FOREWORD

Over the past decade, the assessment of environmental quality has become a more prominent and familiar activity. More recently, there has been an increased emphasis on groundwater quality investigations (including sampling).

The public release of these guidelines contributes to EPA’s broader strategic goal of establishing measures that:

• ensure current contamination of land and groundwater is managed to maximise usefulness of the resource
• protect land and groundwater resources from pollution in the future.

These guidelines aim to assist those sampling groundwater to collect representative samples by:

• highlighting important issues
• identifying objectives and key measures to achieve those objectives
• identifying information and source materials.

Implementation of these guidelines will enable those involved in groundwater sampling to reduce the potential for error, allowing subsequent groundwater management decisions to be based on ‘representative’ groundwater quality data. This is especially important when considering that in the long-term inadequate groundwater sampling can prove to be costly both in terms of environmental and financial outcomes.

These guidelines will be reviewed regularly and updated as necessary on the basis of operating experience. Users are encouraged to provide comment to assist in this review process.

I commend these guidelines to those involved in groundwater investigations and urge their adoption and implementation in the interests of improved environmental performance.
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1. INTRODUCTION

Groundwater is an important resource in Victoria. In addition to being a source of potable water supply, irrigation water, stockwater and water for other uses, groundwater plays a significant role in the maintenance of base flows for many waterways and wetlands. The State Government has recognised the need to protect the quality of groundwater (and its beneficial uses) by declaring the State Environment Protection Policy (Groundwaters of Victoria) in December 1997. These guidelines are produced as part of the implementation of that policy.

In order to protect the beneficial uses of groundwater from pollution, it is important to accurately determine and report its composition. The collection of groundwater samples can be a significant source of error in groundwater quality data. These guidelines have been developed to assist those involved in groundwater sampling to reduce the potential for error, allowing subsequent groundwater management decisions to be based on 'representative' groundwater quality data.

1.1 Statutory framework

Victoria’s environment protection system is based on the Environment Protection Act 1970. The Act establishes the Environment Protection Authority (EPA), defines EPA’s powers, duties and functions and contains a number of instruments to minimise pollution, wastes and environmental risks. These instruments include State Environment Protection Policies (SEPPs), Industrial Waste Management Policies (IWMPs), works approvals, licences and pollution abatement notices, other notices and environmental audits.

The key SEPPs that are directly relevant to the protection of groundwater quality in Victoria include:

- **SEPP (Groundwaters of Victoria) 1997**
- **SEPP (Siting and Management of Landfills Receiving Municipal Waste) 1991.**

The following documents also contribute to the protection of groundwater quality in Victoria:

- the **National Environment Protection (Assessment of Site Contamination) Measure.**
- the draft **SEPP (Prevention and Management of Contamination of Land).** This document is currently being finalised.

1.2 Background and purpose of guidelines

Groundwater sampling and analysis is undertaken to:

- determine background groundwater quality and the relevant beneficial uses of groundwater
- detect any contamination and changes in groundwater quality
- determine the extent and degree of existing groundwater contamination
- evaluate the environmental performance of activities with potential to contaminate groundwater
- assess the quality of an existing or potential groundwater resource.

According to Barcelona (1985), significant errors in groundwater data arise from the methods used in field sampling. It is therefore essential that groundwater sampling is undertaken in a manner that allows subsequent analysis to provide accurate data on which to base groundwater management decisions, including critical decisions regarding the management of contaminated or potentially contaminated sites.
The key objective of this document is to foster practices that will assist with accurate and consistent determination of chemical and biological indicators of groundwater. Such practices will ensure that groundwater samples are representative of groundwater in the aquifer and will remain representative until analytical determinations or measurements are made.

These guidelines reflect current international good practice and provide an outline of the critical issues that should be considered before and during groundwater sampling. They identify objectives and key measures by which the objectives can be met, focus on areas for investigation and identify relevant information and source materials.

Individual components of groundwater sampling should be assessed for their impact on analytical results and the overall sampling technique used should be commensurate with the required sensitivity or use of the data.

These guidelines are suited to activities where a considerable amount of in-field experience and professional judgement are required. As such, they do not provide detailed technical advice and are not intended to be a substitute for technical expertise and professional judgement.

Although these guidelines are not mandatory, the potential exists for regulatory authorities to call up such a document in approvals, licences, notices or permits.

1.3 Who needs these guidelines?

These guidelines are primarily intended for use by those collecting groundwater samples for chemical analysis (ie environmental consultants, officers of EPA and other protection agencies and site owner/occupiers). These guidelines may also be a useful reference for protection agencies that require groundwater sampling to be undertaken by others.

1.4 Additional guidance documents

Other relevant documents that provide information on aspects of groundwater sampling and hydrogeology include:


The two EPA documents, *Hydrogeological Assessments (Groundwater Quality)* and *A Guide to the Sampling and Analysis of Waters, Wastewaters, Soils and Wastes* are referred to extensively. It is recommended that they be read in conjunction with this document.
2. OBJECTIVES OF GROUNDWATER SAMPLING

The primary objective of any groundwater (quality) sampling is to produce groundwater samples that are representative of groundwater in the aquifer and will remain representative until analytical determination or measurements are made.

2.1 Groundwater sampling program

A groundwater sampling program is a document describing the procedures used to collect, handle and analyse groundwater samples to achieve groundwater sampling objectives. A groundwater sampling program should be prepared before sampling, taking into account site specific considerations (eg aquifer type and contaminants).

When designing a groundwater sampling program it is essential that the overall objectives of the monitoring program be established and considered. The objectives of monitoring programs may vary, from long-term groundwater monitoring at landfills or wastewater treatment plants, establishing the status of groundwater contamination at contaminated sites, to determining regional and ambient groundwater quality.

A groundwater sampling program should be scientifically designed and statistically valid. For further information on program design see EPA Publication 668 Hydrogeological Assessments (Groundwater Quality).

2.2 Hydrogeological assessment

Before developing a groundwater sampling program, a hydrogeological desk study should be undertaken (as a minimum).

Ideally, the person responsible for sampling should be aware of the necessary background information to be able to make an informed decision about the sampling program.

The following background information must be obtained and considered as a minimum:

- **Site history**: contaminants of concern and potential for contamination, including, for example, contaminant use, past practices and incident history.
- **Hydrogeological setting**: aquifer type and configuration, groundwater flow directions and rates, vulnerability of the aquifer system to contamination.
- **Previous field investigations**: bore logs, depth and length of screened interval, depth and construction details, past water level measurements.

It is not intended for this guideline to discuss hydrogeological assessments in any detail. EPA Publication 668, Hydrogeological Assessments (Groundwater Quality) should be referred to for further details.
Hydrogeological assessments

Objective
To collect necessary background information in order to make informed decisions about the groundwater sampling program.

Key measures
Undertake a hydrogeological desk study in accordance with EPA Publication 668, *Hydrogeological Assessments (Groundwater Quality).*
3. KEY FACTORS THAT CAN INFLUENCE GROUNDWATER SAMPLES (PRE-SAMPLING)

Drilling, construction and development of bores can have a fundamental effect on the quality of groundwater samples extracted from them, through the introduction of physical or chemical effects or unwanted residues.

Before sampling from a monitoring bore, the impacts of drilling, construction and development need to be understood so that the appropriate sampling equipment and methodology may be selected.

3.1 Drilling

3.2 Drilling techniques

Drilling techniques used for monitoring bore construction need to be carefully considered to reflect monitoring needs. Drilling technique can cause smearing (eg rotary auger) and compaction (eg cable tool) of borehole walls and may also cause transport of geological formation materials and drilling fluids into different zones. This can result in groundwater and contaminant pathway blockage, thereby excluding contamination from the monitored material.

Developing the bore may reduce the impacts of drilling technique – section 3.3 provides more information on bore development.

3.1.2 Drilling fluids

Drilling fluids are generally used during the drilling process to remove cuttings from the borehole, to clean and cool the bit, reduce friction between the drill string and the sides of the borehole and to hold the borehole open during the drilling operation.

Drilling fluids used include air, water and specific drilling mud formulations or native clay slurries. They can have a range of effects on groundwater quality:

- Air may cause oxidation and precipitation of analytes of interest, such as dissolved metals (eg ferric → oxidation → ferrous) or, if contaminated with lubricants necessary for compressor operation, may introduce hydrocarbons into groundwater.
- Air may also cause severe disturbance of hydrochemical profiles in highly permeable formations.
- Water may dilute or flush groundwater near the bore, changing the chemistry of the groundwater.
- Water may also cause precipitation of minerals, thereby blocking contaminant and groundwater pathways (ie pores and fractures).
- Mud may enter the formation and seal preferential groundwater pathways, or clay particles within mud may sorb some electrically charged contaminants (eg dissolved metals).
- The use of additives in mud (eg surfactants and drilling detergents) to overcome drilling difficulties increases the potential for introduction of physical and chemical changes.

