

# module 6

WATERWATCH AUSTRALIA NATIONAL TECHNICAL MANUAL

Groundwater Monitoring

## Module 6 – Groundwater Monitoring

Waterwatch Australia National Technical Manual  
by the Waterwatch Australia Steering Committee

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Published by the Department of the Environment and Heritage

ISBN 0 6425 4856 0

Published September 2005

*Department of the Environment and Heritage*

*Cataloguing-in-Publication data:*

Module 6. Groundwater Monitoring / Waterwatch Australia  
Steering Committee.

p. cm.

1. Water quality – Australia – Measurement. 2. Water  
resources management – Australia – Citizen participation. I.  
Waterwatch Australia.

363.7394'63'0994-ddc21

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## Preface

The *Waterwatch Australia National Technical Manual* was prepared by the Waterwatch Australia Steering Committee to provide guidance and technical support to the Waterwatch community monitoring network throughout Australia. The content has been gathered from a range of publications, including the existing State Waterwatch Technical Manuals. The guidelines and information reproduced in this Manual have been agreed by the members of the committee based on their knowledge and experience in coordinating community monitoring programs in Australia with advice from the scientific community.

The Manual has been published as a series of modules. Each module is a stand-alone document addressing an important aspect of community waterway monitoring. The following modules are available in the Manual:

1. Background
2. Getting Started: the team, monitoring plan and site
3. Biological Parameters
4. Physical and Chemical Parameters
5. Data to Information to Action!
6. Groundwater Monitoring (this module)
7. Estuarine Monitoring

Waterwatch Australia would like to thank BRS for their technical knowledge and support in developing this module.

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# Introduction

*Groundwater* is a valuable resource. It can be found beneath most land and most of the available fresh water on earth is groundwater. Because it is hidden from our view it tends to be somewhat mysterious. Despite much available information, groundwater existence, movement, quantity and quality remains obscure to the broader community. Yet millions of people depend on groundwater as a source of water for drinking, irrigation and many other uses. As industrial and agricultural development of Australia increases, the demand for water also steadily grows. Understanding the basic processes and facts about groundwater as well as the factors that can affect its quality is of vital importance in managing this significant resource.

## Groundwater facts

- Approximately 3% of the earth's water exists in land (97% are the oceans).
- 77% of water on the land exists in the form of ice, 22% is groundwater, and the rest is surface water.
- Most groundwater contains high concentrations of dissolved salts and is too saline for human use.
- Groundwater is extensively used for irrigation, industry and human consumption.
- Up to four million people in Australia depend totally or partially on groundwater for domestic water supplies.
- About 21% of water used in Australia is derived from groundwater sources.
- 32% of groundwater extracted is for urban–industrial use, 51% for irrigation and 17% for stock watering and rural use.
- Between 1985 and 1996–97 the annual volume of groundwater extracted increased from 2600 GL per year to 5000 GL per year.
- A large proportion of groundwater extracted from *aquifers* is wasted.<sup>1</sup> Water losses occur through leaks in *bores*, evaporation or seepage from channels.
- 90% of groundwater extracted from the largest Australian groundwater system – the Great Artesian Basin – is lost before it can be used.
- Over-extraction of groundwater poses a significant threat to sustainability of groundwater–dependent ecosystems (such as springs and soaks) and groundwater resources, along with possible impacts on surface water.<sup>2</sup>

## Scope of this module

This module has been developed for community groups who are participating in Waterwatch and undertaking community water monitoring to use. The main aims of the module are to:

- provide information about basic groundwater processes
- impart an understanding of the implications of human behaviour and actions on the health of groundwater systems
- provide simple and efficient methods for monitoring groundwater systems
- increase understanding of how groundwater monitoring relates to the health of surface water bodies and water dependent ecosystems
- encourage community involvement in knowledge dissemination, groundwater monitoring and, in consequence, protection of local environments.

<sup>1</sup> Terms in *italics* are defined in Appendix 1: Key terms.

<sup>2</sup> Adapted from Australia State of the Environment Report 2001 – Inland Waters Theme Report and Water Resources and use in Australia, <[www.farmweb.au.com](http://www.farmweb.au.com)>.

# Hydrologic cycle

From the time the earth was formed water has been endlessly circulating. This circulation is known as the hydrologic cycle. Groundwater constitutes an integral part of this dynamic cycle and is interrelated with surface water. It is therefore important to understand the processes that water undergoes during the hydrologic cycle.

The distribution of water on the land depends on the complex interactions between the atmosphere and oceans that we call climate (see Figure 6.1). These processes cause water to change state (vapour, liquid, solid) as it moves between the ocean, the atmosphere and the land.

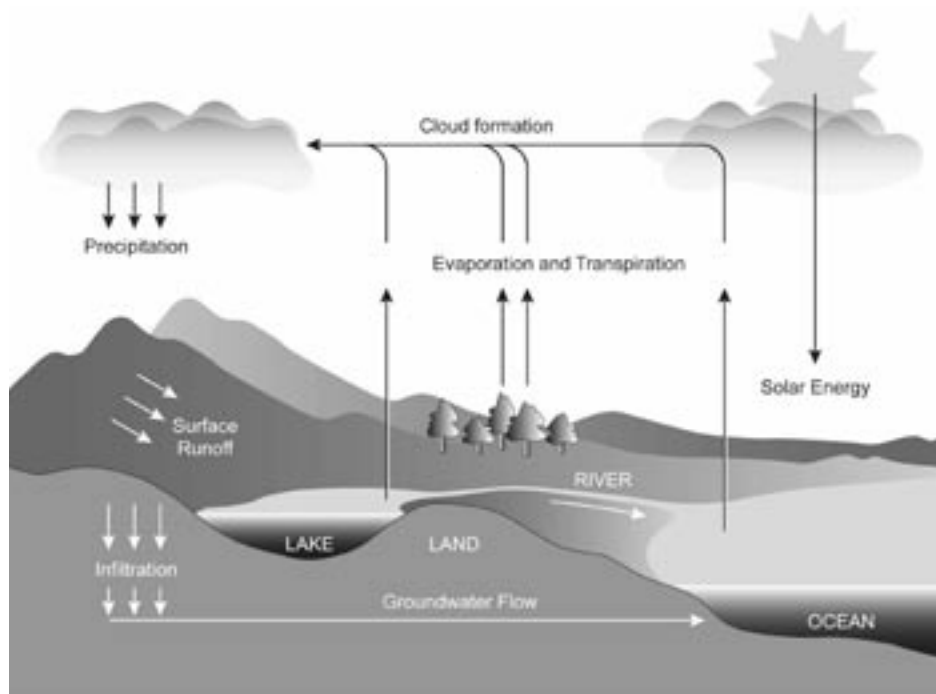
- The cycle begins with the evaporation of water from water, plant and soil surfaces to form water vapour. The vast majority of evaporation (85%) occurs from the oceans. The sun supplies the energy needed to evaporate water.
- Water vapour is drawn into the atmosphere and can be transported over hundreds of kilometres by large air masses.
- When water vapour cools it condenses and forms clouds. Water droplets increase in size until they fall to the earth's surface as *precipitation* such as rain or snow.
- A large part of all water falling as precipitation (nearly one-third) completes the cycle to the oceans by surface *run-off* in streams and rivers.
- Approximately 70% of water that falls to the earth's surface enters soil. Most of it returns to the atmosphere by evaporation from the soil surface or is used by vegetation,

which also eventually ends up in the atmosphere through *transpiration* of plants.

- Only a very small fraction of water falling as precipitation infiltrates below the surface through bedrock or soils to form groundwater.
- Groundwater may move into surface waters such as lakes or streams. In many areas groundwater flow from springs is a primary source of water for rivers.
- Groundwater may remain in storage in aquifers for a very long time.
- The cycle is completed through the evaporation of the surface water and also the *discharge* of groundwater into the oceans.

The planet earth is unique in the universe in that a large part of it is covered by water and also that large quantities of water are bound within land. After oceans, groundwater is the second largest source of water on earth.

Figure 6.1: Components of the hydrologic cycle



## Understanding groundwater

This section contains information about groundwater. It explores what groundwater is, where it comes from and how it is stored; it also discusses how groundwater can move underground and how it can decline or become contaminated. Importantly for Waterwatchers, this section also discusses groundwater chemistry and how to monitor groundwater.

## What is groundwater?

Many people think groundwater is stored in vast underground lakes or is flowing in underground rivers. In fact, groundwater is the water that fills the spaces and cracks between particles of soil, sand, gravel, rock or other materials that lay beneath the surface of the earth, very much in a way that water saturates a sponge. Geological formations composed of *permeable* materials and capable of storing and yielding large quantities of water are called aquifers. The area where water fills the aquifer is called the *saturated zone*. The top of the saturated zone is called a *water table*. The water table may be located very close to the surface of the earth or it can sit hundreds of meters below (see Figure 6.2).

## Groundwater storage

### Aquifers

Aquifers typically consist of gravel, sand, sandstone, or fractured rock such as basalt or granite. These materials are permeable because they have large connected spaces (pores) or fractures that permit water to flow through them.

If a material contains pores that are not connected it is impermeable – groundwater cannot move from one space to another. Materials such as clay or shale have many small pores but the pores are not well connected therefore they restrict the flow of groundwater.

There are two types of aquifers – unconfined and confined (see Figure 6.3).

Figure 6.2: What is groundwater?

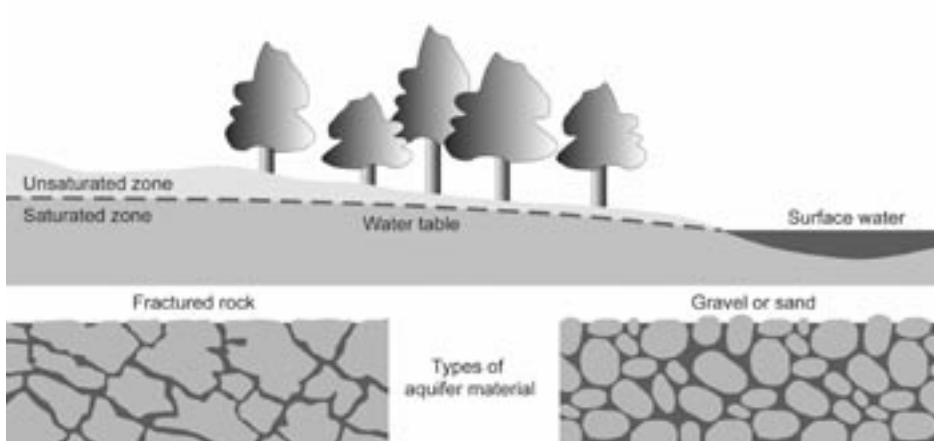
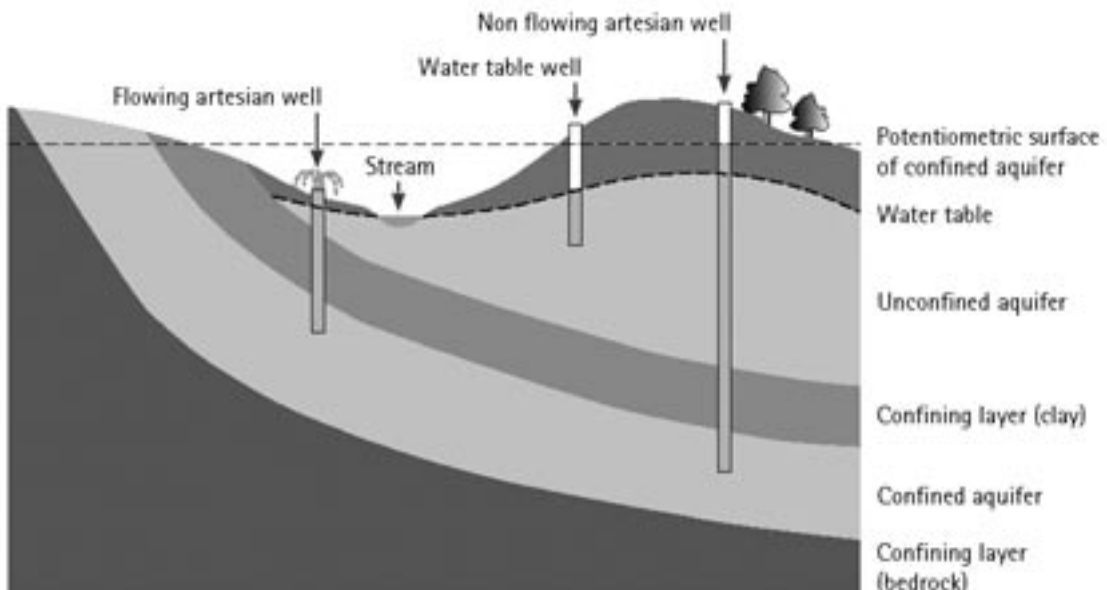


Figure 6.3: Types of aquifers



An *unconfined aquifer* has no confining layers between the saturated zone and the land surface. Groundwater is in direct contact with the atmosphere through the open pore spaces of the overlying soil or rock. The water table forms the upper boundary of the unconfined aquifer. In an unconfined aquifer, the water level in a *well* rests at the water table.

