one should avoid falling-head permeability tests (in which water or a foreign object is added to the well) in favour of rising-head tests (in which water is removed).

The quality of water level data is essential, since it will be used to deduce the direction and speed of groundwater flow and eventually their variations in time. Electrical sensors (with automatic recording for timed measurements) are the instruments of choice for measuring water pressure above the sensor. Before each use, the sensor and the graduated tape for manual measurement must be cleaned using the recommended procedures in *Cahier 1 – Généralités*.

Note that if immiscible phases are present, or if the density of the water column is greater than 1 (as with salt water), an equivalent head in water depth must be calculated to obtain the level of the water table. Due to the lack of precision however, it is not always meaningful to use equivalent head values for calculating the hydraulic direction of groundwater flow.

Photo 2. Initial measurement of water level in the observation well (MDDEP, 2006)

3.3. Measuring the level and apparent thickness of LNAPL and DNAPL

If contaminants bound to immiscible liquids are detected in high concentrations, it may be necessary to rethink the drilling campaign. Otherwise, there is a risk of creating preferential flow paths that would make the situation worse.

3.3.1. LNAPL

This category of contaminants includes a whole range of petroleum products, coal distillates and chemical and organic compounds. The most familiar petroleum products are gasoline, diesel, oils and fuels, while the most common chemical and organic products are acetone, alcohols and organic solvents. All are relatively easy to detect and sample, since their migration in the immiscible phase is limited to the surface of the groundwater, and some have a noticeable smell. On the other hand, their migration in the vadose zone is more complex. Many of their components are only weakly water-soluble, but some compounds (benzene, toluene, ethylbenzene and xylene) are somewhat soluble, while others (alcohols and solvents) are highly soluble.

To detect the presence of LNAPL, the screen interval must straddle the surface of the water. The thickness of LNAPL as measured in an observation well is called the apparent thickness, since it is generally much greater than the real thickness of LNAPL in the floating phase.

Different methods are employed to measure thickness, the most common being to use an interface sensor, which emits different sonic and visual signals on contact with hydrocarbons, then with water.

Another method is to use indicator pastes for hydrocarbons and for water. Indicator paste can measure smaller thicknesses than some sensors (a few millimetres), but the pastes are specific to certain compounds. Note that if the LNAPL must be sampled (see section 5.4), this should only be done after waiting for a return to equilibrium, assuming that its thickness was measured first. A transparent bailer with ball valve can also be used for visual detection of LNAPL, since when it is merely a film or iridescence it can be hard to measure.

3.3.2. DNAPL

DNAPLs include chlorinated organic solvents (e.g. trichloroethylene, tetrachloroethylene, trichloroethanes, dichloromethane and pentachlorophenols), coal byproducts such as creosote and tars, polychlorinated biphenyls (PCBs), certain pesticides, and complex mixtures of chemical and petroleum products and coal derivatives. DNAPLs can give rise to plumes of groundwater contamination through the dissolution and entrainment of compounds in the pure state or at residual saturation.

When DNAPLs accidentally enter into the soil, they migrate through the vadose and saturated zones until they encounter an impermeable barrier. They can be extremely difficult to track in complex geological formations, particularly fractured formations. When DNAPLs are present in an observation well, depending on the contaminant, some of the methods for measuring LNAPL level and thickness may be applicable. The thickness measurement obtained will not necessarily represent the real thickness. When the purpose of a well is to measure DNAPL level and thickness (especially in a phase 3 characterization[8]), the well must be built so that the bottom of the screen is exactly at the top of the impermeable horizon on which the contaminant has accumulated.

3.4. Equipment

Sampling devices fall into two main categories: samplers and pumps. They may be dedicated to a single well or not. The decision to use dedicated equipment will be based on several considerations, including the intended number of sampling campaigns, the difficulty of decontaminating the equipment, the sensitivity of analytes to the presence of suspended matter, and the accessibility of sampling points.

Theoretically, dedicated equipment allows purging times to be shorter, produces more reproducible results, and reduces the risk of cross-contamination. Ideally, each sampling point should have its own sampling equipment. But excellent results can also be obtained using non-dedicated equipment, provided adequate precautions are taken during handling, decontamination and use.

The choice of equipment is directly linked to the choice of sampling method (see sections 3.5 and 3.6). Much depends on the hydrogeological conditions and the contaminants to be monitored: no device is suitable for all conditions and contaminants.

Research and technology are evolving rapidly in this field, so there are always new measuring and sampling devices coming onto the market. The following paragraphs do not attempt to

[8] C.f. *Guide de caractérisation des terrains contaminés*.

describe them in detail, but rather to outline their principal characteristics. The reader must refer to the manufacturer's instructions for complete information on how to use them effectively.

3.4.1. Pumps

When a generator or other motor is used to drive the pump, it is important to ensure that exhaust gases, dust, gasoline etc. are not allowed to contaminate either samples or sampling materials.

3.4.1.1. Inertial pumps

Inertial pumps work by the following principle: on the down-stroke, water enters a tube, where it is trapped on the up-stroke by the check valve on the bottom of the tube. By repeatedly oscillating the tube up and down, water is brought to the surface.