Since these effects are frequently permanent, it is important to record drilling method, fluids used and details of bore development before sampling.

3.2 Installation

3.2.1 Casing and screen

Casing and screen materials may be incompatible with the immediate groundwater environment. Incompatible casing and screen material may result in either leaching or sorption of analytes of interest, while desorption of analytes of interest may occur should water quality change. Diffusion of
organics may also occur through polymeric casing materials.

For example, in extreme cases acidic environments may cause corrosion of metal casing while solvents may dissolve PVC casings (Parker 1992; Aller and Gardner 1995) and these may cause:

- immediate effects on water quality in the bore
- potential for water from different depths to migrate along the borehole.

If casing joints are inappropriately constructed, they may cause leakage. Solvent-bonded casing joints, which are prone to solvation, should not be used when sampling for organics (Parker 1992; Aller and Gardner 1995).

### 3.2.2 Annular fill and gravel pack

Annular space is the space between the borehole walls and the casing or screen (see figure 1). The materials used in the annular space include filter pack materials such as gravels and fine sand and seal materials such as bentonite, bentonite/cement mixtures and cement. Any of these materials, when inappropriately used or installed, may alter the chemistry of groundwater entering the bore. Portland cement, for example, may cause a change in pH, while bentonite may sorb dissolved metals.

### 3.2.3 Location of sampling point (screen depth and length)

The location and length of the screened interval of groundwater quality monitoring bores can be vital. Due to the laminar flow of groundwater, contaminated groundwater flows in discrete zones. Poorly placed screens may fail to intercept these zones. Long screens in monitoring bores are known to result in dilution of groundwater samples due to mixing with uncontaminated groundwater, resulting in collection of unrepresentative samples. Ideally, screened intervals should be short and located specifically within the zone of interest. In some investigations, bores may need to be installed at more than one depth in an aquifer to access the extent of vertical groundwater flow and the distribution of contaminants with depth.

Correct location of the screened interval is especially critical when dealing with aquifers polluted with non-aqueous phase liquids (see section 4.14). Representative samples for analysis of dissolved phase contaminants can be obtained only if the screened interval is outside the direct influence of the non-aqueous phase liquid.

These issues should be considered during a hydrogeological assessment as previously discussed in section 2.2.

### 3.3 Bore development

Development is the process of removing fine sand, silt and clay from the aquifer around the bore screen and breaking down drilling mud on the borehole wall. Development maximises the hydraulic connection between the bore and the formation.
Bore development generally involves actively agitating the water column in a bore, then pumping water out until it is visibly clean and of a constant quality. The development process for monitoring bores should not introduce air, water or other materials into the aquifer.

In most formations, the application of development techniques will result in ‘virtually particulate free’ water returns from bores (ARMCANZ 1997). However, development techniques are limited for small-diameter monitoring bores (typically of 50 mm diameter) in low hydraulic conductivity aquifers. In such conditions, bore development may not result in samples free of turbidity. Specific techniques may need to be employed to maximise the development process.

All bores used for groundwater quality monitoring should be developed after drilling, then left for a period until bore chemistry can be demonstrated to have stabilised (anywhere between 24 hours and seven days) before samples are collected. See section 4.5.1 for further information on stabilisation of bore chemistry.

During development, bore yield should be estimated by monitoring the rate of recovery of water in the bore after pumping. This information can then be used to select suitable methods for subsequent purging and sampling.

**Key factors that can influence groundwater samples (pre-sampling)**

**Objective**

Groundwater monitoring bores should be drilled, constructed and developed such that there is minimal impact on the representativeness of groundwater samples.

**Key measures**

- Drilling technique should minimise compaction or smearing of borehole walls and transport of geological formation materials into different zones.
- Drilling fluids used should cause minimal impact on groundwater chemistry.
- Groundwater monitoring bores should be constructed of materials that are compatible with the groundwater environment and will not leach or sorb contaminants into groundwater samples.
- Groundwater monitoring bores should be developed after drilling and construction and left for a period of time until bore chemistry can be demonstrated to have stabilised.
- Drilling method, drilling fluids used and bore development details should be recorded.
- Groundwater monitoring bores should be assessed to ensure that they will enable sampling program objectives to be met. This will require examination of monitoring bore drilling, construction, development and screen location details and a physical inspection of the bore to establish its physical condition.

### 3.4 Further information

The following documents provide a more detailed discussion of the above issues:

4. GROUNDWATER SAMPLING

4.1 Groundwater samplers

Groundwater sampling requires special expertise and should be undertaken by, or in consultation with, appropriately qualified and experienced personnel (eg hydrogeologists). This is especially critical in situations where a site is underlain by complex hydrogeology. Consultation with a qualified analyst before sampling is highly recommended, especially with respect to the preservation of samples derived from anaerobic environments.

Groundwater samplers

Objective

To ensure that all actions taken during groundwater sampling will result in the collection of groundwater samples that are representative of groundwater in the aquifer.

Key measures

- Groundwater sampling should be undertaken by, or in consultation with, appropriately qualified and experienced personnel.
- Consultation with a qualified analyst before sampling is recommended.

4.2 Planning and preparation

Careful planning and preparation are essential elements of groundwater sampling. This may save time and reduce difficulties commonly experienced during fieldwork. It may also avoid the discovery of errors after sampling has been completed.

Planning and preparation

Objective

To enable efficient and effective groundwater sampling by undertaking careful planning and preparation.

Key measures

The following is a list of information that should be considered or determined before commencing groundwater sampling:

1. The objectives of the groundwater sampling and analysis program.
2. The site-specific parameters to be sampled and analysed.
3. Number and frequency of samples to be collected.
4. Bore details, including location, depth and diameter of bore, depth and length of screened interval, depth to groundwater, bore drilling, installation and development details.
5. Sampling protocol, including purging procedure, in-field measurements, sampling technique and equipment, filtration and preservation requirements and quality assurance/quality control (QA/QC).
6. Sample storage and transportation to the laboratory.
7. Ensure that laboratories performing analyses are accredited by the National Association of Testing Authorities (NATA) for all the tests conducted. In addition the laboratory should be experienced and proficient at testing the types of samples, at the concentration ranges required, for the particular program.
8. Analytical methods and limits of reporting for each method in consultation with the laboratory analyst.
9. Schedule samples for receipt by laboratory. Discuss foreseeable problems with procedures, containers etc. Collect sample bottles, trip blanks, preservatives and spike solutions as required.

10. Calibrate field meters (according to manufacturers’ instructions) that don’t need to be calibrated in the field and ensure that all meters are working correctly. Ensure correct calibration solutions are available.

11. Results from past sample events including groundwater level measurements, field measurements and purge volumes. These may be useful as a comparison and may be read in the field if necessary.

It is useful to compare field results from past sampling events while taking field readings – if readings are greatly different (eg two metre difference between groundwater levels) then readings should be retaken immediately to confirm correct reading. This will save time and minimise the risk of acquiring inaccurate data.

12. Sample documentation (eg QA/QC forms, checklists, chain-of-custody requirements).

13. The owner of the bore(s) should be informed of proposed sampling in situations where they are not the client or site owner.

Items 2, 4 and 11 should be detailed in a hydrogeological assessment (see EPA Publication 668, Hydrogeological Assessments (Groundwater Quality)).

### 4.3 Quality assurance and quality control (QA/QC)

Quality assurance and quality control ensure that the quality of the data that is collected during groundwater sampling is reliable and consistent with the objectives of its sampling program. The quality of data required by sampling programs will vary depending on the objectives of the program.

Groundwater sampling programs should aim to gather information of a quality necessary to support decisions about the condition of groundwater at the site. The quality requirements may vary depending on the purpose of the data and the decisions to be made. For example in some cases a decision may depend simply on whether or not a contaminant is present, while in others it may depend on the actual concentrations of that contaminant. In the latter case the quality requirements will be more stringent.

#### 4.3.1 Quality assurance

Quality assurance (QA) is a critical component of any sampling program and must be in place and considered prior to sampling.

QA is ‘all the planned and systematic activities implemented within the quality system and demonstrated as needed, to provide adequate confidence that an entity will fulfil requirements for quality’ (Standards Australia/New Zealand, 1994). A quality system is defined as ‘the organisational structure, procedures, process and resources needed to implement quality management’ (Standards Australia/New Zealand, 1994).

In terms of groundwater sampling QA involves the organisational procedures, processes, resources and review necessary to ensure that the results of the sampling program accurately reflect the state of the environment at the time of sampling.