The *confined aquifers* are confined between two layers of relatively impermeable material, called *aquitards*. Confined aquifers occur at much greater depth (sometimes hundreds of meters) than unconfined ones. In a confined aquifer groundwater is under pressure and the water level in a well may rise above the top of the aquifer. Such an aquifer is said to exist under artesian conditions and the well is called an *artesian well*. In some cases the water level may rise above the ground surface, and the well is then called a *flowing artesian well*.

## Where does groundwater come from?

Groundwater, like all water on earth, originates from precipitation – rain and snow. Water that is not used by vegetation percolates through the soil until it reaches the saturated zone. The process of water seeping down from the land surface to the ground to become groundwater is called *groundwater recharge*. The area on the surface where water

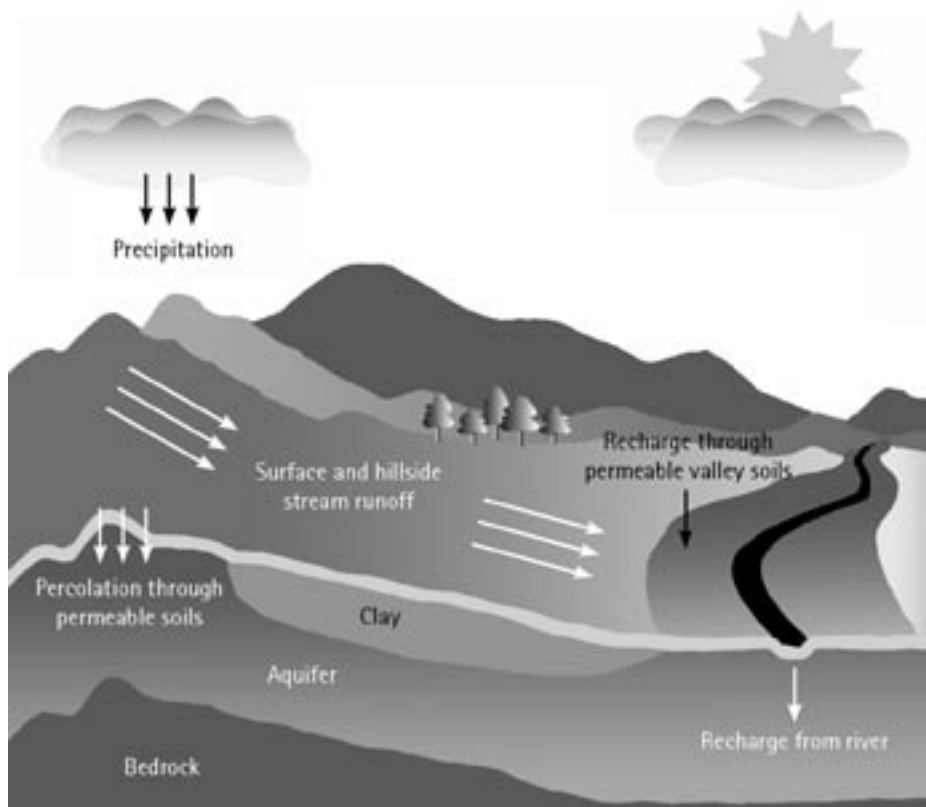
soaks in is called the *recharge area*. Rivers or streams soaking into an aquifer can also recharge groundwater.

Unconfined aquifers are recharged with water that infiltrates directly downward from the earth's surface. In the case of a confined aquifer, water is prevented from percolating down by the overlying aquitard. Instead, water enters the aquifer layer through a recharge area where the aquifer rock is exposed at higher elevations.

The volume of precipitation that enters an aquifer depends on the amount of rainfall and the character of the ground cover. A large proportion of precipitation falling onto the surface is used by plants and lost to evaporation. Significant recharge can be expected only during extended rainy periods (see Figure 6.4). The water table will fall or rise depending on seasonal and annual variations in recharge. Greatest changes will be observed during prolonged droughts or periods of heavy rainfall.

Groundwater is affected by long-term climate cycles. Many groundwater systems were filled in past geological periods when the climate was considerably wetter than it is today. In many areas present recharge from precipitation and outflow from streams may be sufficient to maintain groundwater levels. However in some areas of dry climate with low precipitation, and hence low recharge, groundwater can be used more rapidly than it is being replaced which may cause the aquifer to run dry.

Figure 6.4: Groundwater recharge



## How does groundwater move underground?

Aquifers are not only a storage reservoir for groundwater, but also a pathway for water movement underground.

Groundwater moves from an aquifer's recharge area (where water seeps into the saturation zone) until it reaches a *discharge zone*, an area where the water level is above the land surface.

Groundwater moves very slowly and only if sufficient pressure, or *head*, is available to force water through the spaces (pores) with the aquifer material. The *hydraulic gradient*, or slope of the water surface between two points in an aquifer, the cross-sectional area of the aquifer and the aquifer material combine to determine how rapidly water moves from one location to another.

Groundwater moves from high water surface elevations (high pressure or head) to low water surface elevations (low pressure or head). The direction of groundwater flow normally follows the general *topography* of the land surface.

*Flow rates* in aquifers are measured in meters per day. It may take years, decades or even centuries for water to flow through some aquifers. However in aquifers made of porous materials (coarse gravel) or fractured rock with large openings (fractured basalt) flow rates are much faster. In some cases water may be underground only a few days or weeks before reaching the discharge zone.

Groundwater can be naturally discharged in several ways:

- In streams – groundwater may flow into streams in areas with a relatively high water table.
- As springs or wetlands – water flows out of the ground surface where the water table intersects the ground surface. Springs may also form where fracture systems or cave systems reach the ground surface.
- As ocean discharge – groundwater will discharge to the ocean along the coast.

Water leaving an aquifer and water that is pumped from a well is also called discharge water.

## Groundwater declines

Groundwater is increasingly being seen as an alternative source to surface water supplies. It is a vast resource with relatively constant chemistry and temperature and it is usually biologically pure. In many regions it provides a much cleaner source of drinking water than heavily polluted surface waters. Irrigation and industrial processes also use large amounts of groundwater. Groundwater use has increased substantially all over the world in recent years.

Under natural conditions a balance exists between the volume of water entering an aquifer and the volume of water being discharged from the aquifer. However, because of the increased demand for groundwater extraction and the development of a large number of extraction bores, this natural balance between recharge and discharge rates is often disrupted. When abstraction from the aquifer exceeds the average long-term recharge from rainfall, groundwater levels will steadily decline and the aquifer yield will eventually fall.

As one of the elements of the hydrologic cycle of our planet, groundwater plays an essential part in sustaining natural biodiversity and functioning of the environment as a whole. Any disruption of this system caused by human activities will have its ill effect on the environment. If groundwater levels fall too far, users and the environment may be affected. For example:

- Wells may produce less than their usual yield, or even dry up completely. Lower yields mean less water is available for domestic water supply, stock drinking water, irrigation and other uses.
- Springs, wetlands, streams and rivers that are fed by groundwater may partially or completely dry up, causing adverse ecological effects; whole ecosystems with their diverse animal and plant life may be destroyed.
- Low flows of rivers may not be sufficient for proper dilution of discharged wastewater, resulting in greater surface water pollution.
- An increased danger of *saltwater intrusion* into groundwater supplies in coastal regions.
- Deterioration of groundwater quality.
- With the water removed, aquifers can compact causing land subsidence.

Only appropriate groundwater management policies and practices can ensure a balance between essential groundwater abstraction and the demands of the natural environment and its protection.

To avoid irreversible damage to groundwater systems the extraction amount for any aquifer should be established based on the long-term *sustainable yield* assessment, i.e. a volume of groundwater that can be extracted annually from a groundwater basin without causing adverse effects.

## Groundwater chemistry

As a result of chemical and biochemical interactions between groundwater and the materials through which it flows, groundwater contains a variety of chemical constituents at different concentrations. The greater part of the soluble constituents in groundwater comes from soluble minerals in soils and sedimentary rocks. A much smaller part has its origin in the atmosphere and surface water bodies.

Sodium and chloride are two dominant ions (or salts) found in groundwater. The other naturally occurring major ions are calcium, magnesium, potassium, silica, bicarbonate, nitrate and sulphate. Ions like manganese, iron, boron, fluoride, aluminium, are present in much smaller concentrations (minor ions). Small amount of dissolved organic compounds are also found in groundwater.

The most common measure of the chemical quality of water is *salinity* – the salt content of water. The two most common methods of describing the salt content are *total dissolved solids* and *electrical conductivity*.

The concentration of total dissolved solids (TDS) is a measure of all inorganic constituents dissolved in water and is determined by evaporating a known volume of water and weighing the remaining salts. TDS is expressed in milligrams per litre (mg/L).

Nearly all dissolved constituents are present in water in ionic form therefore a measure of water's capability to conduct applied electrical current provides an indication of the level of total dissolved ionic constituents. This property of water is called electrical conductivity (EC), measured in units of micro siemens per centimetre ( $\mu\text{S}/\text{cm}$  at 25°C). Electrical conductivity is directly linked with the value of TDS (EC units  $\times 0.64 = \text{mg}/\text{L}$ ).

TDS and EC are parameters used for categorising groundwater. Water containing more than 2000 mg/L TDS is generally too salty to drink. The TDS of seawater is approximately 35 000 mg/L.

Dissolved constituents in groundwater provide valuable information about the origins and age of water, its geologic history, its influence on rock masses through which it has passed and the presence of mineral deposits.

The chemical content of groundwater also determines its usefulness for industry, agriculture or drinking. Due to high concentrations of various chemical constituents, most of the earth's groundwater resources are not suitable for drinking or even for use in industry and agriculture – only 8% is estimated to be suitable for extraction and human use.

### Water quality guidelines

National water quality guidelines<sup>3</sup> place specific constraints on the quality of water that is intended for specific uses.

The most stringent standards apply to drinking water. The recommended limits for concentrations of inorganic constituents in drinking water have been in use for many years and are based on their detrimental effect on human health.<sup>4</sup> Limits for organic constituents such as pesticides and other contaminants have also been established.