Usually the tube is made of flexible polyethylene, but it can also be Teflon™ or aluminum. High-density polyethylene is preferable to low-density because the latter is too flexible, breaks easily and can adsorb certain organic contaminants.

Inertial pumps are available in a variety of materials and diameters. They can be used in casings as small as 2 cm in diameter and have several advantages. They are easy to use, reliable, portable and need no particular maintenance. They can be used to a depth of 40 to 60 m. They can be used as dedicated equipment for purging and sampling observation wells.

The main disadvantages of inertial pumps are 1) the turbulence caused by the movement of the tube in the well, which constantly mixes water from the stagnant water column with water drawn from the aquifer; and 2) the wear caused by the tube rubbing against the walls of the well. Also, if the well was not developed correctly, the check valve can clog. The cyclic displacement of the tube can significantly increase turbidity and aerate the water column, potentially distorting the concentrations of various parameters, including VOCs, dissolved gases, trace metals, and hydrophobic contaminants sensitive to suspended matter. What impact these factors may have on the results must be carefully evaluated. To minimize agitation when collecting samples for VOC analysis, one can stop pumping and insert a smaller-diameter tube into the tube from the pump. This method uses the siphon effect, reducing turbulence and contact between sampled water and the air.

3.4.1.2. Suction systems (peristaltic and hand-operated vacuum pumps)

Suction-based sampling systems use negative pressure to withdraw water from the observation well. The vacuum can be applied from the surface using a hand-operated pump or a variable-flow peristaltic pump (photo 3). These methods are limited to wells where the water level is less than 7 m from the surface (or from the top of the external casing). Provided that is the case, the base of the tube can be lowered all the way down to the screen, so that water is drawn directly from the aquifer and the stagnant water column is left undisturbed.

The tubing used for these methods is generally rigid or semi-rigid. When a peristaltic pump is employed, a small length of flexible, durable tubing (up to 1 m) is connected at the top for insertion into the pump's squeeze roller assembly. All tubing must be chemically compatible with the analyses to be done. Each well can have its own dedicated rigid or semi-rigid tubing and small flexible section.

Make sure there is no air in the tubes and that the bottom part is always positioned in the saturated zone.

Photo 3. Example of peristaltic pump (MDDEP, 2010)

3.4.1.3. Variable-speed submersible pumps

Submersible pumps are electric pumps with a controller to vary the flow (photos 4 and 5). This category includes centrifugal turbine pumps. Some of them can operate at rates ranging from 6 l/h up to more than 1800 l/h, depending on depth. They can be used as dedicated sampling systems or for developing and purging. When not dedicated to sampling, cleaning them can be a long process (dismantling the pump and cleaning all parts, including the electric cord).

Some of these pumps use the pumped water to cool the motor, so a certain minimum flow is needed for them to operate properly. This increases the water temperature, which along with the risk of cavitation and corrosion should be considered when choosing such equipment, especially if the analysis will include parameters that are sensitive to such effects (e.g. VOCs and other dissolved gases, hydrophobic contaminants, metals, etc.).

Also in this category are gear pumps. This type of pump can provide flow rates ranging from less than 6 l/h to more than 500 l/h depending on depth, and works well in a variety of situations for sampling groundwater.

Other pumps in this category are used less frequently, such as helical rotor pumps.

Since these pumps push the water by exerting positive pressure, they generally do not cause significant degassing of the water sampled.

Photo 4. Example of submersible pump (MDDEP, 2008)

Photo 5. Example of submersible pump (MDDEP, 2007)

3.4.1.4. Positive-displacement systems

Methods using positive displacement are based on mechanisms that exert pressure directly on the water using gas-lift, a piston, a turbine or a pulsing diaphragm. These methods allow water to be sampled at depths as great as 1000 m. Of all the methods of sampling by positive displacement, the diaphragm pump is the recommended system, except in the presence of DNAPL.

Gas-lift systems apply gas pressure on a column of water, forcing it to rise to the surface through a collecting tube. To avoid altering the chemical composition of the water, nitrogen should be used since it is relatively inert.

Positive displacement systems also include submersible piston pumps as well as flexible membrane systems (diaphragm pumps and bladder pumps).

In principle, flexible membrane systems give samples that are more representative than gas-lift systems since the gases used do not come into contact with the water. Contrary to submersible pumps (piston pumps and turbine pumps), flexible membrane systems agitate the water less, making them more reliable for sampling volatile and hydrophobic compounds, metals, etc.

3.4.2. Passive samplers

Passive samplers are used without any need for purging (see section 3.6). Being single-use equipment, they do not require any cleaning. The volume of water recovered is relatively small, so they may be insufficient for complete execution of some analytical programs. Passive samplers can be especially useful in formations of low hydraulic conductivity. Whether they are appropriate for the analytes sought must be determined on a case-by-case basis.

3.4.2.1. Grab samplers

These devices allow the recovery of water without purging, by capturing samples without first displacing the water (Hydrasleeve™, Snap Sampler™). Depending on the diameter of the well and the permeability of the formation, after inserting a sampler it may be necessary to let the well restabilize before taking the sample. Grab samplers are generally suitable for measuring most contaminants.