QA for groundwater sampling should consider the following (note the overlap with section 4.2, Planning and Preparation):

- objectives of sampling with regard to data quality (the level of uncertainty that is acceptable)
- project responsibilities (who will perform each task)
• protocols to be used for groundwater sampling
• sample custody
• quality control samples (eg which ones, how many)
• the specific analytical methods for each analyte
• storage protocols/procedures and holding times
• sample container and preservative requirements.

QA procedures and protocols do not have to be complex. However, they should clearly state the needs and requirements of the sampling process.

Additional information on QA is provided in appendix D of EPA Publication 441, *A Guide to the Sampling and Analysis of Waters, Wastewaters, Soils and Wastes*.

### 4.3.2 Quality control

QC provides critical aspects for the quality of data, fitting within the framework and system provided by QA. QC ‘involves operational techniques and activities aimed both at monitoring a process and at eliminating causes of unsatisfactory performance at all stages of the quality loop’ (Standards Australia/New Zealand, 1994).

QC involves specific activities to assure the quality of samples, including the collection of information that identifies any errors due to possible sources of cross contamination and inconsistencies in sampling, and provides checks on the analytical techniques used. The reliability of data cannot be assured without the information QC provides.

For example, QA procedures and protocols may require various QC activities such as decontamination of sampling equipment between sampling points to ensure that cross-contamination is avoided and the collection of rinsate blanks to ensure that the decontamination process has been successful and no cross contamination has occurred.

QC in groundwater sampling includes the collection of QC samples (uplicates and blanks), such as:

#### Blanks

A blank is a portion of deionised water that is carried through all or part of the sampling process. The volume used for the blank should be the same as for the samples.

Various blanks may be collected:

**Trip blanks:** These are used to monitor potential contamination during transport and storage. Trip blanks are sent from the laboratory with empty containers and remain with the other samples throughout sampling.

**Field blanks:** These are used to monitor contamination during sampling. These blanks are taken under field conditions during sampling and should include any filtration or addition of preservatives as appropriate.

**Rinsate blanks:** A rinsate blank is generally taken from the final rinse of equipment after decontamination. These samples provide information ensuring that there is no cross-contamination of samples from the sampling equipment.

#### Duplicates

Duplicates are samples taken in immediate succession and subjected to the same filtering, preservation, holding and analysis methods. Duplicates are taken as a check for precision (repeatability) of sample analysis.

The number of sets of duplicate samples required should be commensurate with the required quality of the data (or the limits for the overall uncertainty of results) for decision making purposes.

Duplicates may either be submitted to the same laboratory, as blind replicates, without any indication that they are duplicates or they may be sent to a second laboratory, as split samples,
to provide a further check on the accuracy of laboratory analysis.

Duplicate samples may be compared as relative percent difference (RPD).

RPD = \frac{\text{Result 1} - \text{Result 2}}{\text{Mean of result 1&2}} \times 100

Depending on the analytes and their concentrations, varying RPDs may be acceptable.

Quality assurance and quality control

Objective

To ensure groundwater sampling is undertaken in accordance with appropriate QA/QC.

Key measures

A QA program should be in place. This should consider:

- objectives of sampling with regard to data quality
- project responsibilities
- protocols to be used for groundwater sampling
- sample filtration/preservation
- sample custody
- quality control samples
- specific analytical methods for each analyte
- storage requirements and holding times
- sample preservative requirements.

4.4 Groundwater level measurements

Groundwater level measurements are essential to determine groundwater and contaminant flow directions and rates within aquifers. These measurements can provide information on lateral and vertical head distribution and hydraulic gradients within individual aquifers and between aquifers in layered aquifer systems. Long-term groundwater monitoring programs provide information on the temporal trends in groundwater levels (and therefore flow directions and rates) due to the effects of drought, high rainfall events and groundwater pumping.

Some important factors to be considered when planning the collection of groundwater data include:

- Groundwater levels should always be measured and recorded on the same day (along with the date and time), to a common datum (generally mAHDC – Australian Height Datum), before disturbance of bore water.
- Groundwater levels in new bores may take some time to stabilise after installation and development (in low permeability formations this may require several days or longer).
- In some environments irrigation, pumping or tidal influences may cause rapid groundwater level fluctuations and frequent (hourly) measurement may be required.
- In some situations, water can accumulate in bores. Taking groundwater level measurements after purging, as well as before any disturbance of bore water, may provide results that are more representative of aquifer conditions.
- Methods and instruments used to collect and record changes in groundwater levels can vary substantially depending on the design of the monitoring program and borehole construction. The more common instruments are fox whistles, electrical tapes, pressure transducers and manometers or pressure gauges for flowing bores. Although many electronic methods exist, such as pressure transducers and data loggers, fox whistles remain both accurate and reliable.
Groundwater level measurements

Objective
To obtain accurate and representative measurement of groundwater level.

Key measures
- Before groundwater level is measured it should be allowed to stabilise after bore installation and development.
- Groundwater level should be measured before disturbance of bore water (ie due to sampling).
- Groundwater level should be measured to a common datum.
- All groundwater levels at a site should be measured and recorded on the same day.
- Where there are rapid fluctuations in groundwater level more frequent (hourly) measurements should be taken.

4.5 Purging

In most groundwater monitoring bores, there is a column of stagnant water above the bore screen that remains standing in the bore between sampling rounds. Stagnant water is generally not representative of formation water because it is in contact with bore construction materials (eg casing) for extended periods, is in direct contact with the atmosphere and is subject to different chemical equilibria. Stagnant water often has different temperature, pH, redox potential, dissolved oxygen and total dissolved solids content from formation water. Volatile organic compounds and dissolved gases in stagnant water may volatilise or effervesce within as few as two hours (Nielsen 1991).

Purging is the process of removing stagnant water from a bore before sampling. Purging aims to enable the extraction of a sample that is representative of formation water while creating minimal disturbance to the groundwater flow regime. Although purging is necessary in most situations, purging itself may affect the chemical composition and hence representativeness of samples.

There are a number of different approaches to ensuring that formation water rather than stagnant water is sampled. These approaches are used in different situations and should be considered on a case-by-case basis, depending on aquifer parameters and analytes of concern. Methods include:
- removal of a number of bore volumes of groundwater until chemical equilibrium is reached
- low-flow purging until chemical equilibrium is reached
- passive sampling where minimal purging is required.

In all cases bores should be purged and sampled in order of least (or least likely) to most (or most likely) contaminated.

4.5.1 Removal of a number of bore volumes until chemical equilibrium is reached

Using this purging method, bores should be purged until all stagnant water is removed and water within the bore is representative of formation water. The rate of purging must be less than the rate of pumping during bore development.

Measuring stabilisation criteria such as pH, dissolved oxygen, electrical conductivity, redox potential (Eh) and turbidity can determine when stagnant water has been purged (Puls and Powell 1992; Puls and Powell 1997). Where possible, these parameters should be measured using a flow-through cell.

The parameters may be considered stable when three consecutive readings (obtained several minutes apart) are within:
- ± 10% for dissolved oxygen
- ± 10% turbidity
- ± 3% for electrical conductivity (specific conductance)
• ± 0.05 for pH
• ± 10mv for redox potential.

(Puls 1995; Nielsen 1991)

The most sensitive of these parameters are redox potential, dissolved oxygen and turbidity (Puls et al. 1992).

A number of bore volumes (commonly 3–5 bore volumes) may need to be removed from a bore before drawn water is representative of formation water. The bore volume should be calculated to include the screened interval. The bore volume may be calculated by using the following equation:

\[
\text{Bore Volume} = \text{casing volume} + \text{filter pack volume} = \pi h_1 d_1^2 / 4 + n(\pi h_1 d_1^2 / 4 - \pi h_2 d_2^2 / 4)
\]

Where:
- \(\pi = 3.14\)
- \(n = \) porosity (0.3 for most filter pack material)
- \(h_1 = \) height of water column
- \(d_1 = \) diameter of annulus
- \(h_2 = \) length of filter pack
- \(d_2 = \) diameter of casing

The default removal of a set number of bore volumes (ie 3–5) without measurement of stabilisation criteria does not ensure representative samples and should not be used as purging method. In some situations, 10 or even 20 bore volumes may need to be removed before parameters stabilise (Nielsen 1991, p.465). The time or purge volume required for parameter stabilisation is independent of bore depth and volumes (Puls and Barcelona 1996). Pumping or bailing large volumes of groundwater may lead to:

- sampling water which may be at a depth other that at which the bore is screened; or
- the introduction of groundwater some distance from the bore that may dilute or concentrate some sampling parameters.

This can lead to order of magnitude errors in dissolved chemical constituent data (Barcelona, Wehrmann and Varljen 1994). Over-pumping may cause high turbidity and erroneously high measurements of total metals levels as well as the potential for damage to the filter pack (Barcelona, Wehrmann and Varljen 1994).