Guideline values have been determined for those chemical components that are considered to have significant potential to harm human health at concentrations above the specified limits. Guideline values should not be exceeded in public water supplies. It should also be noted that exceeding the guideline values is generally not a matter for concern, but a trigger for follow-up action.

#### Water categories based on total dissolved solids

Category	TDS (mg/L)	EC ( $\mu\text{S}/\text{cm}$ )
Fresh water	0 – 1500	0 – 2400
Brackish water	1500 – 3000	2400 – 4700
Saline water (stock)	3000 – 14 000	4700 – 22 000
Saline	14 000 – 35 000	22 000 – 50 000
Hyper saline	35 000 – 100 000	50 000 – 160 000
Brine	More than 100 000	More than 160 000

Note: EC value obtained from calculation  $\text{TDS} = 0.64 \times \text{EC}$ .

Source: Freeze, R.A. & Cherry, J.A., 1979, *Groundwater*. Prentice Hall, Upper Saddle River, NJ, USA, 604pp.

- <sup>3</sup> ANZECC & ARMCANZ 2000, *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*. NWQMS Paper No. 4, Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand, Canberra.
- <sup>4</sup> NHMRC & ARMCANZ 1996, *Australian Drinking Water Guidelines*. NWQMS Paper No. 6, National Health and Medical Research Council and Agriculture and Resource Management Council of Australia and New Zealand, Canberra.

In many regions groundwater is used mostly for agriculture. The quality of groundwater is then assessed relative to guidelines established for livestock and irrigation. Since different crops and livestock vary considerably in their ability to tolerate salts in water, the major characteristic to be considered for water intended for use in agriculture is salinity.

Water quality guidelines for aquatic ecosystems also apply to groundwater. Guideline trigger values have been established for selected indicators. For some indicators, trigger values are based on alternative levels of species protection.

## Groundwater contamination

### How does groundwater get contaminated?

The way we use the land can have detrimental effects on the quality of groundwater (see Figure 6.5). Pollution may be associated with specific identifiable point sources such as leaking underground storage tanks, or may not be traceable to a single point of origin but may occur over a wide area (non-point source) like pesticides and fertilisers applied to crops and washed off into the groundwater systems.

Groundwater can become polluted in a number of ways, such as:

- improper disposal of chemicals, oils, pesticides, other wastes and used containers (e.g. small disposal pits located in areas of high porosity and high water table)
- improper use and storage of house and garden chemicals
- poor installation and maintenance of septic systems or too many closely-spaced systems in a small area
- landfills – lack of control over hazardous wastes disposal, no liner or liner failure, leaky landfill cover
- leaking or poorly located storage lagoons used by industries, farms, municipalities, mining operations, oil and gas producers
- leaking underground storage tanks (petrol, oils)
- dumping of wastes in inactive mining pits

- spills of hazardous materials (fuel, solvents, organic chemicals)
- pesticides and other agro-chemicals – excessive or ill-timed application, improper storage, leaching through soil
- over-fertilisation with animal manure
- land application of sludges and wastewater
- urban run-off
- polluted surface water entering groundwater through badly constructed boreholes.

### Effects of groundwater pollution

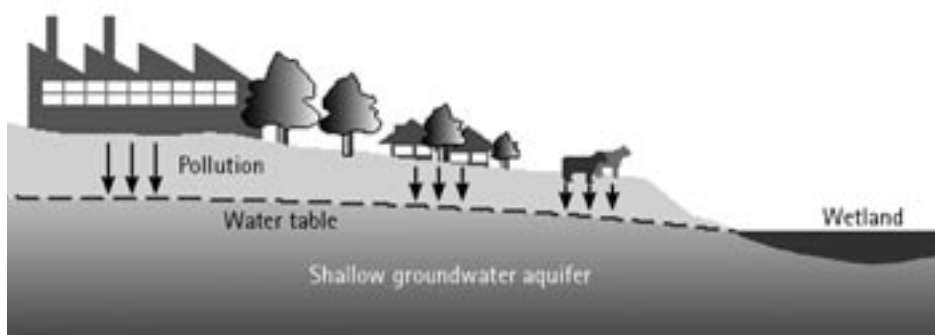
The effects of groundwater contamination are difficult to detect. Unlike surface waters, where signs of contamination are often quickly obvious even to a casual observer, aquifer contamination can often be discovered only after a water supply bore has been affected. It is also difficult and time consuming to assess the true extent of the problem. By that time it is usually too late to apply remedial measures that would be of much benefit. Once contaminants spread in the aquifer they are extremely hard to remedy because groundwater moves very slowly. Often pollution results in permanent damage to the aquifer.

### How to prevent groundwater contamination

It is better to prevent groundwater contamination than risk contamination and subsequently spend large resources to clean it up. There are many ways to prevent groundwater contamination; some are actions that appropriate authorities should take, others can involve participation of individuals on a much smaller, but no less important, scale. Such actions can include:

- careful monitoring of land use
- proper location, design, maintenance, and operation of landfills, storage tanks, storage lagoons, etc.
- use and disposal of house and garden chemicals (e.g. fertilisers and pesticides) according to label specifications

Figure 6.5: Possible modes of groundwater contamination



- restriction of certain activities near groundwater extraction areas
- proper installation and maintenance of septic systems
- closure of unused mining pits by restoring topsoil cover
- proper construction of boreholes and closure of unused bores
- management of urban run-off through street sweeping, established vegetated collection areas and infiltration basins for street run-off, etc.
- where possible, use of alternative environmentally friendly materials.

Proper land use management is the key to groundwater quality protection. Land use activities that result in contaminated groundwater can often be traced to lack of understanding of the potential for contamination, carelessness or negligence. That is why dissemination of information to the public and getting directly involved in monitoring and education activities are of vital importance.

## Groundwater monitoring

Groundwater monitoring provides data on groundwater quality and quantity and is an integral aspect of groundwater management. Continual monitoring of groundwater assesses the impact of human activities on groundwater systems. Ideally groundwater monitoring should be carried out regularly in all areas where groundwater resources are extracted for a variety of uses.

The main objectives of groundwater monitoring are to:

- collect data documenting any change in groundwater storage over time
- provide both long-term and short-term data necessary to assess and predict the response of hydrologic systems to natural climatic variations and human-induced stresses
- establish as accurately as possible the baseline quality of groundwater occurring naturally in aquifers
- detect trends in the concentrations of these groundwater constituents, which may pose a risk to human health or impact on other human activities.

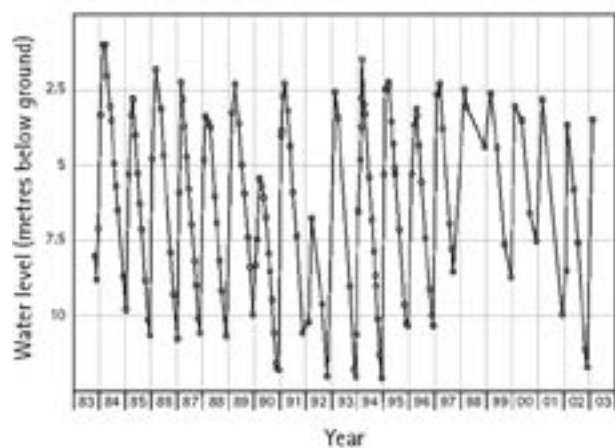
One of the most pressing problems of Australian agriculture is human-induced salinity. General land clearing and introduction of wide-scale agricultural practices, in particular irrigation, has in many cases exacerbated naturally occurring processes, leading to the more rapid development of salt affected soils and water. Since groundwater has the ability to mobilise and transport soluble salts when it moves through the soils, it is important to know where the water table is, and understand its movements, in particular with respect to rainfall events and certain agricultural practices (e.g.

irrigation). By understanding and monitoring groundwater movement and quality, agricultural land can be managed to help suppress and avoid problems like salinity.

## Groundwater level monitoring

Groundwater levels are affected by natural climatic conditions (amount of recharge reaching the aquifer) as well as by a range of human activities, such as land use and groundwater extraction. It is of vital importance to monitor changes in the water level within the aquifers as it helps to manage the groundwater resources properly and plan land use activities to minimise their impact on the environment. Seasonal and yearly changes in groundwater levels are represented in a hydrograph (see Figure 6.6).

Figure 6.6: Example of a hydrograph



Frequent (monthly or even weekly) and regular groundwater level monitoring helps to answer important questions such as:

- At what depth is the groundwater?
- Is the groundwater rising or falling over time?
- What effect does irrigation or other management practices have on water table movement?
- How big is the effect of rain events on the water table?
- How long does it take to see the effects of a rain event on the water table?
- What is the effect of a prolonged dry spell on the water table?

Data collected over long periods (years) can provide information on long-term effects of the climate and extraction levels on the aquifer.

## Groundwater quality monitoring

Groundwater quality monitoring can be done for variety of purposes. Some of them are:

- understanding the current state of water quality in the aquifer
- checking compliance with standards
- detecting long-term trends in groundwater quality
- determining suitability for specific uses
- understanding the causes of salinity
- detecting suspected contamination
- preventing and/or remediation of saltwater intrusion in coastal aquifers
- tracing movement of contamination within the aquifer.

Depending on the purpose of the monitoring, a variety of parameters can be tested. Comprehensive chemical analysis of groundwater involves specific sampling protocols for different water constituents and contaminants and some analyses can be done only in a laboratory, as specialised equipment is necessary. Often only certain parameters pertaining to a specific problem are tested.

Electrical conductivity (EC) is one of the most important and commonly measured parameters. It provides information on the salt content (salinity) of groundwater. *Seawater intrusion*, the most common pollutant of fresh groundwater, is a growing problem in areas where coastal aquifers are used as a source of drinking water for growing populations of coastal communities. As little as 2% seawater in freshwater can render the water unpotable. The salinity of the groundwater also determines its uses in agriculture and industry. Long-term salinity monitoring helps identify and possibly prevent and/or remedy problems of groundwater *salinisation*.

## Groundwater in Australia

Groundwater can be found beneath most land in Australia, however the resources are unevenly distributed and vary in quality and aquifer yield (see Figure 6.7). In some regions groundwater provides for the majority of water needs, while other regions have no access to viable groundwater resources. Many of the potentially high-yielding aquifers represent a limited resource as they are located in arid and semi-arid areas of the continent and receive relatively low rates of natural recharge compared with the volume of water they store. Poor quality of groundwater (high salt content) can be

a major impediment to development of the resource in other areas. It has been estimated that the total volume of drinking quality groundwater that can be sustainably extracted is about 25 000 GL/year.<sup>5</sup>

Some groundwater resources are already overdeveloped. In coastal regions with high population and industrial growth (i.e. high water demand) the rates of extraction often exceed the rates of recharge. On the other hand many underdeveloped groundwater resources are in remote, sparsely populated areas.

Overall about 21% of water used in Australia is derived from groundwater sources. About 32% of groundwater is extracted for urban-industrial use, 51% for irrigation and 17% for stock watering and rural use, but this varies by state. South Australia, New South Wales and Victoria primarily use extracted groundwater for irrigation, while Western Australia's use is mostly for urban and industrial purposes. Queensland uses large amounts of groundwater for rural stock and domestic uses.<sup>6</sup>

## Groundwater management units

Australia has 61 major groundwater provinces – areas of broad uniformity of hydrogeological and geological conditions with reasonably uniform water-bearing characteristics (predominantly sediment or fractured rock).