3.4.2.2. Passive diffusion samplers

These systems allow chemical compounds in the groundwater to diffuse through a barrier, such as the walls of a polyethylene diffusion bag (PDB), a regenerated-cellulose dialysis bag, or a Gore-Tex™ membrane. In the first two, contaminants accumulate in the distilled water within the sampler. In the third, they accumulate by adsorption (Gore Module™). All such systems require a wait of several days between putting the sampler in place and removing it, to allow chemical equilibrium to be reached (up to two weeks for a PDB, depending on the diffusion coefficient of the contaminants). Diffusion bags and adsorption devices are designed specifically for measuring the concentrations of certain parameters.

When installed at different depths in the same well, these samplers can indicate the vertical profile of concentrations in the screen interval or along fractured rock. That information, obtained during the first sampling campaign, can then serve to determine the best depth for samplers to be installed during subsequent campaigns. Note however that the water in an observation well can be subject to mixing due to hydraulic or thermal gradients, and a certain homogenization throughout a well can occur through the diffusion of contaminants. The stratification of concentrations in a well is therefore not necessarily representative of the vertical stratification of concentrations in the formation. For these reasons, if a thorough evaluation of the vertical gradient of contamination is desired, the best solution is to install observation wells of different depths (i.e. a well nest).

3.4.3. Bailers

There are many types of bailers. All allow the collection of a small volume of water (on the order of a litre) at a specific depth. They are sometimes used for development or purging. Lowering and recovering the bailer is done manually from the surface, using a cable. Purging must be done first to ensure a representative sample. The agitation caused by installing the sampler in the well can lead to turbidity and degassing in the samples. Also, when the water to be sampled is particularly far down, using a bailer can be laborious.

A bailer is a sampler with a check valve at the bottom end. The tube fills on descending, but when it starts to move upwards the water is trapped inside by the check valve. Bailers are easy to handle and to clean. The sample obtained is not very precise, since a certain amount of mixing can occur when the tube is lowered. Some models have a second check valve at the top end, to prevent any mixing of water during recovery. Bailers allow sampling of LNAPL, and to some degree of DNAPL.

Contact between sampled water and the air must be minimized. For this purpose, depending on the type of bailer employed, there are devices for controlled-flow emptying of the tube from the bottom.

Bailers must only be used as a last resort. They are not desirable for parameters that are sensitive to agitation and oxidation, especially VOCs, trace metals, hydrophobic contaminants sensitive to suspended matter and dissolved gases.

3.4.4. Syringe systems

This technique is no longer in common practice. There are other techniques that can be used.

3.5. Methods with purging

3.5.1. Purging a predetermined volume

This method is based on the principle of purging the well of a previously calculated volume of water, before collecting samples (see installation on photo 6). The purpose is to completely renew the water in the well with water from the surrounding formation. The need for this is two-fold: first, the insertion of sampling equipment can cause mixing of the water column, which would make samples unrepresentative of any one horizon. Second, stagnant water in the well can be altered by contact with the materials, of which the well is composed, by contact with the atmosphere, degassing and biological activity. Purging must allow the renewal of a sufficient amount of water as explained below.

It is important to limit the rate of purging, since a flow rate that is too strong can disturb the hydrogeological system by causing overly high hydraulic gradients, which could distort the results. For example, water could be pulled (with or without contaminants) from layers above and below the layer one wishes to sample. Turbidity could also be generated, which is always to avoid.

Equally damaging in wells where the screen is intended to be completely submerged, excessive drawdown could partially expose the screen to the air, potentially volatilizing gases and oxygenating water in the horizon to be sampled. In theory, the flow rate should not exceed the natural rate of groundwater flow in the formation captured by the screen. In practice this can be hard to achieve, so the rule is to pay close attention to drawdown and keep it to the minimum.

For permeable materials, it is recommended to withdraw a volume of water equal to three to five times the total of the volume of water contained in the well and in the gravel packing. Variations in piezometric level must be measured during purging to avoid overpumping (photo 7). Essentially, the purge rate is controlled by controlling drawdown, adjusting the rate of flow to reduce drawdown until stabilization is attained. The stabilized drawdown and rate of flow can then be used to calculate the hydraulic conductivity of the target stratum (CAN/BNQ 2501-135).

With weakly permeable materials that are not conducive to removing that much water (because recovery would take too long), a sampling method that does not require purging must be used. If you decide a purge cannot be avoided, the stagnant water in the casing above the screen must be emptied at least once; this can be done in stages if necessary, to avoid causing the transmission zone to run dry. Sampling should then be done only after the water has returned to its initial static level. Section 3.5.2 proposes a method of purging/sampling for wells with very low permeability.

Photo 6. Overhead view showing the protective casing, the PVC inner casing and the tubing in position for the purge. Note that the annular space above the ground has been filled with granular material to support the casings (MDDEP, 2006)

Photo 7. Purge of a predetermined volume from the observation well. Both drawdown (note the piezometric probe) and volume pumped (container blank) are controlled throughout the operation (MDDEP, 2006)

3.5.2. Low-flow, minimal drawdown purge

Low-flow purging and sampling was developed in the early 1990s to avoid or minimize the following phenomena, which sometimes occur when purging a predetermined volume:

- stagnant water mixing with water from the aquifer;
- increased turbidity due to the pumping action;
- water being pulled from parts of the hydrogeological formation that are outside the zone of interest;
- the well running dry, exposing part of the hydrogeological formation to atmospheric conditions (potential volatilization of certain contaminants and alteration of the physicochemical conditions of the water);
- poor reproducibility of results.