At contaminated sites, treatment and disposal of contaminated groundwater removed during purging and sampling require care to avoid occupational health and safety risks or pollution of surface water, land or uncontaminated groundwater.

### 4.5.2 Low flow purging until chemical equilibrium is reached

Purging large volumes of water can be impractical, hazardous or may adversely affect the contaminant distribution in the sub-surface (eg through dilution). Low-flow purging (or micro-purging) involves minimal disturbance of the water column and aquifer and is preferable to the removal of a number of bore volumes. This method removes only small volumes of water, typically at rates of 0.1 to 0.5 L/min (Puls and Powell 1997), at a discrete depth within the bore.

Low-flow purging relies on the concept that groundwater moves horizontally through the screened interval in a bore and that formation water does not mix with the stagnant water above the screened interval (see figure 2).

Low-flow purging consists essentially of the following steps:

- The pump inlet is carefully and slowly placed in the middle or slightly above the middle of the screened interval at the point where the contaminant concentration is required (dedicated pumps are ideal for low-flow sampling). Placement of the pump inlet too close to the bottom of the bore can cause increased entrainment of solids, which have collected in the bore over time.
• Purging begins, typically at a rate of 0.1 to 0.5 L/min, although higher rates may be possible providing the rate of purging does not cause significant draw down in the bore.

• During purging, groundwater stabilisation parameters should be measured and recorded as per Section 4.5 to determine when they stabilise.

• When parameters have stabilised the sample may be collected, at a rate slower or equal to purge rate.

4.5.3 Passive sampling

Passive sampling is the process of acquiring a sample from a bore without disturbing the stagnant water within the bore. A pump is permanently installed in the bore, the intake placed within the screened interval and left for a sufficient period of time until water in screened interval has reached chemical equilibrium. During sampling no agitation of the water column occurs as the sample device does not need to be inserted into the bore (see figure 2). It is therefore possible to generate very low purge volumes (less than 1 bore volume according to Barcelona, Wehrmann and Varljjen 1994) by pumping at a low-flow rate as the only purging required is for evacuation of the sampling device (pump body, tubing, etc).

As passive sampling relies on the sample/purge device not agitating the water column, inertial samplers and bailers cannot be used during passive sampling. It is not always necessary to measure stabilisation parameters during purging for passive sampling. However, it is advisable to measure these parameters the first few times a bore is sampled to enable a purge volume to be established.

Passive sampling techniques have the potential to provide the best contaminant concentration data (Puls and Powell 1997).

4.5.4 Low hydraulic conductivity aquifers

In some low hydraulic conductivity formations it may not be possible or practical to pump bores until field parameters stabilise, as bore recovery is slower than pump rates, including low-flow pump rates. Low hydraulic conductivity formations are generally fine

Figure 2: Groundwater flow through a bore

![Diagram of groundwater flow through a bore](modified from Puls and Powell 1997)
grained (e.g. clay) and are naturally more susceptible to producing turbid water samples.

The recommended procedures for purging low hydraulic conductivity bores are:

1. Use of low-flow purging (ideally, passive sampling) as discussed in sections 4.5.2 and 4.5.3. Purging at less than 0.1 L/minute may be required. Packers may be useful to isolate the section being sampled.

2. Where significant drawdown in the bore is unavoidable the screened interval should not be dewatered. This may require repeated recovery of bore water during purging while leaving the pump in place within the screened interval of the bore.

Purging the bore dry is not recommended as this may expose the sample to air and other gases or floating substances, producing an unrepresentative sample.

### Purging

**Objectives**

To ensure that formation water is sampled rather than stagnant water.

**Key measures**

- In all cases bores should be purged and sampled in order of least (or least likely) to most (or most likely) contaminated.
- Field parameters (e.g. pH, specific conductance, dissolved oxygen, redox potential, temperature and turbidity) should be allowed to stabilise before samples are taken.
- Field measurements of stabilisation criteria should be recorded.
- Bailers and inertial samplers should not be used for low-flow purging as they can cause repeated disturbance and mixing of bore water.
- Use consistent purging and sampling methods over time from the same bore.
- The screened interval in the bore should not be dewatered.
- The rate of purging must be less than the rate of pumping during development.
- Purging method used should be recorded.

### 4.6 Field measurements

Field measurement of groundwater parameters provides a rapid means of assessing certain aspects of water quality. It has the advantage of reducing the possibility of contamination or change in sample composition between collection and analysis.

Field measurements are generally taken to:

- Ensure that formation water is being sampled.
- Provide on-site measurements for water quality parameters that are sensitive to sampling and may change rapidly (e.g. temperature, pH, redox and DO). Careful field measurement enables representative analysis.
- Compare with laboratory measurements of these parameters to assist in the interpretation of analytical results of other parameters (e.g. check for chemical changes due to holding time, preservation and transport).

Groundwater parameters measured in the field must include pH, temperature, dissolved oxygen, redox potential and conductivity and may include turbidity. Some ions, such as fluoride and sulfide, can also be determined using ion selective electrodes, although their determination can be subject to matrix interferences.

Field measurements may be taken either *in situ* or after groundwater has been extracted from a bore. If groundwater is being pumped, it is recommended that a flow-through cell with probes be used for field measurements, as it allows for continuous measurement and minimises sample contact with the atmosphere.

Field measurements should be taken immediately before collecting each sample.

Ensure field instruments are robust and reliable and that they are capable of measuring to the appropriate level of accuracy. They must be calibrated before use with fresh solutions. pH and dissolved oxygen meters need to be calibrated before every use. Calibration can be
performed either in the laboratory or in the field. The manufacturer’s instructions are the best guide for the use of any particular meter. However, meters must be calibrated according to the NATA publications, *General Requirements for Registration: Supplementary Requirements: Chemical Testing* (NATA 1993) and Technical Note No. 19 (NATA 1994).

The meter must be calibrated over an appropriate range for the samples analysed. If the meter is to be used over several hours, periodic readings of a reference solution must be made to ensure the calibration is stable. If excessive drift is observed, readings taken over the period of drift must be discarded.

While field meters are designed to withstand a level of harsh treatment (such as knocks, vibration and extreme temperature changes), good maintenance and calibration regimes ensure that meters produce reliable and accurate data.

Secondary parameters such as temperature, salinity, altitude and air pressure may affect some field measurements. For example, all of the above parameters affect dissolved oxygen readings. If the field meter does not automatically measure and compensate for a secondary parameter, then this parameter must be measured using the appropriate equipment and a manual compensation performed. The manufacturer’s instructions should be consulted for correction factors.

Many factors may cause interference when taking field measurements. These interferences cannot be compensated for. In particular, oily films, high levels of suspended solids and electrical fields may cause problems. If the measurements are being taken in unusual situations, the field conditions should be recorded and the manufacturer’s instructions should be consulted to establish whether interference could occur.

### Field measurements

**Objective**

To ensure accurate measurement of water quality parameters using field meters.

**Key measures**

- Field measurements should be taken immediately before collecting each sample.
- Where groundwater is pumped a flow-through cell should be used to take field measurements.
- Field meters must be calibrated according to manufacturer’s instructions and according to the NATA publications, *General Requirements for Registration: Supplementary Requirements: Chemical Testing* (NATA 1993) and *Technical Note No. 19* (NATA 1994).
- If field meters are to be used over several hours, periodic readings of a reference solution must be made to ensure calibration is stable.

Potential causes of interference in the field must be recorded.

### 4.7 Sample collection

Groundwater samples should be collected when the solution chemistry of the groundwater removed from a bore has stabilised as indicated by pH, DO, redox, EC, temperature and turbidity readings (see section 4.5.1). Where a flow-through cell is used to monitor water quality parameters, it should be disconnected or bypassed during sample collection as solutions in the probes can affect sample chemistry.

Samples should be collected at a rate slower or equal to the purging rate. Where samples are collected at a faster rate than purging, particles previously not removed during purging may be forced out of the aquifer/gravel pack and into the sample.

The same device should be used for sampling as previously used for purging.
4.7.1 Processes responsible for altering sample chemistry

The major processes involved in altering the chemistry of samples and which may be directly controlled by choice of sampling device are volatilisation, degassing, oxidation, precipitation and sorption.

**Volatilisation** is the loss of dissolved compounds by evaporation upon contact with a gas phase and is controlled by the vapour pressure of the solute or solvent. Compounds most susceptible to volatilisation include volatile organic compounds such as chlorinated hydrocarbons (e.g., TCE) and monocyclic aromatic hydrocarbons (e.g., benzene).

**Degassing** is the loss of dissolved gas from solution and can result from either an increase in temperature or a decrease in pressure. Parameters potentially affected by degassing are pH (likely to increase through loss of carbon dioxide) and pH-sensitive parameters such as heavy metals, alkalinity and ammonium (all likely to decrease). Total dissolved solids and total organic carbon are also affected and are likely to decrease in concentration due to degassing.