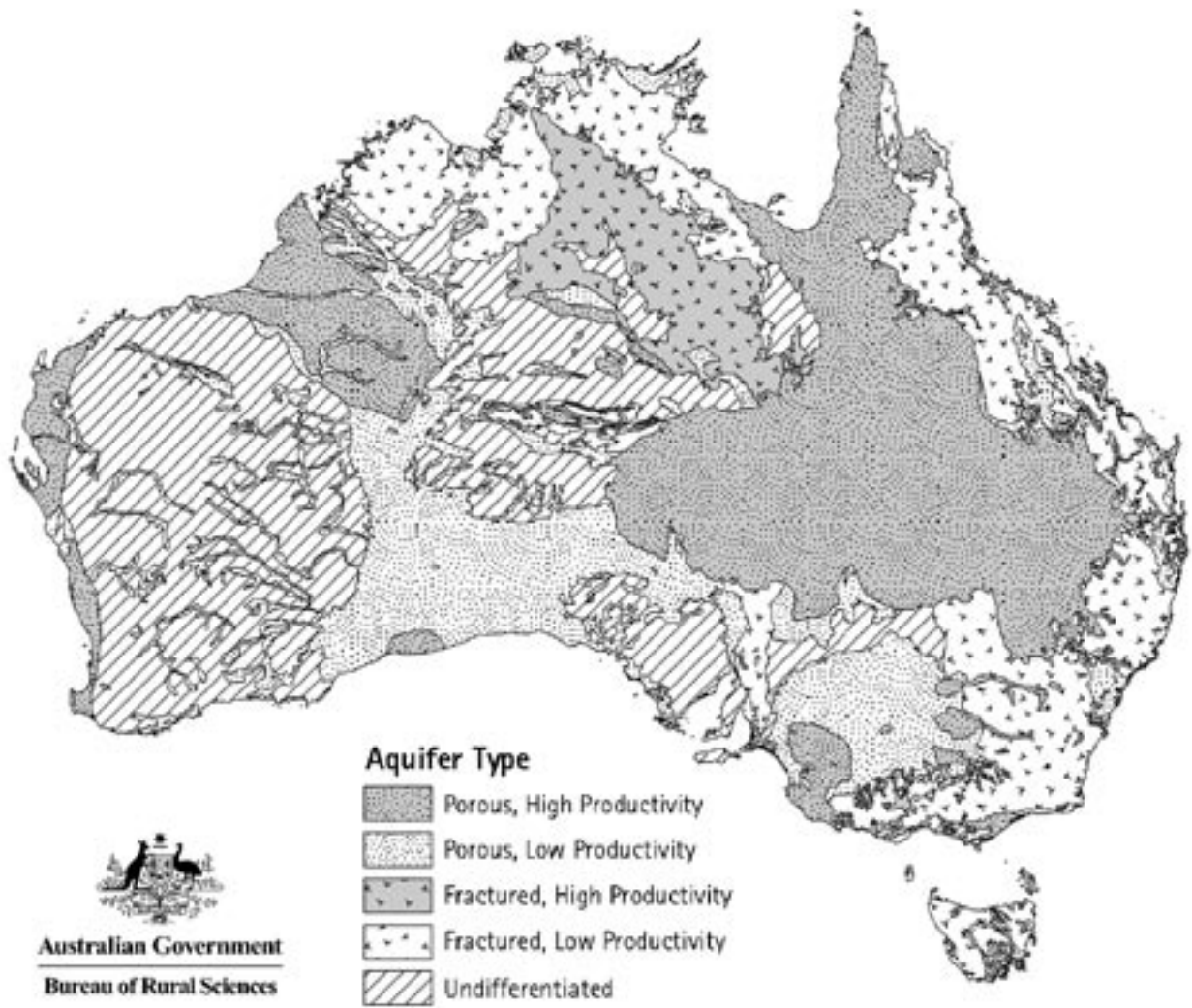
The Great Artesian Basin, the largest groundwater province of approximately 1.7 million km<sup>2</sup>, stores 8 700 000 GL of water. The Great Artesian Basin is one of the largest groundwater basins in the world. Eight of the ten provinces with the highest groundwater use are in eastern Australia.

For the purposes of better and more efficient groundwater management, smaller groundwater management units have been used. There are 422 GMUs in Australia. Groundwater management units are defined by state and territory governments and are based on areas where groundwater has a low salinity and high use or where groundwater is used in environmentally sensitive areas. Groundwater management units include one or more hydraulically connected aquifers; and one unit may lie below or above many other units. Since the states and territories undertake groundwater management, groundwater management units do not cross state or groundwater province boundaries. Areas outside of groundwater management units are called 'unincorporated areas'.

<sup>5</sup> National Land and Water Resources Audit 2001.

<sup>6</sup> State of the Environment Australia 2001.

Figure 6.7: Map of groundwater basins in Australia





## Access to groundwater

It is often quite complicated to obtain groundwater samples because groundwater is not easily accessible and has to be brought to the surface. How can this be done?

The simplest way to tap groundwater is to dig a well. Wells are usually dug manually to reach the shallow water table within the unconfined aquifer. However, if a water-yielding aquifer is deeper than a few meters, a proper borehole has to be constructed. Choosing a site for water bore and bore construction are complex tasks requiring knowledge of an expert hydrogeologist, a skilled driller and expensive drilling equipment.

Many issues need carefully considered before a bore can be constructed. Some of the questions that need to be answered include:

- What is the geomorphology of the area?
- How deep is the aquifer?
- What is the most suitable depth of the bore?
- What is the purpose of the bore (monitoring or production)?
- If it is a production bore, how much water is needed and how much water can be safely extracted?
- Are there any other bores in close proximity?
- Is the proposed location far enough from potential contamination sites like irrigation, septic tanks, drainage lines, animal feedlots, etc.?
- If it is a monitoring bore, is it in a suitable position to monitor the impacts of potential contamination sites?

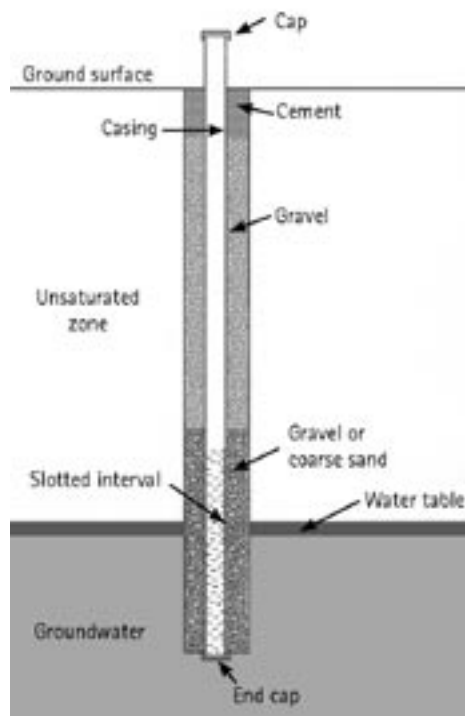
All groundwater bores should be drilled, cased and equipped according to construction standards defined in *Minimum Construction Requirements for Water Bores*.<sup>7</sup> This document deals with a broad scope of issues pertaining to water bore construction from licensing to construction, development and decommissioning for shallow small-diameter and low-yielding bores, through to high-yielding, deep and large-diameter bores.

**It is recommended that sampling be conducted from existing bores for the Waterwatch groundwater monitoring program.**

## Monitoring bores

Monitoring bores are constructed for the sole purpose of monitoring water levels, with water sampling being a subsidiary function. They are usually sunk into shallow aquifers, have a 50 to 100 mm diameter casing (50 mm diameter casing limits the type of monitoring that can be done, so a minimum of 80 mm is recommended) and are not equipped with permanent pumping devices (see Figure 6.8). Installation of a shallow monitoring bore is relatively simple and inexpensive since they penetrate only several meters of soil to reach a shallow unconfined aquifer.

**Figure 6.8: Diagram of monitoring bore**



<sup>7</sup> Agriculture and Resource Management Council of Australia and New Zealand 1997.

A typical monitoring bore is usually constructed as follows:

- During or after drilling, a metal or plastic pipe (casing) is lowered into the borehole. Usually 80 to 100 mm diameter PVC pipe is used. The casing supports the walls and prevents the rocks and debris from collapsing the bore. It also protects the bore from contamination by surface run-off. Groundwater is drawn through the casing, from the aquifer to the surface.
- The casing is perforated (slotted) along its lower length that is installed within the water-bearing section of the bore, preferably at the bottom of the aquifer. This allows groundwater to percolate from the surrounding aquifer into the casing.
- Gravel or coarse sand is used to fill the space between the soil and the slotted section; this allows water but not soil to flow into the bore.
- An end cap with a hole punctured in it is placed on the bottom of the casing to allow water to drain freely out of the pipe if the bore goes dry; this prevents false readings due to trapped water.
- The upper 1 to 2 metres just below the soil surface is a solid pipe; space around the casing is filled with soil and a cement seal or bentonite clay is set around the casing at ground level to prevent surface water from seeping down the outside of the casing.
- An end cap with a small hole in the side to allow air to escape is placed on the top of the casing to protect it from contaminants such as rain or soil; bore identification information can usually be found inside the cap.
- The upper part of the casing can serve as a housing for the pumping equipment.

## Production bores

Production bores are constructed with the aim of extracting water for different purposes (irrigation, industrial, drinking water). They are generally sunk deeper into an aquifer than a monitoring bore. Often the aquifer used is the confined aquifer lying below the surface aquifer that stores water of poorer quality (e.g. high salinity).

Although construction of the production bore is, in principle, similar to the monitoring bore, there are some differences:

- Installation of the production bore, especially if it taps into a very deep aquifer, requires special drilling equipment and can be very costly.
- Choice of drilling equipment and method depends on whether it is a low-yielding bore for obtaining a usable supply of water for livestock watering and/or domestic use, or a high-yielding bore penetrating multiple aquifers and supplying large volumes of water for irrigation or a town drinking water supply.
- Casing of the production bore is usually of much larger diameter and depending on the characteristics of the layers through which the bore is drilled, different materials can be used.
- To prevent contamination of a fresh aquifer by an overlying saline one, it is essential that the entire casing be properly cemented over its entire length. This can also prevent loss of pressure by the upward leakage of water behind the casing.
- Different types of energy can power the pumping equipment: electrical, solar, or the wind (a windmill).
- The upper portion of the casing serves as a housing for the pumping equipment.
- Depending on the scale of water extraction and its use, pumping equipment can be quite simple or very sophisticated with water being reticulated by a pipe system to its final destination.
- Where the bore is artesian, *headworks* must be designed to prevent water running to waste when not in use.

Many city or shire councils, commercial enterprises and individuals (farmers) have production bores installed on their properties.

**If you are considering using such a bore for a Waterwatch monitoring program, you must obtain permission from the owners/custodians before starting sampling.**



# Designing groundwater monitoring plans

This chapter is based on Module 2 of Waterwatch Australia National Technical Manual, *Getting Started: the team, monitoring plan and site.*

## What is groundwater monitoring?

Groundwater monitoring is a means of gathering information about the condition of the aquifer. It involves obtaining a representative sample of water stored in the aquifer and performing a variety of tests and measurements. Monitoring should occur at defined intervals (preferably over a number of months or years), in accordance with an agreed plan and the observations and results should be recorded so they can be shared.

The information from your monitoring will help you describe the state of the groundwater body (water levels falling or rising, salinity, water contamination) and understand changes that may occur. Often its main purpose will be teaching and raising awareness about groundwater issues within a community, but in some cases it can also be used to initiate action leading to protection of the aquifer by changing the land use and water use practices.

Often a single issue will trigger the interest of individuals and groups. One way to identify issues is to ask questions about uses, values and threats. The sorts of questions you could ask are:

- What factors affect the local aquifer?
- How is the groundwater used now?
- What is the quality of the groundwater in your area?
- Is the quality of groundwater changing due to over-extraction or continuous pollution?
- Does a risk of pollution exist in your area (use of agricultural chemicals, industrial pollution, etc.)?
- Is the high salinity of surface water and soil a problem in your area?