Besides reducing such problems, low-flow, minimal drawdown purging has the added advantage of reducing the volumes of water that must be pumped, stored, and sometimes treated before disposal. The method is described in standard ASTM D6771.

This method requires a good understanding of the numerous factors that can influence the representativeness of groundwater samples, including the hydraulic properties of the aquifer, the design and construction of the observation well, the characteristics of different sampling and measuring equipment, and so forth. It requires more complex instrumentation and handling than purging a predetermined volume, and both are potential sources of error (e.g. inadequate maintenance of instrumentation).

Low-flow purging is based on the fact that when a well is properly constructed and developed, groundwater will flow naturally through the screen, even in formations of low hydraulic conductivity. The water in the screen is thus constantly renewed, even if the rate is very slow. Depending on the type of geological formation, this method can obtain representative samples of aquifer water at the level of the sampling point.

In wells where the entire screen is submerged, only the water in the casing above the screen is stagnant. This water is in prolonged contact with atmospheric conditions and the walls of the well, both of which can alter its physicochemical conditions. The purpose of a traditional purge is to pump enough water to ensure that all the water in the sampling zone is renewed before sampling begins. In contrast, with low-flow purging the objective is to induce a laminar flow at the level of the screen, from the aquifer toward the well. Stagnant water is not drawn in, and thus is left isolated. Note however that in wells where the screen is not totally submerged, all the water in the well is constantly renewed. Nonetheless, the top of the water column is in contact with atmospheric conditions during the time that it is in the well.

The choice of pump is crucial for the proper performance of low-flow purging and sampling. Any equipment that creates turbulent flow and turbidity must be avoided. Diaphragm pumps and gear pumps are the best choice, though in some cases peristaltic pumps may be used.

It is preferable to use dedicated equipment for purging and sampling by the low-flow, minimal drawdown method. Besides eliminating the need for decontamination, dedicated equipment avoids disturbing the water column since it remains in the well. The time required for purging is therefore reduced, and the results are generally more reproducible. Nevertheless, good results can be obtained with non-dedicated equipment if proper precautions are taken. For example, the pump must be inserted very delicately to minimize disturbance to the water column. Also, once it is in place, one should wait at least 15 minutes, even 30, to ensure that the water column is no longer agitated.

In a well where the screen is totally submerged, the pump must generally be placed at the midline of the screen. Too near the base of the screen, sediments accumulated at the bottom of the well could be drawn into the pump. Too near the top of the screen, overlying stagnant water could get in. As for wells where the screen is not totally submerged, the pump must be placed about halfway between the top of the water and the base of the screen. In some cases however one may wish to position the pump in a more permeable or contaminated horizon.

To induce a laminar flow from the aquifer toward the well, one must minimize the impact of pumping on the aquifer. To monitor that impact, drawdown must be measured, the aim being to keep it as slight and constant as is practical. While the optimal pumping rate will vary from aquifer to aquifer (depending on permeability), flow rates ranging from 6 to 30 l/h are mentioned in the literature.

Once drawdown is stabilized, the following physicochemical parameters should be measured throughout the duration of the purge: temperature, pH, conductivity, dissolved oxygen and oxidation-reduction potential (photo 8). Turbidity measurements can also be useful. Purging should continue until all parameters are stable, noting that dissolved oxygen and oxidation-reduction potential can take longer than the others.

In general, stabilization is considered to be achieved when readings vary by less than the following values for at least 3 consecutive readings:

- temperature: ± 0.2 °C;
- pH: ± 0.2 unit;
- conductivity: ± 3 % of the previous reading;
- dissolved oxygen: ± 10 % of the previous reading, or ± 0.2 mg/L (whichever is less severe);
- oxidation-reduction potential: ± 20 mV.

Sometimes it can be difficult to reach these objectives, especially in aquifers of unconfined groundwater. Interpreting the results therefore requires professional judgment, and any change to the purging protocol should be documented.

As for turbidity, even though it is not a reliable indicator of whether purging is complete, measuring it can be useful. Since turbidity is due to the presence of particles in suspension, it indicates the degree of stress on the hydrogeological formation due to pumping, and can point to a poorly designed or badly installed well. Suspended matter can bias the analysis of metals, hydrophobic organic compounds and other contaminants, so one should aim for low and stable turbidity values. If high turbidity is measured, the pumping rate should be reduced. If it persists, consider developing the well again. The need to measure turbidity and seek low and stable values will depend on the objectives of the study, the analytic program chosen and the degree of quality assurance required. Decisions in this respect require great expertise.

To minimize contact between the water being purged and ambient air, an in-line flow-through cell is required (Photo 8). The choice of measuring devices can have a decisive effect on results. For example, certain devices are sensitive to the rate of pumping and are unreliable at very low flow rates. Between readings, leave enough time for the water in the measuring cell to be completely renewed.

Lastly, sampling must be done directly from the outlet of the pumping equipment, upstream from the measuring cell.