**Precipitation** is the formation of solids from constituents that were once dissolved. Precipitation can be caused by a change in conditions, such as temperature, pH, chemical concentration, or the presence of seed particles to begin the process. For example, where a groundwater sample experiences loss of carbon dioxide, a rapid change in pH can occur, causing precipitation of metals such as iron.

**Oxidation** is caused by the introduction of oxygen (in air) to the sample. Oxidation results in increased dissolved oxygen, pH and redox. These changes can potentially lead to decreases in concentrations of calcium ions, magnesium ions, heavy metals (particularly iron and manganese), hydrogen sulphide and ammonium. Oxidation could also cause a decrease in the concentrations of bulk organic parameters, chemical oxygen demand, biological oxygen demand and total organic carbon, due to accelerated oxidation of organic constituents such as volatile fatty acids and semi-volatile organic carbon.

**Sorption** involves the attraction of dissolved constituents to the surface of solid particles. Any process or activity that increases suspended solids in samples can change the measured concentrations of dissolved major ions, heavy metals and hydrophobic organic compounds (e.g., organochlorinated pesticides). A loss of dissolved constituents from samples due to sorption can result where the dissolved constituents sorb onto solids in suspension before the solids are separated from the sample for laboratory analysis. Alternatively, where additional solids/colloids remain in solution or suspension (i.e., turbid samples) during analysis, increased concentrations of ions and metals may be recorded. The presence of fine grained materials combined with low redox potential conditions may promote increased turbidity by the formation of colloids (Saar 1997).

4.7.2 Sampling device

According to Barcelona (1995), field sampling (of groundwater) can often be the most significant source of error in determining analytical results that are representative of field conditions. Error introduced during sampling is a significant issue. While very low detection limits are possible in the laboratory, they may be limited by practical considerations related to the performance of sampling devices in the field.

An appropriate device should be selected for collection of groundwater samples. To do so, the following issues need to be considered and will directly affect the quality of groundwater samples collected (these issues are also relevant to choice of purging device):

1. The sampling device should cause minimal physical or chemical alteration to the sample. As discussed in section 4.7.1, it is important that the sampling device does not cause degassing, aeration, volatilisation, oxidation, sorption or precipitation through:
- the mode of transporting the sample to the surface
- interaction with the materials of construction of the device, or
- transfer of the sample to its container.

To gain the most representative data it is recommended sampling devices be constructed from inert materials such as stainless steel and Teflon. Flexible components such as tubing should comprise flexible PVC or polyethylene. However, the materials selected will depend on the sensitivity of the information required.

Appendices A and B provide information on sampling devices in relation to their adequacy for contaminants of concern and their potential impacts on sample quality.

- The possibility of using a dedicated sampling device permanently installed in the bore should be considered. This approach can reduce time (and cost) involved in set-up, sampling and decontamination procedures. A dedicated pump also enables passive sampling techniques to be employed, allowing collection of more representative groundwater samples.
- Ideally, it should be possible to use the same sampling device for sampling and for purging to reduce the amount of decontamination required and to reduce turbulence in the bore.
- Where a bailer is used, use cord that can be decontaminated between each bore. Cotton or cloth cord should not be used.

The following issues are important practical considerations that need to be addressed before sampling:

1. The depth from which the sample is collected is important, as the deeper the sample interval the more head the device must overcome to deliver the sample to the surface.
2. The bore must be able to accommodate the sampling device. The smaller the diameter of the bore, the more limited the options.
3. Ease of operation, cleaning and maintenance.
4. Ease of repair – it is a distinct advantage to be able to repair the device in the field.
5. Reliability and durability – especially where the sampling device is to be used for an extended period in groundwater environments containing chemical constituents that cause corrosion of metallic parts or degradation of synthetic materials.

The sampling device selected should be assessed for its impact on results and the sampling technique used should be commensurate with the required sensitivity or use of the data. In general, bladder pumps are likely to cause minimal disturbance to samples during collection. They are generally the most effective sampling devices for sampling gas-sensitive analytes and VOCs (Parker 1994; Barcelona et al. 1984).

4.7.3 Diffusion samplers for volatile organic compounds (VOCs)

Diffusion samplers are an alternative method for sampling VOCs. Diffusion samplers consist of distilled water enclosed by a polyethylene membrane. The membrane allows diffusion of VOCs from aquifer water into the distilled water until equilibrium is reached (Vroblesky and Hyde 1997). The process involves:

1. placing diffusion sampler at screened interval in bore
2. leaving diffusion sampler within bore for approximately two weeks, until equilibrium is reached and the sampler can be removed.
The advantages of this method over conventional purging/sample collection (bailing in particular) are:

- no purging required
- minimum disturbance of sample leading to minimal loss of volatile contaminants
- diffusion sampler can be accurately placed so that sample is taken from the screened interval.

### Sample collection

**Objective**
To minimise impact on representativeness of groundwater sample due to sample collection.

**Key measures**

- Groundwater samples should be collected when the solution chemistry of the groundwater removed from a bore has stabilised.
- Disconnect or bypass flow-through cell before collecting sample.
- Samples should be collected at a rate slower or equal to the purging rate.
- The same device should be used for sampling as previously used for purging.
- Sampling device should cause minimal physical or chemical alteration to the sample.

### 4.8 Filtration of groundwater samples

Filtration is the process of separating suspended solids from a sample by forcing it through a porous barrier (filter). Filtration is undertaken to enable samples to be preserved (eg addition of concentrated acid to samples for metals analysis) as soon as possible after sampling without suspended solids adversely influencing the representativeness of the sample. As with other components of sampling, filtration is known to significantly affect the resultant analytical data. Thus, the need for filtration must be thoroughly considered before (and during) sampling.

#### 4.8.1 Is filtration necessary?

The objectives of sampling need to be considered in determining the need for filtration. *Ideally, samples should be collected so that there is no need to filter.* The purging and sampling techniques used should minimise disturbance and agitation and therefore introduce little suspended solids to the sample.

Even when suitable purging and sampling techniques are used, filtration of groundwater samples may be necessary when:

- sampling to determine truly dissolved concentrations of analytes; or
- it is not possible or practical to obtain a sample with low turbidity (ie visually clear) due to solids suspended as a result of purging and sampling, and
- sampling to determine mobile concentrations of analytes (dissolved and colloidal) subject to sorption by suspended particles (predominantly metals and hydrophobic contaminants such as PCBs and organochlorine pesticides).

The decision to filter or not to filter groundwater samples must be reported with resultant analytical data. Spatial and temporal consistency in methodology are important to ensure comparability of groundwater quality data.

#### 4.8.2 Purging and sampling technique

Purging and sampling methodology can have a large impact on whether a sample needs to be filtered. Techniques that cause agitation of water in a bore (eg inertial lift pumps and bailers) are more likely to produce samples that are highly turbid. Increased pump rates (greater than 1 L/min) increase sample turbidity and bring larger particles into suspension (Puls et al. 1992). Samples obtained by low flow or passive sampling are
more likely to be low in turbidity. In situations in which a bore may produce turbid samples, techniques should be used that obtain the least turbid, and subsequently the most representative, samples of groundwater.

Filtration should be avoided where it is reasonably possible to change sampling practice to eliminate turbidity caused by purging and sampling. Filtration should not be used to compensate for inadequate sampling practice (Barcelona et al. 1995).

4.8.3 Effects of sample filtration

Some effects that filtration may have on a sample are described below:

- The exposure of sample to air during filtration can cause metals such as iron to oxidise and precipitate. The iron precipitates may clog the filter, thereby further lowering the iron concentration in the sample. Iron precipitates may also entrain other metals (through co-precipitation) resulting in further reduced metal concentrations in the sample.
- Adsorption of dissolved metals in the sample onto the filter material.
- Clogging of filter pores by suspended solids.
- Removal of small suspended solids that are naturally mobile in groundwater.
- Increased sample handling.

Adverse effects of filtration on the sample may be minimised in the following ways:

- Exposure of the sample to air can be avoided by using an in-line filtration apparatus.
- Adsorption of metals may be reduced by rinsing the equipment with sample water before sample collection.
- Pore clogging may be reduced by increasing the ratio of filter surface area to volume of water filtered by:
  - changing the filter regularly
  - increasing the filter diameter
  - using filter cartridges, which have much greater surface area
  - processing the minimum amount of water needed for analysis.

4.8.4 When sample filtration is necessary

Where filtration is necessary, it should occur in the field, immediately after each sample has been collected and before chemical preservation.

The mechanism for filtration may be either through gravity or applying vacuum or pump pressure. In all cases, only low pressures should be applied.