Monitoring of groundwater is important for a variety of reasons. For example:

- it can help us understand the actual state of the aquifer
- it can help us to understand the effects of our land and water management practices – good or bad
- the data collected during monitoring can dictate management decisions and later for evaluating the effects of these decisions.

## A team approach

It is usually best to form a group or team to do the monitoring. Potential team partners include schools, Landcare or conservation groups, community groups, service clubs, industry, local businesses, state government agencies, *catchment* boards, local government and interested individuals.

Through a team approach, you can spread the workload. A team has more contacts than an individual, and can more easily collect local knowledge and the anecdotal evidence of the problems. A team can gain access to the expertise and resources of local authorities concerned with groundwater issues by inviting them to join. Conversely, local authorities can benefit from your monitoring work and from the greater understanding spread through the community. With teamwork, the monitoring project is more likely to be kept on the schedule chosen for it and to be continued for a useful period of time.

Start by contacting your Commonwealth facilitator who will put you in touch with a local or regional coordinator. They will be able to advise you on how to get started. You will have access to the expertise of Waterwatch across Australia, and assistance and guidance as well as training sessions. You will be able to link with other monitoring groups and water authorities within the catchment.

## Goals and objectives

The team needs a reason for monitoring. Once you have a reason for monitoring, your team can form a specific objective – for example, to collect the information needed to achieve a set of individual goals.

Your reasons for monitoring will guide your answers to all other choices, so it is important to consider these carefully. By choosing your goals carefully you will avoid difficulties such as:

- collecting irrelevant data
- asking a question in such a way that no solution is possible
- accepting the wrong solution before understanding the problem.

During group discussions, you will progressively fine-tune the question/objective for monitoring. In the end, the goals and objectives you tackle should:

- be specific
- say what is to be measured
- be achievable given the skills of the group and resources available
- indicate when monitoring will be completed or if it is to continue.

It is important that your goals and objectives are public, and that everyone involved knows what they are. This is the key to involving others and sustaining group membership. The next step for the group is to begin preparing a monitoring plan.

## Monitoring plan

It is important to prepare a good monitoring plan. The plan will describe where, what, why, how and when you will be monitoring, and who will be doing it.

The monitoring plan should be prepared in consultation with:

- key local stakeholders (farming groups, education providers, local interest groups)
- Waterwatch group members
- a regional Commonwealth facilitator as they can provide technical advice, training and support
- people you expect to use the information (e.g. Catchment Management Authorities)
- potential sponsors (see Waterwatch Sponsorship Guidelines).

It is important to carefully consider the objectives of your plan and make sure it is within the financial and technical means of your group.

When you are designing your monitoring plan, issues of possible hazards as well as standard behaviour at the sampling site should be considered. By observing basic safety rules you will minimise the risk of accidents and ensure safety of the members of your monitoring group. Safety issues include:

- Always let someone know where you going and when you will return; do not work alone.
- Students must be fully supervised by their teacher in accordance with Education Department guidelines.
- Make sure access to the sampling site is safe and easy.
- Protect yourself from sun exposure by wearing shirt, hat and sunscreen.
- During summer snakes can pose a danger, especially in long grass surrounding the sampling site; always wear suitable clothing (good shoes and long trousers) and work in pairs to minimise risk.
- When drawing a considerable volume of water from the bore, make sure it does not pool around the casing but is directed away from it.
- Do not leave any rubbish at the sampling site; always take it away with you.
- Do not drop any objects down the bore casing.
- Do not spill chemicals, use liquid waste bottle.
- Always leave a sampling site as you found it.

Build your plan around the following questions:

- Q1 Why are you monitoring?
- Q2 Who will use your data?
- Q3 How will the data be used?
- Q4 What will you monitor?
- Q5 What data quality do you want?
- Q6 What methods will you use?
- Q7 Where will you monitor?
- Q8 When and how often will you monitor?
- Q9 Who will be involved and how?
- Q10 How will the data be managed and reported?
- Q11 How will you ensure your data are credible?

### Q1 Why are you monitoring?

The first step in planning is to determine why you want to monitor. The reasons for the monitoring will determine how detailed the monitoring plan needs to be and guide the degree of data quality control.

#### Goals for groundwater monitoring

- Determine trends in groundwater levels.
- Determine the effect of irrigation and/or other management practices on groundwater levels and quality.
- Determine the effect of climate (rain, drought) on groundwater levels.
- Detect possible seawater intrusion into aquifers in coastal regions by monitoring salinity levels.
- Determine long-term trends in groundwater salinity.
- Detect suspected contamination near potential contamination source (feedlot, septic tank, storage lagoon).
- Educate the local community and encourage involvement in groundwater issues.
- Provide students with skills, experience and understanding of groundwater issues, monitoring goals and methods.

## Q2 Who will use your data?

Knowing who will use the data or information your team collects is helpful in developing a good monitoring program. Work with your local coordinator to establish as many links as possible with potential users of your data and ask what data they need. Invite the potential users to participate in your planning process.

### Potential data users

- Waterwatch members
- Teachers and students
- Industry
- Landholders/farmers
- Catchment Management Authorities
- Environmental organisations
- Local planning officers in councils
- Government departments
- Parks and wildlife staff
- State or local government water quality analysts
- Educational institutions (e.g. universities)

## Q3 How will the data be used?

For some groups the main purpose of groundwater monitoring may be to involve the community, raise awareness and to disseminate the knowledge about groundwater issues. For other groups, the data may have a different, more specific, purpose.

Find out what will make your data suitable for its intended use. This will help to determine the kind of data needed, and the level of effort required to collect, analyse and report it. Some users, for example government planning agencies, will require data that have been collected using a high level of quality assurance and quality control.

## Q4 What will you monitor?

Depending on the relevance to the identified issues, groundwater can be tested for a wide range of parameters. For example:

- To establish base line conditions or discover long-term trends of unknown groundwater systems a comprehensive sampling program and complete chemical analysis of collected samples may be necessary.
- In an aquifer that has been previously characterised, long-term monitoring at regular intervals may be established for certain characteristics of the system (like salinity or nitrate content) in order to assess influences of land use practices on groundwater.

- A choice of particular indicators (parameters) may be necessary to detect suspected contamination and to monitor its movement within the aquifer.

Wide-scale monitoring programs or testing for specific contaminants requires an understanding of the hydrogeology and flow dynamics of the tested systems and a high level of expertise in sampling techniques. Specialised equipment and laboratory analyses are often costly.

Your Waterwatch group needs to decide which parameters are relatively easy to measure and lie within its financial and technical capacity.

The main parameters Waterwatch groundwater monitoring programs need to consider are:

- depth to water table (or standing water level)
- temperature
- pH
- electrical conductivity (salinity)
- nutrients – nitrate and phosphate.

For a detailed description and discussion of these parameters see Chapter 7.

Other parameters that can be measured in groundwater (e.g. faecal indicator bacteria) require thorough decontamination of sampling equipment and sample containers and are unsuitable for measurement in most community monitoring programs.

## Q5 What data quality do you want?

The quality of the data you collect will depend on the question(s) you are asking and how you intend to use the data. It will also depend on the skills of the group members.

For groups with a focus on education and awareness, the quality of data is secondary to the actual process of collecting it. It is not always easy to decide on data quality or achieve it.

Good quality data is derived from surveys that are representative and comparable.

- **Representative** refers to the extent to which your data actually represents the fresh groundwater residing in the aquifer. For example, if stagnant water is not completely removed (in the process of purging) from the bore before sampling, the sample will represent a mixture of groundwater and stagnant water.
- **Comparable** samples allow you to make valid comparisons of data. Only samples obtained using the same methodology and techniques are comparable. Consistency in following sampling and testing protocols will ensure comparability of the data.

Good quality data is derived from analysis that is accurate, precise and sensitive.

- **Accuracy** is how close the sample test result is to the true value. Accuracy is most affected by the equipment and the procedures used.
- **Precision** is how well are you able to repeat the result on the same sample, regardless of accuracy. Human error in sampling and analytical technique is a major cause of imprecision.
- **Sensitivity** refers to the smallest change or the lowest concentration your equipment or methods can detect. The equipment you use should be sensitive enough to give useful data. For example if you are measuring electrical conductivity (salinity) your equipment (EC meter) should be able to work within the specific range and detect changes down to 10 standard units ( $\mu\text{S}/\text{cm}$ ).

Data quality is enhanced by quality control measures such as taking replicate and split samples. Two replicates or splits should produce the same result in a test. The closeness of the two results is a measure of your precision.

## Q6 What methods will you use?

The methods you use depend on your objectives and resources. There may be several methods of testing a single parameter or obtaining a sample. For example, using a bailer for obtaining a groundwater sample will result in a sample, which is less representative of groundwater rather than one that could be obtained using a more expensive pump.

Use the same methods and equipment at all sites and over the duration of the monitoring program to ensure comparability of the results.

When choosing a method, ask:

- How accurate is the method?
- How precise is the method?
- How sensitive is the method?
- Will the method measure the parameter in the range you need?
- Will the method produce data of the right quality?
- Will the method give representative results of the conditions you are monitoring?
- Is the method comparable with methods used by government agencies?
- Do you have the resources to use the method?
- How difficult is the method?

For each parameter you have chosen to measure, briefly describe the following attributes:

- The parameter – what are you measuring.
- The collection procedure – how the parameter is being sampled.
- The containers you will use to hold the sample.

- The preservation method – how you intend to keep the sample to prevent the change of parameters.
- The maximum holding time – how long the sample can be stored before the measurements are misleading.
- The equipment and method that are used to measure the parameter.

At this planning stage, it is also important to be aware of the need to keep track of samples. The labels your group uses should be clear and unambiguous and allow each individual sample to be tracked accurately from collection to completion.

Every sample collected in the field should be labelled to record the:

- site code – a unique code which identifies the location of the bore used for sampling
- bore number/name – a unique number of the bore used for sampling
- sample number – a unique number for the sample
- date and time of collection – hour/day/month/year
- sample type – what will be analysed
- sampler's name
- preservation method, if any.

## Q7 Where will you monitor?

Selection of optimal groundwater sampling locations will depend on the information you want to obtain and the aquifer characteristics, but also on availability and access to the boreholes suitable for sampling.

Before choosing your monitoring sites it is important to find out as much as possible about the groundwater resources in your area. Contact your Commonwealth facilitator or the nearest state water resource office. They may be able to provide:

- maps of the watershed (or groundwater management units)
- groundwater flow systems information
- geology information for the area
- lithology information for the bore
- type and size of an aquifer
- average depths to the water table
- existing information on water quality
- location and ownership of monitoring and production bores
- information on construction and parameters of the bores.

If, for example, your aim is to understand the characteristic regional variations in groundwater quality (e.g. salinity) or groundwater levels, this can be accomplished through sampling of a dedicated monitoring network already existing

in your area, or production bores where no network is available. In this case your monitoring area should encompass a large region. It will be necessary to involve a large group of people to manage such a project.

Monitoring at potential point sources of pollution can be conducted. For example at waste disposal sites, feedlots or a septic tank suspected of leaking. In this case sampling may be necessary both down gradient of the source of contamination and up gradient to determine natural groundwater conditions.

### Guidelines for selecting a monitoring site

When selecting a monitoring site you should:

- use a map with location of bores that appear to meet your needs
- get permission to enter private land if sampling from private bores
- record landholder contact details in the monitoring plan
- go to each site and check that it is accessible and safe to work at
- record details of the site location in your monitoring plan
- photograph each site and record directions to the site for future visits
- list all the sites selected, along with your reasons for choosing them
- register the site with your Waterwatch coordinator (see Site Registration Form).