Photo 8. Measurement of physicochemical parameters. The measuring cell is on the roof of the car (MDDEP, 2010)

3.5.3. Minimal purge

Sometimes an observation well must be installed in a formation of very low permeability (silty clay, fine till, etc.). Such wells tend to run dry during pumping, even with a flow rate as low as 6 l/h. Since this can alter the physicochemical properties of the water, the minimum purge method was developed in the mid-1990s to eliminate the problem.

As its name suggests, the minimum purge method consists of extracting as little water as possible. The volume pumped corresponds to the volume of water initially contained in the submerged pump and its tubing. A sample is collected immediately following the purge, on the supposition that once the water in the pump and tubing is removed, the water recovered comes from within the screen and is therefore representative of the hydrogeochemical conditions in the target formation. This method demands either that dedicated equipment be used or that non-dedicated equipment be put in place well ahead of time, in the screen interval, to avoid any perturbation of the water column and any stirring up of fine particles. The wait required between pump insertion and purge initiation will depend on the volume of the pumping equipment, how it is installed, the formation's hydraulic conductivity, and so on. It can vary from a few hours to several days, indeed weeks[9].

Generally, pumping must be done at a rate less than 6 l/h. Even at that low rate, it is often impossible to avoid increasing drawdown. When sampling, pumping must be stopped before stagnant water from above the screen descends to the level of the pump. Take care to leave a margin of safety in this regard. The volume of water available for sampling will depend on various factors, including the length and diameter of the screen, the type of equipment, the hydraulic conditions of the formation, etc. In some cases, there may be too little water available for complete performance of the planned analytical program.

Pump positioning in the well is particularly important with this method. To allow recovery of as much water as possible for sampling, the pump must be low as possible in the screen interval. Avoid placing it too low however, since otherwise sediments at the bottom of the well could be stirred up. A distance of around 0.3 to 0.6 m between the pump and the bottom of the well is generally sufficient.

The minimum purge method does not require the measurement of indicator parameters like temperature, pH, conductivity, etc. However, regular and frequent monitoring of drawdown is imperative to ensure that stagnant water above the screen never reaches the pump. And of course, in a well where the screen is not totally submerged, the pump must be stopped before air can get into it.

The minimum purge method should only be chosen when no other method is possible.

3.6. No-purge or passive methods

Like minimum purging, no-purge or passive methods were first developed in the mid-1990s for sampling groundwater in formations of very low permeability, and also as a way of limiting the amount of purge water to manage when repeatedly monitoring large-diameter wells. These methods depend on the supposition that water in the screen is representative of hydrogeochemical conditions in the target formation. They are relatively simple and reliable, and generally give less turbid samples than methods that involve purging.

In all cases, a stabilization delay must be left between installing equipment and taking samples, to avoid any disturbance to the water column in the well. The wait required can vary considerably, depending on the volume of the equipment, how it was installed, the formation's permeability, the diffusion coefficient of contaminants, water temperature and so forth. It may be a few hours, several days, or even weeks. In the case of passive diffusion samplers, a minimum delay of two weeks should be scheduled. For each device it is best to refer to the manufacturer's instructions, or to the scientific literature for practical guidelines. For many of these methods, no maximum wait time is given.

[9] Another way to obtain representative water is to take a sample of intact aquitard, then extract the water in the laboratory (see section 5.5).

One no-purge sampling method is to use grab samplers. The equipment is installed in the screen, and after a stabilization delay, is made to capture a sample at its exact location. The devices can be used for measuring concentrations of most (if not all) analysis parameters, both organic and inorganic. Generally the method produces good quality, reproducible results. Depending on the type of geological formation, it provides a representative sample of aquifer water at the level of the sampling point.

A second no-purge sampling method is to use passive diffusion samplers (photos 9 and 10). This equipment is installed in the screen interval, where contaminants are allowed to penetrate the device by molecular diffusion; the device remains in place for the entire equilibration period (the time required for contaminants to reach equilibrium on both sides of the container wall). The method provides an indirect determination of groundwater quality without really collecting a sample. These methods were developed primarily for measuring VOC concentrations. Many other contaminants cannot be detected, including inorganic compounds, so it is important to consult the manufacturer's documentation to be sure of what can be measured. A second type of passive diffusion sampler uses regenerated-cellulose dialysis membrane, which does allow both organic and inorganic compounds to be detected. At present there is no supplier for such samplers, but regenerated-cellulose membrane is available on the market, so it is possible to make one's own. Depending on the geological formation, this method can provide an accurate representation of aquifer water at the level of the sampling point. However, if the water quality varied over the course of the equilibration period, the sample will be representative of concentrations over the period as a whole. It will not be representative of aquifer water quality at a given moment.

The third passive sampling method consists of using passive adsorption samplers. The analysis results from this type of sampler correspond to the mass of contaminants adsorbed onto the sampler during the equilibration period, not to the concentration of that contaminant in the groundwater. Consequently, analysis results obtained by this method cannot be compared to standards or criteria that are based on concentrations.