Direct, in-line filtering of samples is recommended. Direct, in-line filtration occurs by attaching the filter directly to a pump’s discharge line or to the discharge tube of a grab sampler (e.g. bailer).

Careful consideration of an appropriate pore diameter is necessary before filtering. The most common size of filter used in collection of groundwater samples is 0.45 µm. The use of this filter diameter does not achieve an accurate representation of:

- truly dissolved metal concentrations – 0.1 µm or 0.05 µm may be more appropriate (Puls and Barcelona 1989)
- concentrations of contaminants that are sorbed to colloids larger than 0.45 µm that are naturally mobile in groundwater (Saar 1997)

A wide range of filtration media exists. These include cellulose nitrate, cellulose acetate and glass fibre filters. Cellulose nitrate filters are commonly used for major ions (excluding nitrates) and metals, while cellulose acetate is used for nutrients (including nitrates). Glass fibres are sometimes used as they block less frequently, however, they do not have a well-defined pore size (Murray-Darling Basin Commission 1997).
Filtering devices should be cleaned in a similar manner to sample containers and care taken to ensure that contamination is not introduced in the field. Filters from the same batch used in the field and the filtering device itself should be provided to the laboratory so that blank levels can be determined. On-site (between sample) final rinses from filtration equipment should also be submitted to the laboratory as ‘rinsate blanks’ for analysis.

4.8.5 Where filtration is necessary but cannot be undertaken in the field

Where field filtration is necessary but is expected to affect the representativeness of samples due to extreme field conditions, or may pose an unacceptable health or safety risk to field personnel, it may be necessary to undertake filtration in the laboratory. In such situations it will be necessary to:

- overfill and immediately seal sample containers
- cool the sample
- transport the sample to the laboratory with minimum delay
- inform the laboratory of the need to filter immediately on receipt of the sample and
- filter in the laboratory.

An analyst should be consulted where preservation is delayed due to not filtering in the field.

<table>
<thead>
<tr>
<th>Filtration of groundwater samples</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Objectives</strong></td>
</tr>
<tr>
<td>To enable samples to be preserved as soon as possible after sampling without suspended solids adversely influencing the representativeness of the sample.</td>
</tr>
<tr>
<td><strong>Key measures</strong></td>
</tr>
<tr>
<td>- Filtration should be undertaken where the objective of sampling is to determine truly dissolved concentrations of analytes.</td>
</tr>
<tr>
<td>- Filtration should be avoided where it is reasonably possible to change sampling practice to eliminate turbidity caused by purging/sampling and sampling to determine mobile concentrations of analytes.</td>
</tr>
<tr>
<td>- Filtration should not be used to compensate for inadequate sampling practice.</td>
</tr>
<tr>
<td>- Where filtration is necessary, it should occur in the field, immediately after each sample has been collected and before chemical preservation. In line filtration is recommended.</td>
</tr>
<tr>
<td>- The decision to filter or not to filter groundwater samples must be reported with resultant analytical data.</td>
</tr>
</tbody>
</table>

4.9 Sample containers, preservation, labelling and logging, transport and holding times

Decisions concerning the selection of sample containers, preservation procedures, labelling and logging, transportation and holding times should be made during the planning phase of any sampling program. Sample preservation, containers and holding periods for groundwater samples should be in accordance with EPA Publication 441, A Guide to the Sampling and Analysis of Waters, Wastewaters, Soils and Wastes.
4.10 Decontamination

All equipment that either enters the bore or carries the water from the bore to the sampling container should be decontaminated before each sample is taken. Decontamination ensures that sampling equipment is clean and contains no trace of the previously sampled groundwater, which can cause erroneous analytical results (cross-contamination).

Decontamination procedures should be developed on a site-specific basis, considering the objectives of the sampling program, potential contaminants, and sampling and purging equipment.

In general, decontamination procedures include the following steps:

- Sampling and purging equipment should be decontaminated away from the sampling location to minimise the potential for cross-contamination.
- Decontamination solution to be used may be phosphate-free detergent, bleach or solvent. The cleaning solution will depend on the contaminants being investigated. For example, when sampling for microbiological parameters, bleach should be used to sterilise equipment between sample points. However, bleach would not be used if sampling for chlorine.
- Contaminant-free water (eg tap water) followed by distilled or deionised water (final rinse) should be used to wash and rinse equipment.
- In some cases (eg when investigating the presence of organic contaminants) it may be necessary to rinse equipment with solvent (eg acetone).
- Final rinsate (QC) samples should be taken from equipment as blanks to ensure that all contamination has been removed.
- Equipment should be air dried before use for sampling. Care should be taken to ensure that exhaust, from motor vehicles or compressors, does not contaminate equipment.

Provision should be made for disposal of contaminated wastewater or solvent from the decontamination process. It may require containment and disposal at an appropriate disposal or treatment facility.

4.11 Health and safety

For information on health and safety precautions and warnings that must be observed during sampling refer to EPA Publication 441, *A Guide to the Sampling and Analysis of Waters, Wastewaters, Soils and Wastes.*

4.12 Documentation

When conducting long-term monitoring programs it is essential that samples be collected in a consistent manner so that the resultant analytical data is comparable. For this to be possible, it is essential that groundwater
sampling methodology be thoroughly documented on each sampling occasion.

**Documentation**

**Objective**

Documentation of sufficient data during sampling to ensure that sampling practice is consistent during each subsequent sampling occasion.

**Key measures**

The following items should be recorded in a logbook or sampling work plan:

- purpose of sampling
- location, description and photographs of sampling point
- detail of sampling site (elevation of casing, casing diameter, integrity of casing, casing depth, interval sampled, condition of bore)
- weather conditions during and immediately preceding sampling (eg has it rained in the preceding days?)
- reference to procedures for preparation of reagents or supplies that become an integral part of the sample (eg filters and absorbing reagents)
- identification of sampling team
- decontamination procedures
- sample method (including purging)
- standing water level
- pump rate for purging and sampling
- purged volume
- field measurements
- potential for interference with field measurements
- date and time of sample collection
- number and volume of samples taken (including any QC samples)
- field observations
- signature and date, by the responsible personnel
- sample preservation including storage method
- sample transportation
- specific comments and remarks.

**4.13 Reporting groundwater sampling results**

Overall, the groundwater sampling report should fully describe sampling methodology and state any possible impacts sampling methodology may have had on the quality of the sample.

Analysis and interpretation of analytical data should be undertaken by appropriately qualified and experienced professionals (eg hydrogeologists). Guidance on data presentation is provided in EPA Publication 668, *Hydrogeological Assessments (Groundwater Quality)*.

**Reporting groundwater sampling results**

**Objective**

Accurate and consistent reporting of groundwater sampling details that assist in interpretation of analytical results.

**Key measures**

Analytical results of groundwater sampling should be presented along with the following information:

- bore drilling, construction and development details
- purging and sampling equipment used
- purge technique (including volumes removed and stabilisation criteria)
- visual observations of the sample
- field measurements
- whether samples were filtered or unfiltered
- whether samples were filtered in the field or in the laboratory
- preservation techniques
4.14 Sampling for non-aqueous phase liquids (NAPL)

Non-aqueous phase liquids (NAPLs) are organic fluids that are immiscible (do not mix) with water. NAPLs may be lighter (LNAPL) or denser (DNAPL) than groundwater, forming discrete layers or pools within the ground (e.g., layer of petrol situated on the water-table). When present in aquifers, NAPLs are considered to be an uncontrolled source of groundwater contamination that require investigation and in most cases clean up. The presence of NAPLs can be significant for groundwater sampling. Where light non-aqueous phase liquid is present within a bore, it is not possible to obtain a representative sample of groundwater for dissolved phase petroleum components.

Sampling of NAPLs is a specialised subject and a detailed methodology is beyond the scope of these guidelines. However, here are some of the issues that should be considered before sampling NAPLs:

- When investigating LNAPL contamination, monitoring bores must be constructed so that the screened interval intersects the top of the water table above which the LNAPL is most likely to be encountered.
- When investigating DNAPL contamination, monitoring bores must be constructed so that the screened interval intersects the base of the aquifer or a low permeability layer, where the DNAPL may be encountered.
- DNAPLs may migrate in a different direction to that of groundwater flow. This will affect positioning of bores.

The following should be considered during the sampling of NAPLs:

- Sample at the interval where the NAPL is most likely to be encountered (i.e., the top of the water column in a bore when sampling LNAPL or the bottom of the bore when sampling DNAPL).
- Do not purge before measuring the thickness of or sampling from the NAPL layer.
- Measure LNAPL thickness with either a LNAPL/water interface probe or a weighted tape coated with a water and LNAPL sensitive substance to distinguish between the air/LNAPL and LNAPL/water interfaces.
- Measure DNAPL thickness with an interface probe.
- Equipment decontamination may be quite difficult therefore use of disposable equipment should be considered.
- Single or double check valve bailers may be used for LNAPL collection, while double check valve bailers may be used for DNAPL collection. Peristaltic pumps may also be effective.