### Registering the site

To ensure that data collected from Waterwatchers around the country can be available to other Waterwatchers you are invited to fill in a Site Registration Form and return it to your Waterwatch coordinator. This form is a summary of all site details. The data from the Registration Form will be added to state and national databases for Waterwatch Australia and will assist in decision making at all levels.

### How to complete a Site Registration Form

- Eastings and Northings are the coordinates from the universal grid that tells us the exact location of your site on the map – they can be read from the map or, more accurately, a GPS unit.
- Map number, name and scale – you can get this information from the map.

- Bore identification number (each bore has an ID number, engraved on or attached to the top part of the bore casing).
- Bore type – record what kind of bore it is (production, monitoring).
- Site name – e.g. name of the property on which bore is located.
- Bore location – description of the location in relation to landmarks, e.g. side of X road, 150 metres from south side of bridge.

### Q8 When and how often will you monitor?

The frequency of monitoring depends on the issue being examined. Your group may follow a long-term schedule of regular measurements and sampling (weekly, monthly, seasonal or annual), or respond to one-off events requiring immediate action.

If, for example, you want to determine the influence of climate on groundwater levels, surveys should be done at regular (monthly) intervals for a long period (several years). If, however, your goal will be to determine the effect of extensive pumping of large volumes of water (e.g. for irrigation) on water levels in the surrounding bores and the ability of the aquifer to recover, the measurements will have to be done at specific times as determined by, for example, pumping schedules during irrigation season.

### The schedule

The main challenges on sampling days are to:

- organise participants so they are effectively and safely occupied
- keep track of each monitoring or survey result
- ensure parameters are measured within the time limits for accuracy
- ensure the bore is left in good condition.

Work out a schedule for your monitoring work composed of field observations, sampling, and laboratory analysis. Include the anticipated time for each, and back-up people for emergencies. Allow extra time on the first sampling day to sort out the inevitable last-minute glitches.

Be aware that the process of groundwater sampling may be quite time consuming, depending on the depth of the sampled bore and equipment used. Remember to plan the proper sequence of the events and never change it:

- survey of the immediate surroundings of the sampling site
- bore depth and water level measurement
- purging of the bore
- sampling of the bore
- sequence of the tests.

Be aware of how long each sample can be held before it has to be processed for a given parameter. For example, the maximum holding time before testing refrigerated water samples for dissolved phosphate is 24 hours, so collecting the water sample, cooling and transporting it to a suitable laboratory, for example, at a school, and testing it must all be done within 24 hours to get accurate results. Take into consideration how long it takes to process each sample.

### Q9 Who will be involved and how?

Programs can vary in size from ten to hundreds of Waterwatchers and from a single group to many scattered over the catchment. Consider questions such as:

- Who is going to collect and analyse samples?
- Who will coordinate activities?
- How will team members be trained and transported to and from sites?

Consider all the tasks that should be done and encourage someone to fill each position. You don't need to list actual names, but rather the positions and a brief description of what each position does, for example:

- draft and get approval for the monitoring plan
- ask potential members to become involved
- organise and present Waterwatch training sessions
- gather baseline information about sampling sites (bores)
- obtain permits for sampling bores
- water quality sampling
- data processing and analysis
- maintenance, cleaning and calibration of sampling equipment
- reporting.

Training in the consistent use of standard procedures is the best way to ensure each participant is collecting credible data. Your local Waterwatch coordinator can provide you with appropriate training.

Your equipment should be regularly checked and calibrated with fresh standard solutions. See the sampling notes for details about these and other data confidence procedures for individual parameters (see Module 4, Physical and Chemical Parameters).

Maintenance and decontamination of the sampling equipment as well as calibration and inspection of instruments used for water testing should be a part of group training, and can be tasks assigned to one position in your group.

### Q10 How will the data be managed and reported?

Data collected in the field by Waterwatchers should be written on, or transferred accurately to, record sheets before being sent to the coordinator. There it will be screened and reported to the community and stakeholders (see Module 5, Data to Information to Action!).

All observations and notes made at sampling sites need to be labelled with the relevant site code, date and time. It is a good idea to have a photographic record of the sampling sites and their surroundings. If possible, use a camera that automatically imprints the time and date on your photographs. Always use a notebook to keep a record of your photographs as you take them and transfer these notes to the backs of the photographs when they are developed.

At the end of each sampling event the results, record sheets and photographs must be placed in a recognised secure storage place, such as a lockable filing cabinet. They are known as 'raw data' and are the primary links between your group's efforts for that day and the information your efforts have produced.

Standard record sheets will help you to ensure the data is consistent and comparable, and make it easy for groups to exchange information. The record sheets have spaces for all relevant information so it can be recorded consistently. It is very important that all group members understand how to use them and they are careful to avoid errors in transcribing data from instruments to record sheets. (One way to avoid errors is to state each reading aloud, record it, and then repeat it aloud to verify what was reported.) The sheets also simplify entry of the information into a computer database.

Your Waterwatch group must form a clear plan for dealing with the data. Choose one member to take on the role of data manager. That role could include:

- keeping a complete and accurate record of all surveys and tests
- making a copy and storing all records in a safe place
- checking result sheets for completeness and unusual results
- entering checked data into the Waterwatch Australia database program.

### Waterwatch Australia database

To help volunteers manage data and make it more accessible to data users, the Waterwatch Australia Database has been developed.

The Waterwatch Australia database was developed to enable data to be stored and reported in an easily comparable and consistent manner. The focus, when the database was developed, was for data sharing and data ownership at the regional level. This remains the focus of the database. Waterwatch recognises that community data is increasingly in demand, and not just at a regional level, but also at a state and national level. As a response to this demand some states, in consultation with the regional Waterwatch monitoring programs, are working with government scientists and data managers to compile regional Waterwatch databases at a state level to be incorporated into state data warehouses.

The Waterwatch Australia Database allows your regional coordinator to:

- enter your Waterwatch data and store it as a record or file
- develop graphs and produce short reports about your data
- perform simple analyses on the Waterwatch data you have collected from your catchment.

Finally, the group should have a plan for interpreting the data – that is, developing and reporting conclusions based on the findings and developing the recommendations for action and further monitoring.

The importance of data confidence cannot be overemphasised. Some monitoring groups in your Waterwatch program may use good data confidence techniques while others may not. Keep the data from both groups separate when recording results. You will be able to use the well-controlled data with more confidence to interpret trends, etc., and the other data to support your findings. Your Waterwatch coordinator can play a role in providing feedback to the group on the quality of your monitoring results.

When the time comes to present your information and results, the people you identified in Question 2 of the monitoring plan will be your primary audience.

### Q11 How will you ensure your data are credible?

Data confidence procedures ensure and assess the quality of the information and check that it meets your data quality goals, as described in Question 5.

Data confidence for sampling and analysis includes:

- putting in writing all the steps taken to survey, monitor, analyse, store, manage and present data
- encouraging qualified individuals to be responsible for specific quality assurance tasks
- proper training, testing and retraining of participants
- maintenance and calibration of equipment
- using quality control checks to ensure equipment produces accurate data
- assessing the quality of your results and making necessary adjustments
- reviewing your progress after an initial pilot stage.

Data confidence for data management includes following the procedures to ensure the data are properly recorded on result sheets and accurately transferred to the computer, as well as following up unusual results.

Quality assurance or quality control measures (i.e. data confidence) allow you to identify contamination of samples, inadequate practices and procedures, and failure of equipment. The data produced using good data confidence techniques is of high value to users.

Developing specific answers to questions 1–11 (the monitoring plan) is the first step in increasing confidence in your data. Your written monitoring plan, together with your group's objectives and strategies, is the most valuable document your group can have. It will keep the project running along the path that has been chosen for it, even months or years after it has begun, and will ensure continuity of the project even though the people involved may change.

If your group is aiming to achieve high quality data that can be used not only at the local level but also at the regional or national level you should try to base your monitoring program on the principles set out in the *National Natural Resource Management Monitoring and Evaluation Framework*.

## National Natural Resource Management Monitoring and Evaluation Framework

The Natural Resource Management Ministerial Council established the *National Natural Resource Management Monitoring and Evaluation Framework* to assess Australia's progress towards improved natural resource condition. The National Framework is based on a set of principles for monitoring, evaluating and reporting on the health of the nation's land, water, vegetation and biological resources. The main objective of the National Framework is 'to promote the conservation and sustainable use of Australian natural resources'.

The most relevant indicators through which to monitor change in resource condition and management practice, are being identified and the National Standards and Targets Framework is being established. The indicators are being selected on the basis of cost, simplicity, consistency and practicality along with their ability to deliver information from the local level through to the national level. The most important aspect is the need to use consistent methods by adopting (where possible) agreed national standards. Only then will the quality of the data be ensured and the data will be able to be aggregated and used at all levels.

Defining indicators, measurements and reporting protocols for water quality matters, including salinity, has been the first priority of the National Framework.



## Methods - groundwater sampling

This section contains information about how to obtain a groundwater sample from different types of boreholes and the procedures that have to be followed before sampling can begin.

## Bore information

When you have devised the monitoring plan and chosen boreholes for groundwater sampling your group needs to obtain permission from the bore owner or custodian to use it for sampling. Next you need to gather as much information as possible about the chosen sampling site. Your regional or state coordinator or local water authorities will be the best initial source of information. Fill out the Bore Information Sheet (see Record sheets).

Find out:

- where the bore is located (catchment, sub-catchment, shire, property)
- exact location coordinates (northing, easting) using GPS equipment – if a GPS is not available find the approximate coordinates using topographic maps
- when the bore was drilled
- who drilled the bore
- what the bore is used for (monitoring, production bore for irrigation or drinking water supply, etc.)
- if the bore is equipped with a permanently installed pump.

Include information about:

- bore casing material
- casing diameter (m)
- casing above ground level (m)
- type of seal (cement/bentonite mix)
- total bore depth (m)
- depth to the water table (m)
- depth of the slotted interval (m).

Organise a pre-sampling visit to the site and survey the bore and its immediate surroundings and note your observations on the Bore Information Sheet. The sort of information you need to note includes:

- is the bore construction sound? (e.g. is the hole collapsing or in good condition, is the bore well secured – cap, cementing around, etc.?)
- is the bore surrounded by crops, is it on the road side, close to the irrigation channel?
- is the bore easily accessible?

## Measuring total depth of the bore

When monitoring unequipped bores the first parameter to be measured is total depth (TD) of the bore. When monitoring a bore that has pumping equipment permanently installed and does not provide access to the bore casing, the total depth cannot be measured. Total depth should be obtained from the owner or custodian of the bore and noted on the Bore Information Sheet.

### Equipment

Total bore depth can be measured using a weight attached to a tape measure. Use a tape measure that is at least as long as the deepest bore to be measured. To avoid mistakes in depth measurements use quite a heavy weight that can easily reach the bottom of the bore.

### Procedure

1. Lower the weight into the casing until it reaches the bottom of the hole – as this happens the tape will become slack.
2. Lift and drop the tape several times to 'feel' the bottom of the bore.
3. Remember to add the length of the weight onto the tape measurement.
4. Subtract the height of the casing above the ground level from the measurement.
5. Record the result as total depth (in metres) of the bore on the Bore Information Sheet.
6. Clean the tape before using it again.

## Measuring depth to water table

What is depth to water table and why does it matter?

**Depth to water table** (depth to groundwater) is the depth in metres from the ground surface to the water table (recorded in monitoring bores) at a specific point in time.