Photo 9. Example of passive sampler: diffusion bags (MDDEP, 2008)

Photo 10. Operation to recover the sample in a diffusion bag: gloves and scissors must be free of contaminants (MDDEP, 2008)

3.7. Filtration of samples

Whether samples must be filtered in the field depends on their purpose. If they are to be analyzed for the dissolved form of a contaminant (to characterize its displacement in the groundwater), filtration is recommended, especially in the case of dissolved metals. If they are to be analyzed for whether the water is good enough to use (especially in the case of drinking water) or to be disposed of into a sewer, the total concentration of the parameter is wanted; therefore the samples must not be filtered. The particular case of metals, where three different forms may be sought (dissolved, acid soluble, total extractable) is detailed in the CEAEQ document *Terminologie recommandée pour l'analyse des métaux*. Samples to be analyzed for volatile and non-volatile organic compounds or dissolved gases must not be filtered.

When filtration is done in the field, it must be performed immediately after collection, using 0.45 μm filters. These will retain most of the silty particles, most of the clayey particles and bacteria, and part of the iron hydroxides and manganese. Organic macromolecules (humic and fulvic acids) and viruses will not be retained.

Polycarbonate filters are recommended since they seem to work with all parameters. The filter (new) should be conditioned by passing through it a fixed volume of the water to be sampled, before filling the sample bottle. A filter can only be used for a single sample. When reusable filtration equipment is used it must be properly washed between sampling points. If a sample cannot be filtered in the field, it must be sent to the laboratory very quickly so that filtration can be done within 24 hours.

3.8. Field notes

3.8.1. Measurements in the field

Both the methods of measurement used and their results must be noted down for later interpretation in the final report. This includes the inspection of the well, measurements of gases, water levels, LNAPL or DNAPL levels, and so on.

3.8.2. Groundwater sampling

All information collected during purging and sampling should be documented. This includes a description of the equipment, the purging and sampling techniques used and their details (date, duration, volume, flow rate, etc.) along with the values of all physicochemical parameters measured in the field. Besides documenting the sampling methodology, this information is critical to the interpretation of groundwater quality.

3.9. Potential reasons for not sampling or for rejecting samples

Any unusual event during sampling that could cast doubt on the representativeness of a sample must be recorded in the field notes and the report (see sections 3.8 and 4.3). This could include an unusual weather event, a minor change to the physical integrity of the well, the presence of water around the well, and so forth.

To eliminate the risk of false interpretation, sometimes samples may have to be rejected and not sent for analysis, especially (but not only) when:

- The integrity of the observation well is no longer ensured.
  A well with a damaged protective cap or surface seal must not be sampled. Generally one must question whether a well that was not deemed satisfactory on inspection should be sampled (see section 3.1).

- The state of the sample is unsuitable for the objectives of the sampling campaign.
  This could be due to the unexpected presence of free phase when the intention is to analyze dissolved phases, the significant presence of suspended matter, etc. Turbid samples must always be considered dubious.

- The sampling procedure was not respected to the full.
  Any deviation from the sampling procedure must be documented, since it could necessitate rejection of the sample. Such deviations would include not following guidelines with respect to collecting the sample, decontaminating equipment, respecting wait times, filtering, adding preserving agent, and so on.

3.10. Description of samples

Information on collected samples should be recorded for each site and sampling campaign, with all such records being signed and dated by the sample collector. This information will be crucial to the accurate interpretation of analytical results. A non-exhaustive list of what should be recorded is given in the following sections, with further details in *Cahier 1 – Généralités*.

3.11. Identification of samples

To be able to keep track of all the samples collected during a campaign, it is crucial that they always be properly identified. Containers can be identified using a self-adhesive label, burin, etc., as long as the marking is indelible (felt pens should not be used in the field). The identification must correspond to a single, properly completed analysis request form, and specify the exact location of the sampling point. If multiple containers are given the same number, the parameters to analyze must be indicated separately on each container. It is good practice to identify not only the bottles, but their stoppers as well. Optional information can also be noted on the containers: the sampling point (e.g. as a code), preserving agents, date, etc.

See *Cahier 1 – Généralités* for more information.

3.12. Preservation and transportation of samples

During transportation or storage, care must be taken to avoid cross-contamination between samples. This can mean physically separating more contaminated samples from those that are less contaminated. Guidelines for the conditions and maximum duration of conservation, for each analysis parameter, are given in *Modes de conservation pour l'échantillonnage des eaux souterraines*.

3.13. Chain of responsibility

The chain of responsibility document contains all the information needed to track samples from the field to the laboratory. It should be prepared as soon as possible, and filled out clearly and unambiguously. There should be enough copies to allow the retrieval of all pertinent information about the sample so the consistency and validity of the results can be verified. All samples sent to the laboratory should appear in this document.

The laboratory as well must sign and date the chain of responsibility document, including the time of reception. A copy should be included in the analysis report.

3.14. Quality assurance and control in the field

A quality assurance and control program is a set of steps to ensure that the results achieved are of satisfactory quality to meet the campaign's objectives. The procedures used in the field for sample collection, preservation and identification, and the procedures used in the laboratory for conservation, analysis and data recording are all equally important for achieving quality results.

3.14.1. Quality assurance

Quality assurance is a set of operating principles that, if properly applied, will obtain data of known and justifiable quality. The goal of quality assurance is to ensure that the data acquired is representative, complete, precise, and obtained in accordance with the rules and procedures in application.