Further information on sampling NAPLs is contained in specialist texts such as:

## GLOSSARY

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
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</thead>
<tbody>
<tr>
<td>Annular space/Annulus</td>
<td>The space between a bore casing and a borehole wall.</td>
</tr>
<tr>
<td>Aquifer</td>
<td>A geological structure or formation, or part thereof, permeated with water or capable of:</td>
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<tr>
<td></td>
<td>(a) being permeated permanently or intermittently with water;</td>
</tr>
<tr>
<td></td>
<td>and</td>
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<tr>
<td></td>
<td>(b) transmitting water.</td>
</tr>
<tr>
<td>Bailers</td>
<td>A bailer is a hollow tube with a check valve at the base (open bailer) or a double valve (point source bailer) – used to remove water from a bore.</td>
</tr>
<tr>
<td>Bentonite</td>
<td>A hydrous aluminium silicate clay mineral available in powdered, granular or pellet form that swells when wet. It is used to provide a seal between the bore casing and borehole.</td>
</tr>
<tr>
<td>Bore</td>
<td>Any bore, well or excavation or any artificially constructed or improved underground cavity used or to be used for the purpose of (a) the interception, collection, or storage of groundwater; or (b) groundwater observation or the collection of data.</td>
</tr>
<tr>
<td>Bore screen</td>
<td>A filtering device that allows groundwater to flow freely into a bore from the adjacent formation, while minimising or eliminating the entrance of sediment into the bore.</td>
</tr>
<tr>
<td>Casing</td>
<td>Impervious, durable pipe installed temporarily or permanently into a borehole to counteract caving, to advance the borehole, and to isolate the zone being monitored.</td>
</tr>
<tr>
<td>Colloid</td>
<td>Particles (organic or inorganic) with diameters less than 10µm.</td>
</tr>
<tr>
<td>Contamination</td>
<td>A change in water quality that produces a noticeable or measurable change in its characteristics</td>
</tr>
<tr>
<td>Filter pack</td>
<td>Sand or gravel that is generally uniform, clean and well-rounded that is placed in the annulus of the bore (between the borehole wall and the bore screen) to prevent formation material from entering through the bore screen and to stabilise the adjacent formation.</td>
</tr>
<tr>
<td>Formation</td>
<td>A unit of consolidated or unconsolidated geologic material characterised by a degree of lithologic homogeneity which can be charted.</td>
</tr>
<tr>
<td>Groundwater</td>
<td>Any water contained in, or occurring in, a geological structure or formation or an artificial landfill.</td>
</tr>
<tr>
<td>Head</td>
<td>Energy contained in a water mass, produced by elevation, pressure or velocity.</td>
</tr>
<tr>
<td>Hydrogeology</td>
<td>The geological science concerned with the occurrence, distribution, quality and movement of groundwater.</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
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<tr>
<td>-------------------------------------------</td>
<td>------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>In situ groundwater measurements</td>
<td>Measurements of groundwater quality parameters collected from within a bore or aquifer.</td>
</tr>
<tr>
<td>MAH</td>
<td>Monocyclic aromatic hydrocarbons (e.g., benzene and toluene).</td>
</tr>
<tr>
<td>Non-aqueous phase liquids</td>
<td>A liquid which has low solubility in water that is in sufficient quantity to form a discrete layer or separate phase.</td>
</tr>
<tr>
<td>Packer</td>
<td>A device placed in a bore or borehole that isolates or seals a portion of the bore, bore annulus or borehole at a specific level.</td>
</tr>
<tr>
<td>Permeability</td>
<td>The ability of a porous or fractured medium to transmit a fluid.</td>
</tr>
<tr>
<td>Representative sample</td>
<td>A sample that retains the chemical and physical character of the in-situ formation water.</td>
</tr>
<tr>
<td>TCE</td>
<td>Trichloroethene (trichloroethylene).</td>
</tr>
<tr>
<td>TDS</td>
<td>Total dissolved solids.</td>
</tr>
<tr>
<td>TOC</td>
<td>Total organic carbon.</td>
</tr>
<tr>
<td>TOX</td>
<td>Total organic halogen.</td>
</tr>
<tr>
<td>Turbidity</td>
<td>Cloudiness in water due to suspended, colloidal (organic and inorganic) material.</td>
</tr>
<tr>
<td>VOC</td>
<td>Volatile organic carbon.</td>
</tr>
<tr>
<td>Water-table</td>
<td>The surface of saturation in an unconfined aquifer at which the water pressure is equal to atmospheric pressure.</td>
</tr>
</tbody>
</table>
## APPENDIX A: SAMPLING EQUIPMENT


<table>
<thead>
<tr>
<th>Sampling equipment</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Bailers</td>
<td>• Can be constructed from a variety of materials compatible with analytes of interest.</td>
<td>• Aeration, degassing and turbulence can occur while lowering the bailer through the water column or while transferring the sample from the bailer to the sample container. Bailers are generally not suitable for volatile and gas-sensitive analytes.</td>
</tr>
<tr>
<td></td>
<td>• Can be different diameter and length to suit the sampling point.</td>
<td>• Surging effect of bailers that fit tightly into a bore casing may induce fine particles from the formation to enter the bore.</td>
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<tr>
<td></td>
<td>• No external power source required.</td>
<td>• When used in a deep bore, prolonged sample handling may affect air-sensitive chemical constituents.</td>
</tr>
<tr>
<td></td>
<td>• Easy to clean, or disposable.</td>
<td>• It may be difficult to determine the point within the water column that the sample represents.</td>
</tr>
<tr>
<td></td>
<td>• Inexpensive and readily available.</td>
<td>• Lines used for the bailer can be difficult to decontaminate.</td>
</tr>
<tr>
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<td></td>
<td>• Bailer check valves may fail to function properly under certain conditions (eg high suspended solids).</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• In deep bores, purging becomes time-consuming and labour-intensive.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• The person sampling the bore is susceptible to exposure to any contaminants in the water sample.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Bailing does not supply a continuous flow of water to the surface.</td>
</tr>
</tbody>
</table>

A bailer is a hollow tube with a check valve at the base (open bailer) or a double valve (point source bailer). The bailer is attached to a line and lowered into the water. The bailer is pulled up when the desired depth is reached with the weight of the water closing the check valve.
2. Inertial lift pump
This pump consists of a foot valve at the end of a flexible tube which runs into the water. Initially the water column in the tube is equal to that in the well. An initial rapid upstroke lifts the water column in the tubing a distance equal to the stroke length, on the down stroke the foot valve opens allowing fresh water to enter the tube.

- Simple construction, inexpensive.
- Manual, gas or electric motor driven.
- Good for sediment-clogged bores.
- If dedicated, avoids cross contamination.
- For use primarily in small diameter bores as large bores increase the possibility of tube sway.
- Pumping action agitates bore, introducing suspended material.
- Works optimally with deep installation of tubing. This may result in the bore not being properly purged.
- Low-flow capacity.

3. Syringe devices
A syringe or similar device attached to tubing is lowered to a selected depth in the water column. Suction is applied to the tubing and the syringe, filling the syringe with water.

- Neither aeration nor degassing of the sample occurs, as the sample does not come in contact with the atmosphere.
- Can be made of any material.
- Inexpensive, highly portable and simple to operate.
- Can be used in small diameter bores.
- Sample can be collected at various intervals
- Can be used as sample container, thereby reducing the potential for cross contamination.
- Inefficient for collecting large volumes.
- Syringes cannot be used for purging.
- Sample contamination by components of ‘home-made’ syringe sampling devices is possible unless fabrication materials are carefully selected.
- The use of syringes is limited to water with a low suspended solids content as some leakage may occur around the plunger when syringes are used to sample water containing high suspended solids.

4. Gas-drive devices
Positive gas pressure applied to the surface of water within the sample chamber forces the sample to the surface through an open tube.

- Relatively portable
- Readily available
- Inexpensive
- Some are suitable for bore development – depends on yield rate of device
- Can provide delivery of sample at a controlled, nearly continuous rate.
- If air or oxygen is used as the driving gas, oxidation may occur, causing precipitation of metals and gas stripping of volatiles. CO\textsubscript{2} may also be driven from the sample causing a pH shift. Consequently, air-lift sampling may not be appropriate for many gas sensitive analytes.
- Gas stripping of volatiles may occur.
- An air compressor or large compressed air tanks must be transported to deep bores, reducing portability.
- Excessive air pressure can rupture gas entry or discharge tubing.
5. **Suction lift pumps**

Suction lift pumps apply a vacuum to either the bore casing or to tubing that runs from the pump to the desired sampling depth.