Rising trends in the average level of water tables may be a consequence of inappropriate land practices. Falling water table levels, on the other hand, may be an indicator of the effectiveness of land conservation strategies. It may also be a consequence of reduced recharge due to climatic factors or increased groundwater extraction from the aquifer. Static water table depths indicate that recharge to the aquifer is equal to discharge.

Depth to water table – also called depth to groundwater or standing water level – has been included on a list of indicators in the *National Natural Resource Management Standards and Targets Framework* (National Framework). It is considered as one of the crucial indicators of potential risk of land salinity in the areas where rising water tables reach the capillary zone (i.e. approximately 2 metres below ground surface). By monitoring water table levels we can identify whether and when groundwater levels are rising, falling or remaining static and hence the areas at risk from salinity.

### Suggested methods and equipment

Depth to water table should be measured and recorded before every sampling event. Water level cannot be measured in production bores that have permanently installed pumping equipment as there is no direct access to the bore casing. These bores cannot be used for water level monitoring.

Some production bores may, however, have additional casing of small diameter that was installed specifically for the purpose of water level monitoring. This casing will run alongside the main bore casing used for water extraction.

#### Equipment

Depth to water table, or standing water level, can be measured using a tape measure with an attachment that is designed to make noise or some other signal when it touches the water surface. The simplest version is the 'plover' made from a 15 to 20 cm stainless steel tube and a tape measure (see Figure 6.9).

Figure 6.9: Plover and tape measure



The metal tube is sealed at the end at which it is attached to the tape with a loop wire. The other end that touches the water should be left open. When the tube is lowered into the bore and touches the water surface it makes a distinctive plopping sound.

#### Procedure

1. Lower the plover into the bore until it hits the water.
2. Lift and drop the plover several times to find the exact water level, this should give a reading accurate to within 1 cm.
3. Remember to add the length of the plover onto the tape measurement.
4. Subtract the height of the casing above the ground level from the measurement.
5. Record the result as water level (in metres) with the date of the measurement on the Bore Information Sheet.
6. If the water level is below ground, record the result as negative (-) and positive (+) if it is above ground (water standing in the casing above ground).
7. Wash the tape and the plover thoroughly with tap water before using it again to prevent contamination of the next bore.
8. Old monitoring bores can silt up over a period of time. Quite often the silting of bores can occur to the top of the slotted/screened interval. Total depth of casing readings determines the status of the bore.

#### Equipment maintenance

After each use thoroughly clean tape and plover with tap water. Dry and roll the tape.

### Data confidence

Make sure your measuring tape is in good condition and you can easily read the numbers on it.

Repeat your depth reading several times to make sure it is correct. Ask another member of the group to confirm your reading.

Never forget to subtract the height of the casing and add the length of the plopper to your measurement.

If the aim of your monitoring plan is to measure the level of the water table in order to assess risk of land salinisation, adopting the procedures suggested in the National Framework will ensure your results will be of high quality. Following the advice on choosing monitoring locations and frequency, measurement procedures, data analysis and interpretation will ensure your data will be comparable with data other groups or organisations collect and will be able to be used more widely than just the local context.

Your Waterwatch coordinator will be able to provide you with more information.

### Interpreting your results

Before starting a monitoring program, obtain information on original depths to water table in your chosen bores. You will be able to compare these values with the results obtained during your monitoring project and interpret them accordingly.

Your interpretation will depend on the specific problem for which you may be monitoring. Consider all possible reasons for the trends you may be observing. For example: water table consistently dropping over time may be caused by intensive extraction of groundwater for irrigation (during irrigation season) or a long period of drought (and therefore lack of recharge) in the area.

## Bore purging

The purpose of groundwater sampling is to retrieve a water sample that represents the characteristics of water below the ground surface. To obtain a representative sample it is necessary to remove the stagnant water from the bore casing before a sample is taken. This is called purging. It is recommended that at least three casing volumes of water should be removed before sampling. Usually pumping of the bore is continued even after three casing volumes have been removed until such time as the pH, EC and temperature of the discharge water are seen to stabilise. Only then is the obtained sample truly representative of groundwater residing in the aquifer surrounding the borehole.

**Important: Bore has to be purged before each sampling event.**

### How to calculate the volume of water in the bore

The volume of the water in the bore casing is calculated using the following formulae:

$$V = \pi r^2 \times L \times 1000$$

where:

- V – volume (in litres)
- r – radius of the casing in metres
- L – length of the water column in metres
- $\pi$  – constant (3.14)

- Measure the radius of the bore casing in metres.
- Measure TD – the total depth of the bore (see 'Measuring total depth of the bore').
- Measure water level – the depth to the water table or water level (see 'Measuring depth to water table').
- Calculate the length of the water column (total depth – water level).
- Calculate the volume of water using the formulae above.
- Multiply by three to calculate three casing volumes.
- Approximate values for common casing widths are shown below.

Casing diameter	Volume of 1 metre of water column	Volume of water to purge per metre
50 mm	2 litres	6 litres
80 mm	5 litres	15 litres
100 mm	8 litres	24 litres
125 mm	12.5 litres	37.5 litres
150 mm	17.7 litres	53 litres
200 mm	31.5 litres	95 litres

## Purging using a bailer

A bore can be purged using a bailer only when a reasonably small volume of water is to be removed. It will take a considerable length of time to purge even a very shallow bore. When using a bailer it is difficult to ensure that all stagnant water has been removed from the bore and consequently the sample may represent a mixture of fresh and stagnant water.

### Equipment

A bailer is a simple mechanical device that can be used to draw water from the bore (see Figure 6.10). It consists of some form of tubing with a one-way check valve at the bottom. When the bailer is lowered into the bore casing below the water level, it fills with water. The check valve closes once the bailer containing the water sample is lifted to the surface.

Figure 6.10: Bailer



Bailers come in various types (polyethylene, Teflon, stainless steel, acrylic), lengths (from 30 cms to 180 cms), widths (19 mm to 90 mm) and with numerous features like weighted, unweighted, single check-valve, double check valve, controlled flow bottom, etc.

Bailers offer several practical advantages over other sampling equipment. They:

- are of simple construction and reliable operation
- do not require electric or pneumatic power
- are easy for one person to operate
- are extremely portable
- are relatively easy to clean and maintain
- are inexpensive.

### Procedure

1. Lower the bailer to the level of the slotted part of the casing (screened interval)
2. Lower and withdraw the bailer slowly and try not to disturb the water column by splashing
3. Use a bucket of known volume to record the volume of water being discharged
4. Remove the calculated volume of water
5. Continue purging until pH, EC and temperature readings stabilise.

## Purging using a pump

Truly effective purging that can guarantee the integrity of the sample can be done using a pump.

### Equipment

There is a wide range of groundwater pumps employing different operating methods, available on the market. There are pneumatic pumps that require a compressed air source, electric pumps that require 240 volt AC or 12–24 volt DC, and mechanical pumps, which use linkages to provide the lift mechanism.

Your choice of pump will depend on the:

- cost of the equipment
- depth of the bore
- diameter of the bore casing
- amount of water that has to be lifted.

Small electric pumps in plastic housings that operate from a 12-volt battery are the most convenient pumps to use for groundwater sampling (see Figure 6.11). The advantage over other pumping equipment is that they are simple and safe to operate, require only a 12-volt battery as a power source and can be used in small diameter (50 mm) monitoring bores.

There are several types of submersible, battery operated, pumps available, which have slightly different parameters such as maximum flow rate and ability to pump to a certain depth. Before deciding which pump to use make sure you know the depth of the bores you are going to monitor and the depth to the water table.

**Note:** *Turbidity* can affect submersible electric pumps. Silty bores will restrict the effective pumping rate, by restricting the rotation of the pump. Use a bailer to check turbidity of water before using submersible pumps to purge the end sample.

Your regional Waterwatch coordinator will be able to help you choose appropriate pumping equipment and will provide necessary training.

### Using DC electrical powered pumps

You will need:

- two 12-volt submersible pumps
- 40 m of 2- or 3-core electrical cable
- 40 m of clear plastic hose, 12 mm inside diameter
- battery clips
- a 12-volt lead-acid battery
- a battery charger.

Figure 6.11: Submersible 12 volt pump



#### Procedure

1. Lower the pump to about 1 m above the screens (if known) or to about 1–2 m from the bottom of the bore if the screen depth is not known; beware of the risk of drawing sand into the pump which can occur if it is set too close to the screens.
2. After starting the pump, establish the highest flow rate possible without causing the bore to stop yielding.
3. Calculate the flow rate (see information box below).
4. Once a constant flow rate is established, the bore can be 'vacuumed'. This is done by slowly lifting the pump to near the top of the water column while pumping, then slowly lowering it to the previous depth. This way the column of stagnant water sitting in the casing above the slotted level is evacuated.
5. Pump for calculated length of time needed to remove the three casing volumes of water or until pH, EC and temperature readings stabilise.

**Note:** If silt is in the hole, operators can unknowingly lower the 12-volt pump into silt and thus block the pump.

Usually pumping of the bore is continued even after three casing volumes have been removed until such time as the pH, EC and temperature of the discharge water are seen to stabilise. Only then is the obtained sample truly representative of groundwater residing in the aquifer surrounding the borehole.

#### How to calculate flow rate

Measure the time needed to fill a 10 L bucket with discharge water.

Calculate flow rate in litres per minute (L/min) using the formulae:

$$FR \text{ (L/min)} = (60 \text{ divided by seconds taken to fill 10 L container}) \times 10$$

Knowing the volume of water standing in the casing (V) and the flow rate (FR), calculate how much time (T) it will take to pump out three casing volumes

$$T = (V/FR) \times 3$$

#### Purging production bore

##### Equipment

No special equipment is needed.

##### Procedure

1. If the bore is pumped only occasionally, turn on the pump and run it for the amount of time you think is necessary to remove three casing volumes.
2. If bore is used for continuous pumping at certain times of the day (e.g. irrigation, town water supply) there is no need to purge – simply correlate the time of sampling with times when the bore is used.

## Sampling monitoring bores

To draw water from a monitoring unequipped (no pump installed) bore a bailer or a pump has to be used.

In most cases Waterwatch groups will be using existing monitoring bores for their sampling. It will be the most convenient and cost effective way to obtain groundwater samples. However in areas where such bores are not available and water table levels are known to be very close to the ground surface (2 m), installation of a very simple monitoring bore, called a *piezometer*, may be considered. See Appendix 2 'Construction and installation of piezometer'. Piezometers should be sampled using the same procedures as described for monitoring bores.

### Bailing

#### Equipment

Equipment you will need includes:

- a bailer. Bailers come in various types (polyethylene, Teflon, stainless steel, acrylic), lengths (from 30 cms to 180 cms), widths (19 mm to 90 mm) and with numerous features like weighted, unweighted, single check-valve, double check valve, controlled flow bottom, etc. (see Figure 6.10).

#### Procedure

1. Depending on the type of the bailer available, follow the manufacturer's instructions on how to use it.
2. Lower the bailer slowly and gently into the water column of the bore until it is submerged, do not allow the bailer to come into contact with the bottom of the well.
3. Before removing the sample, purge the bore by removing the calculated volume of water. A bore can be purged using a bailer only when a reasonably small volume of water is to be removed. It will take a considerable length of time to purge even a very shallow bore. When using a bailer it is very difficult to ensure that all stagnant water has been removed from the bore and consequently the sample may represent a mixture of fresh and stagnant water.
4. Carefully remove the water sample and empty it from the bottom of the bailer into a prepared sample container.