The principle of quality assurance should govern the following elements in particular:

- planning the campaign;
- following recommendations and procedures for the choice of sampling methods and the equipment needed to collect, conserve and transport samples;
- following recommendations and procedures when collecting samples and performing field measurements;
- documenting the work in sufficient detail to verify whether the points cited above were carried out according to the procedures in application.

3.14.2. Quality control

Quality control is a set of technical procedures to ensure and verify the quality of the successive steps of sample collection, storage, transportation and analysis.

Cahier 1 – Généralités describes the types of control samples commonly taken in the field, including blanks (transportation, field, cleaning) and field duplicates.

In a groundwater sampling campaign, the collection of duplicate samples is essential to quality control. At least 10% of samples (at least 1 duplicate per lot) must be taken in duplicate to verify the precision of sampling. The number of parameters analyzed in duplicate must not be too restricted. Duplicates can be sent to the same laboratory or to two different laboratories. In the latter case, it is important to ensure that the second laboratory uses comparable methods of preparation and analysis, and that performance differences are known so the analysis results can be compared meaningfully.

As well, when water samples are collected for VOC analysis, along with transportation blanks there should also be field blanks.

Depending on the specific needs of the campaign, additional control elements for particular objectives can add certainty to the interpretation of results. For example, when non-dedicated equipment is used it may be appropriate to have cleaning blanks, depending on the circumstances.

4. POST-SAMPLING

4.1. Changing sampling method

Ideally, once monitoring has begun the sampling method should not be changed. One should therefore make sure, when deciding which sampling method to use, that it can be continued season after season and year after year if need be, and that it will satisfy long-term objectives.

If it does turn out that the sampling method really should be changed, the justification for doing so must be documented in the report. Also, both methods should be maintained in parallel at certain wells over several campaigns, so their results can be compared.

For this purpose, the parameters analyzed in samples collected by the initial method can be limited to those that are detectable. One can stop using one of the methods when there is sufficient data either to match the results of the new method to those of the old one, or to invalidate the results of the old method. At a minimum, both methods should be pursued together for one full year of monitoring, so that one campaign is during minimum flow conditions and one is during recharge conditions. If necessary the two methods can be maintained in parallel over an even longer period, e.g. to ensure the validity of statistical comparison. Determining the number and location of double sampling points, and deciding when double sampling can stop, should be based on the interpretation of data.

4.2. Quality assurance and control in the laboratory

Analyses performed at all MDDEP-accredited laboratories must meet the requirements of a quality assurance program. See the CEAEQ website for the list of accredited laboratories.

When planning a sampling campaign and choosing a laboratory, it is important to make sure that the laboratory which does the work is accredited by the MDDEP for the parameters concerned. If no MDDEP accreditation exists for a particular parameter, the laboratory that receives requests for such analysis must use a qualified laboratory accredited to ISO/IEC 17025 by a recognized organization.

The laboratory quality control program requires the use and analysis of control samples. Such controls may include field blanks, reference samples (reference materials), procedure blanks and duplicate samples analyzed in the laboratory. It is not the responsibility of the supervisor to prepare such control samples, the latter being the responsibility of the laboratory.

4.3. Study report

The supervisor of the sampling campaign receives all data collected by the fieldwork supervisor. He or she then compiles and interprets them for presentation in a study report. Depending on the project, the raw data gathered in the field as well as the laboratory certificates should both be appended to the field report.

It is up to the supervisor of the sampling campaign to establish the type and structure of the study report. However, the contents of a standard study report should include the following information:

- context;
- mandate and objectives;
- location and description of the site and sampling points;
- review of previous studies (if necessary, i.e. especially if there was a change in sampling method or analysis laboratory);
- work performed and work method, justification of the choice of sampling method;
- results;
  - presentation of quality control results (field blanks, transportation blanks, duplicates, etc.) and interpretation;
  - presentation and interpretation of analysis results;
  - discussion of the impact of the methods used or other factors on the results;
  - discussion of any change in method (if applicable);
  - discussion of how the analysis results evolved (if applicable).
- conclusion;
- recommendations;
  - discussion of the effects of the contamination and actions to be taken.
- references;
- tables and illustrations;
- appendices (analysis certificates, etc.).

5. SPECIAL CASES

5.1. Sampling groundwater in an intake structure

Groundwater flows toward natural springs and resurgences can be drawn from such sources for various uses, can be pumped from sandpits, gravel pits, quarries, tunnels and mines can be collected in drains or sumps under buildings, roads or farmland. Sampling it, is therefore not limited to observation wells, but may be necessary wherever it flows and has an impact on health, ecosystems and the environment.

It is often essential that a drinking water well or intake well for some other use (drainage, heat pump, industrial, cooling, irrigation, pisciculture, fire, etc.) be sampled to evaluate the quality of its water. Unfortunately, intake wells are not designed for the purpose of determining water quality. The results must therefore be interpreted with care, taking into account the construction details and the characteristics of the portion of aquifer intersected by the screen or the open well in rock. When a source of drinking water is contaminated, the Direction de la santé publique will examine the results of samples taken from the supply well. For recommendations on sampling distributed drinking water, see the appendix 4 in the Règlement sur la qualité de l’eau potable (Q-2, r.40).