- Highly portable.
- Readily available.
- Flow rate can be controlled.
- Inexpensive.
- Can be constructed for small diameter bores.
- With peristaltic pumps, the pump does not come in contact with the sample – only the tubing contacts the sample.
- Limited sampling depth (6–9 m)
- The application of strong negative pressure (suction) causes degassing of the sample and loss of volatiles.
- Potential for hydrocarbon contamination of samples due to use of petrol or diesel for running the pump.

6. **Gas-operated piston pump**

Gas-operated piston pumps consist of one or more pistons moving inside a submerged cylinder or barrel. When gas pressure drives the piston up and down, one-way check valves direct water moved by the pistons to the surface.

- Sample is isolated from the driving gas, therefore no aeration of sample occurs.
- The pump provides a continuous sample over extended periods of time.
- Easy to operate.
- Flow rates can be controlled by varying the driving gas pressure.
- Can achieve pump lifts of 100 m.
- The pump’s valving mechanism may cause a series of pressure drops in the sample, leading to sample degassing and pH changes.
- Unless the pump intake is filtered, particulate matter may damage the pump’s intricate valving mechanism.
- Not highly portable – it must be vehicle mounted.

7. **Bladder pump**

A flexible bladder within the device has check valves at each end. The pump is lowered into the water, gas from the ground surface is cycled between the bladder and sampler wall, forcing water to enter the bladder and be driven up the discharge line.

- Sample is isolated from the driving gas, minimising the problems of sample aeration and gas stripping.
- Samples collected with these devices lose very little of even the most volatile constituents (Parker 1994).
- Portable, small diameter.
- Pumping rate of most of these pumps can be controlled to allow for both bore purging and collection of large sample volumes.
- Most models are capable of pump lifts greater than 60 m.
- Deep sampling requires large volumes of gas and longer cycles, thus increasing operating time and expense and reducing portability.
- Check valves in some pumps may fail in water with high suspended solids content.
- Most pump models are expensive.
- Minimum rate of sample discharge of some models may be higher than ideal for sampling of volatile compounds.
| 8. Gear-drive electric submersible pump | • Constructed from inert or nearly inert materials.  
• Wide range of diameters.  
• Readily available.  
• High pumping rates are possible for removal of large volumes.  
• Provides a continuous sample over extended periods. | • Conventional units are unable to pump sediment-laden water without incurring damage to pump.  
• Smallest diameter pump is relatively expensive.  
• No control over flow rates. |
|---|---|---|
| 9. Submersible centrifugal pump | • Small diameter pumps can be operated at variable rates.  
• Constructed from inert or nearly inert materials.  
• Portable.  
• Pumping rate of these pumps can be varied. | • Does not handle viscous fluids efficiently.  
• Conventional large diameter submersible centrifugal pumps are subject to excessive wear in abrasive or corrosive waters. |
| 10. Helical-rotor pump | • Portable and relatively easy to transport.  
• High pumping rates are possible.  
• Constructed from inert or nearly inert material. | • The flow rate cannot be controlled.  
• High pumping rates may lead to creation of turbulence which may cause changes to sample chemistry.  
• Thorough cleaning and repair in the field may be difficult, as the pump is difficult to disassemble.  
• Water with high suspended solids content can cause operational problems.  
• The pump must be cycled on/off every 20 minutes to avoid overheating. |
## APPENDIX B: GROUNDWATER SAMPLING DEVICE MATRIX

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

<table>
<thead>
<tr>
<th>Sampling device*</th>
<th>Minimum Bore Diameter*</th>
<th>Sample Delivery Rate or Volume</th>
<th>GROUNDWATER PARAMETERS</th>
<th>INORGANIC</th>
<th>ORGANIC</th>
<th>BIOLOGICAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>EC</td>
<td>pH</td>
<td>Redox</td>
<td>Major ions</td>
</tr>
<tr>
<td>Bailer (open)</td>
<td>13 mm</td>
<td>variable</td>
<td>•</td>
<td>○</td>
<td>○</td>
<td>•</td>
</tr>
<tr>
<td>Point source bailer</td>
<td>13 mm</td>
<td>variable</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Syringe</td>
<td>39 mm</td>
<td>0.05 – 0.1 litres</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Gear-drive</td>
<td>51 mm</td>
<td>0 – 2.3 lpm</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Bladder pump</td>
<td>39 mm</td>
<td>0.9 lpm</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Helical rotor</td>
<td>52 mm</td>
<td>0.5 lpm</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Piston pump</td>
<td>39 mm</td>
<td>0 – 2.3 lpm</td>
<td>•</td>
<td>○</td>
<td>○</td>
<td>•</td>
</tr>
<tr>
<td>Centrifugal (low rate)</td>
<td>52 mm</td>
<td>variable</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Peristaltic</td>
<td>13 mm</td>
<td>0.05 – 1.4 lpm</td>
<td>•</td>
<td>○</td>
<td>○</td>
<td>•</td>
</tr>
<tr>
<td>Gas-lift pump</td>
<td>26 mm</td>
<td>variable</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Gas drive</td>
<td>26 mm</td>
<td>0.1 lpm</td>
<td>•</td>
<td>○</td>
<td>○</td>
<td>•</td>
</tr>
</tbody>
</table>

* It is assumed that existing monitoring bores are properly installed and constructed of materials suitable for detection of the parameters of interest.

† Converted from imperial units to metric units.

Sample delivery rates and volumes are average ranges based on typical field conditions. Actual delivery rates are a function of diameter of monitoring bore, size and capacity of sampling device, hydrogeological conditions and depth to sampling point. For all devices, delivery rate should be carefully controlled to prevent aeration or degassing of the sample.

• Indicates device is generally suitable for application (assuming device is cleaned and operated properly and is constructed of suitable materials).

○ Indicates device may be unsuitable or is untested for application.

Source: Modified from USEPA 1992
## APPENDIX C: FIELD RECORD SHEETS

<table>
<thead>
<tr>
<th>Site:</th>
<th>Location:</th>
<th>Date:</th>
<th>Weather:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Person sampling:</td>
<td>Sample device:</td>
<td>Sampling location (depth):</td>
<td></td>
</tr>
<tr>
<td>Pre-purging groundwater depth:</td>
<td>Post-sampling groundwater depth:</td>
<td>Flow cell: Yes/No</td>
<td></td>
</tr>
<tr>
<td>Pump on (time):</td>
<td>Sample nos:</td>
<td>Pump off (time):</td>
<td></td>
</tr>
</tbody>
</table>

### Field meter calibration

<table>
<thead>
<tr>
<th>EC</th>
<th>pH</th>
<th>DO</th>
<th>Redox potential</th>
<th>Temp</th>
</tr>
</thead>
</table>

### Field Measurements and stabilisation criteria

<table>
<thead>
<tr>
<th>Time</th>
<th>Purge rate (mL/min)</th>
<th>Volume purged (L)</th>
<th>Temp (°C)</th>
<th>Electrical conductivity (mS/cm)</th>
<th>pH</th>
<th>Redox (mV)</th>
<th>Dissolved oxygen (DO) mg/L</th>
</tr>
</thead>
</table>

|                            |                      |                   |           |                                 |     |            |                           |
|                            |                      |                   |           |                                 |     |            |                           |
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|                            |                      |                   |           |                                 |     |            |                           |
|                            |                      |                   |           |                                 |     |            |                           |
APPENDIX D: FIELD EQUIPMENT CHECKLIST

Map of bore locations
Bore logs
Field measurements from past sampling
Field notebook, pencils, pens, markers calculator
Field record sheets
Chain-of-custody sheets
Key for bores
Lubricant for locks
Keys to access site
Water level gauge
Tape measure
Field meters
Flow-through cell
Purging device
Sampling device
Sample containers
Filtration equipment
Preservation materials (eg ice, nitric acid)
Decontamination equipment
  buckets for washing and rinsing
  detergent solution
  spray bottle
  deionised water
  plastic sheeting
Personal protective clothing and equipment
  sun screen
  hat
  sunglasses
  overalls
  gloves
Business cards/ID
Camera and film
Toolbox
APPENDIX E: CHAIN-OF-CUSTODY FORM

General Information

PROJECT NAME ..........................................................................................................................

Name and Address of Organisation ..........................................................................................

Name of Person Requesting Analysis: ............... Telephone: ............. Fax: .................

Sample Data

Samplers (names and signatures): ................................ ................................ ...........................

<table>
<thead>
<tr>
<th>Sample number</th>
<th>Date sampled</th>
<th>Time sampled</th>
<th>Sample description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tbody>
</table>

Chain-of-Custody

<table>
<thead>
<tr>
<th>Relinquished by</th>
<th>Received by</th>
<th>Date and Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>(name and signature)</td>
<td>(name and signature)</td>
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REFERENCES