5.2. Sampling water in the vadose zone

The vadose zone is the portion of the subsoil that is above the saturation line. It is composed of solid, liquid and gaseous phases. Water in the vadose zone cannot be sampled using observation wells described in this document.

There are numerous situations in which sampling the interstitial water of the vadose zone can be crucial. For example, it provides a way of tracking the advance of a contamination front from a point or diffuse source on the surface in order to predict its arrival in the groundwater.

Interstitial water in the vadose zone can be sampled using devices called lysimeters. Several types of lysimeters are available. The decision to use a particular type will depend on the campaign objectives and the hydrogeological characteristics (more specifically its porosity).

5.3. Sampling for a tracing test

Tracing tests are used to characterize the hydraulic behaviour of an aquifer, including hydraulic linkages, the speed of displacement, effective porosity and dispersion.

The four main kinds of tracers are fluorescent dyes, salts, radioactive tracers and biological tracers. This section focuses on the two most common types of tracers: fluorescent dyes and salts.

When working with tracers, it is essential that doses be chosen with care to achieve concentrations in the groundwater that are not excessively high but will still be measurable at the observation well. Second, if drinking water is involved, prior authorization is required from the regional public health authority before tracers can be used.

5.3.1. Fluorescent dyes

The principal fluorescent dyes are uranine, rhodamine WT, sulforhodamine G, etc. Commercially they are referred to as fluorescein, *red dye*, *green dye*, *green/yellow dye* and *orange dye*. Fluorescent tracers are easy to use, but care must be taken to avoid cross-contamination. That is, when preparing to inject a tracer, the product must be handled carefully (especially if in powdered form) to avoid soiling any item (equipment, clothing, skin, etc.) that could subsequently transfer it to containers or samples. As a precaution, when a sample will not be used for contaminant analysis, sample container and lid should be rinsed at least twice with the water to be sampled to prevent any contamination. Another point to keep in mind is that fluorescent tracers can be photodegradable. Samples should therefore be stored away from light as soon as possible; tinted containers are also recommended. Finally, some dyes are affected by pH or temperature, or can be adsorbed by clayey particles or organic matter.

5.3.2. Salts

Salt tracers used include sodium chloride, potassium chloride, ammonium chloride and lithium chloride. They are less sensitive than dyes to physicochemical conditions, but require the handling of large amounts of electrolytes. As with dyes, before taking a sample the container and stopper should be rinsed well with the water to be sampled, and the sample should immediately be stored away from light.

5.4. Sampling immiscible liquids

Sometimes LNAPL or DNAPL must be sampled, whether to determine their exact composition (and thus the potential solubilization of components), identify the source of contamination, or assess the applicability of different rehabilitation methods. Note however that when seeking the concentrations of contaminants in the aqueous phase, it is best to drill boreholes outside of the zone with immiscible liquids, downstream in the direction of groundwater flow. Information about the design of observation wells when immiscible liquids are present is given in section 2.1.

There are several methods of obtaining LNAPL samples from wells, including bailers, check valve hand pumps, and suction pumps (if the LNAPL is at a depth of less than 7 m). If the water table is particularly shallow, grab samplers of the Coliwasa™ or Kemmerer™ type can be used. Ideally dedicated systems must be used, since on-site decontamination of sampling instruments is practically impossible.

Sampling of DNAPL can be done using a check valve hand pump connected to polyethylene tubing. This system too should be dedicated.

With LNAPL as with DNAPL, a sample of sufficient volume should be taken to allow laboratory analysis of the parameters targeted.

5.5. Obtaining undisturbed samples from the aquitard

Obtaining intact samples from an aquitard requires, first, a non-destructive drilling method. A stationary piston sampler with a nominal diameter of at least 7.5 cm must be used, to preserve both the internal structure of the soil and its interstitial water. The borehole from which soil samples are obtained can also serve for installing measurement instruments, which must be perfectly sealed in short filter zones (packed with a very fine sand) separated by long sections of bentonite sealing. These methods are used in clay deposits of very low permeability, where groundwater movement is so slow that traditional methods are inadequate.

Interstitial water in the soil samples is extracted in the laboratory using special low-pressure equipment (less than 700 kPa) to avoid altering the quality of the water. Only small amounts of water can be obtained by these methods, so it is important to make a judicious choice of parameters to be analyzed.

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Appendix

Requirements and recommendations on groundwater sampling are given in various documents issued by the MDDEP and other authorities, including (but not only):

a) Certificates of authorization and depollution attestations granted under the Environment Quality Act.

b) Certain regulations, including the following:

- Groundwater Catchment Regulation
- Land Protection and Rehabilitation Regulation
- Regulation respecting the quality of drinking water
- Regulation respecting the burial of contaminated soils
- Regulation respecting the landfilling and incineration of residual materials
- Regulation respecting pulp and paper mills
- Regulation respecting hazardous materials
- Regulation respecting contaminated soil storage and contaminated soil transfer stations

c) Certain technical or guidance documents, including the following:

- *Politique de protection des sols et de réhabilitation des terrains contaminés,* Les Publications du Québec, 1999, 120 pp.
- *Guide de caractérisation des terrains*. 2003. MENV, coll. “Terrains contaminés”, Les Publications du Québec.
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