#### Bailer decontamination

- If using a conventional bailer, the equipment should be cleaned after each use to avoid contamination of the next sample.
- Wash the bailer thoroughly, using tap water and detergent.
- Using disposable bailers eliminates the need to clean the equipment.

#### Integrity of the bailed sample

It is difficult to obtain a representative groundwater sample using bailers. It can be useful as a sample collection device only if there is a small volume of stagnant water to be removed from the bore prior to sample collection.

Even then the bailer has to be introduced to the well numerous times. This repeated intrusion into the well increases the potential for contamination (mixing of aquifer and stagnant water) and causes excessive aeration of the sample.

### Pumping

Using a pump is a much more efficient way of sampling a bore. When using a pump, you can be more confident of efficient bore purging and that the obtained sample is representative of aquifer water.

#### Equipment

See description of 12 volt submersible pumps and their use at 'Purging using pump'.

#### Procedure

1. Assemble a single pump system, keeping in mind how much water your particular pump can lift, and that any extension of the casing above ground level will reduce this capacity.
2. Purge the bore by pumping out appropriate volume of water (see 'Purging using pump' for details).
3. Continue pumping water to obtain sample, with the pump in the same position as for purging.
4. If the position of screened section is not known, lower the pump almost to the bottom of the bore (be careful not to hit the bottom) and lift up 2–3 m, pump from this position.

#### Pump decontamination

The pump should be cleaned after each use to avoid contamination of the next sample. Cleaning is done by submerging the pump in a container of pure (tap) water and pumping continuously for several minutes to ensure the pump and plastic hose are rinsed thoroughly.

#### Integrity of pumped sample

Using a pump for purging and sampling a bore ensures that a representative sample of water residing in the aquifer will be obtained. Make sure your pumping technique is consistent and every sample is obtained following the same procedure.

## Sampling of production (equipped) bores

The use of existing production bores for sampling is the cheapest method available. Generally production bores have high yields and are often used for extended periods every day.

### Equipment

No special equipment is needed.

### Procedure

1. If the bore is pumped only occasionally, turn on the pump and run it for the length of time estimated to purge the bore (i.e. remove three casing volumes).
2. Collect water sample after purging is completed.
3. If the bore is used for continuous pumping at certain times of the day (irrigation, town water supply), there is no need for purging; correlate time of sampling with times when bore is used.

## Methods - tests

This section is based on Module 4 of Waterwatch Australia National Technical Manual, *Physical and Chemical Parameters* and contains information about tests you can conduct, what they are for and how to do them.

The tests fall into two categories according to the level of difficulty. The first includes pH, salinity (electrical conductivity) and temperature. These can be measured by anyone in the community including students at all levels of schooling. The second category – measuring concentrations of phosphate and nitrate – even though relatively easy to do, is suitable only for members of the community and for students in upper primary and secondary school.

## Before you begin

To ensure your samples are representative and your test results accurate and precise you should always:

- consistently use the same sampling methods throughout the whole monitoring period
- stick to planned sampling times
- handle, test and analyse in the same way
- make sure your sample containers and collection methods are appropriate for the parameters you are testing.

### Equipment

Details on what equipment to purchase, where to purchase it and how to use it can be obtained from your regional or state Waterwatch coordinator. Make sure that members of your monitoring group are properly trained and confident in using the equipment and testing techniques.

Have a list of all equipment needed for a sampling event. Such equipment will include:

- clean containers for the samples
- boxes to carry samples
- plastic/latex disposable gloves and safety glasses
- an esky to keep the samples cool (when planning to transport them to a laboratory)
- equipment for making measurements (e.g. thermometer, tape measure, etc.)
- reagents
- electronic meters (pH and EC meters)
- record sheets
- instruction manuals
- pens, first aid kit
- containers for solid and liquid wastes.

### Sampling containers

Plastic or glass bottles are adequate for basic water quality tests. The most important consideration is to make sure the containers, whether new or reused, are clean. When using detergent to clean the containers, make sure it is phosphate-free (check the label).

### Cleaning sample containers

Cleaning sample containers:

- in a laboratory, wash each bottle and cap with a brush and phosphate-free detergent
- rinse three times with tap water
- rinse three times with deionised water
- drain upside down on a rack
- when dry, replace cap.

Containers used for collecting samples for nutrient analysis have to be acid rinsed:

- after washing with detergent and rinsing with tap water rinse with 5% hydrochloric acid
- rinse three times with deionised water
- drain, when dry replace cap.

**Warning:** Do not use nitric acid when rinsing containers for samples for nutrient analysis.

## How to get good results

### Calibrate

To maintain your equipment in good working order and get high quality results, you should regularly inspect and calibrate each piece of test equipment, and record the calibration results in a table (use the Waterwatch Equipment maintenance and calibration record sheet).

In all cases, calibrate all kits or instruments against appropriate standard solutions (which contain known amounts of the substance to be tested), and adjust them as necessary.

### Avoid contamination

- To avoid contamination and contact with possibly toxic chemicals, never put your thumb over test tubes when you shake or swirl them.
- Do not empty excess reagents back into their original containers; instead, put them into a special waste container that you can dispose of safely at the laboratory.
- Do not allow droppers to touch the test bottles or tubes – this will contaminate the droppers.

**Field replicate**

A field replicate is a sample taken at the same time and treated identically, or a measurement made immediately after another at the same spot and in the same way.

**Waterwatch mystery solution**

Mystery solutions, available from Waterwatch coordinators, are solutions that have been analysed by experienced analysts. Test these solutions yourself, and then compare your own test results with the original analysis. This will help you assess the accuracy of your techniques and of your equipment.

**Make 'internal' quality control checks**

- Test one or two field replicates every 10 samples to check for precision of sampling and analysis.
- Where appropriate, test a Waterwatch mystery solution every six months to check for problems with equipment, method or reagent.

**Consider using external checks**

For external checks, send 10% of your samples to a different laboratory to be analysed, and then compare their results with your own for the same samples.

You can increase the quality of your data with your current equipment simply by always using the hints and checks above. If the extra results obtained by internal and external checks do not exactly agree with your own results, calculate by how much the results differ. This can be expressed as a percentage. The smaller the percentage variation between your results and the external ones, the more confident you can be about their value.

**Reagents**

A reagent is a substance, which, on account of the reactions it causes, is used, in chemical analysis. For accurate results, reagents need to be kept in good condition and used before their expiry date.

Many reagents in test kits can become contaminated and degrade quickly under field conditions. The inevitable result is inaccurate measurements of water quality, extra expense and a lot of wasted time. By checking the condition of the reagents and taking a few simple precautions, you can avoid these problems.

Check the appearance of reagents and look for any changes such as colour, cloudiness and formation of solids. If you doubt the condition of reagents, test a water sample with reagents and compare your result from a test carried out with another kit, or with fresh reagents, or with a meter. Replace any reagents that have been degraded.

Reagents degrade more quickly at high temperatures, so store and transport them away from heat and sunlight.

Many reagents react with oxygen or carbon dioxide in the air so keep bottles tightly capped when not in use. Contamination of reagents with foreign matter or other chemicals will cause degradation. Use dedicated spoons and droppers for each reagent to avoid cross contamination.

Replacing reagents is a major ongoing expense for Waterwatch groups. However, avoiding expired reagents is important for all groups particularly where data quality is important. Reagents have a limited life span from the date of manufacture and it makes little sense to continue using them after expiry date. The manufacturer provides an expiry date for each reagent (check the label on the box or bottle).

# Temperature

## What is it and why does it matter?

Temperature tells us how hot or cold a substance is.

The temperature of water directly affects many of its physical and chemical characteristics. Salts are more soluble in warmer water, so temperature can affect the water's salinity. In contrast, oxygen is less soluble in warmer water and this can affect aquatic life in surface water bodies. Warm surface waters are more susceptible to eutrophication – a build-up of nutrients and possible algal blooms because photosynthesis and bacterial decomposition both work faster at higher temperatures.

## Temperature of groundwater

Because groundwater is stored underground it generally has a constant temperature throughout the year. In the upper 100 metres below surface, the temperature of groundwater is normally 1–2°C higher than the average air temperature. Penetration of the seasonal surface temperature fluctuation is determined by geological factors, like the distance from the surface to the groundwater, the heat transferability of the rocks, the groundwater formation, and by anthropogenic factors. Temperatures of shallow aquifers reflect annual surface temperatures and differ according to the climatic zones.

The increase of groundwater temperature with depth depends on the nature of the rocks and on the heat flow in that particular area of the earth's crust. In different groundwater basins, geothermal gradients range from about 2 to 5 degrees per hundred metres. Temperatures of groundwater from deep *artesian aquifers* can reach very high values, often above 80°C.

## Suggested methods and equipment

Water temperature is measured in degrees Celsius (°C), with a glass thermometer or a digital meter. It must be the first parameter measured in the field after obtaining a groundwater sample. Thermometers filled with alcohol are preferred over those filled with mercury because they are less hazardous if broken. Armoured thermometers for field use can withstand more than unprotected glass thermometers and are worth the additional expense. Meters designed for other tests, such as pH, may also measure temperature and can therefore be used instead of a thermometer.

### Equipment

The equipment you will need for this method is a glass thermometer or a digital meter. Before using a glass thermometer, check the glass for cracks and check the alcohol or mercury column for breaks.

### Procedure

1. Place the thermometer a few centimetres into the water sample as soon as it has been collected.
2. Wait one minute, until the reading is stable.
3. Read the temperature to the nearest 0.5°C while the thermometer bulb, or temperature probe, is still immersed in the water; make sure you take the reading as close as possible to eye level.
4. Repeat the reading at least once; if the results are variable, take up to 10 measurements.
5. Record all your results on a Water Quality Results sheet (see Record sheets).

### Maintenance

After use, rinse the thermometer or meter probe with clean water, dry it and return it to its protective container. Keep the thermometer free from dirt and other contaminants. Make sure the glass does not get scratched or cracked.

### Calibration

You should make sure your thermometer and digital meter read the same as at least two other thermometers – at room temperature, in an ice bath and in hot water. Test your thermometer annually. It is best to get a reputable laboratory to do the calibration.

### Data confidence

Readings of temperatures should be accurate to  $\pm 0.5^{\circ}\text{C}$ .

### Interpreting your results

Over a series of measurements through the year you can build up a picture of the temperatures at your sampling site. You may be able to observe seasonal trends in groundwater temperature in relation to air temperature.

#### Safety considerations when measuring temperature

- Let someone know where you are going and when you will return.
- Don't work alone.
- Students must be fully supervised by their teacher in accordance with Education Department guidelines.
- Ensure safe and easy access. Beware of possible presence of snakes in long grass surrounding a bore.
- If sampling near a road be wary of passing traffic.
- Avoid contact with contaminated water. Use gloves while sampling, but take them off as soon as you've finished; don't touch your skin with wet gloves.
- Keep a first aid kit available.
- Feet should be covered; remember sunblock, hat and t-shirt.

# pH

## What is it and why does it matter?

**pH is a measure of acidity of a solution.**

The concept of pH was developed for hydrogen-ion concentration, but has since been modified to mean the hydrogen-ion activity. It is expressed as the negative logarithm of the hydrogen-ion activity, i.e.  $\text{pH} = -\log_{10}[\text{H}^+]$ . In practice it is a scale, which is conventionally taken to range between the limits of 0 (the acidic end) and 14 (the alkaline or basic end) with neutral pH taken as 7.

pH can be a little misleading unless you remember that one pH unit represents a ten-fold change. So if the pH of a water sample falls from pH 7 to pH 6, that is equivalent to a 10-fold increase in acidity. pH is arguably the single most useful measurement we can make in water chemistry since it is the main controlling variable in a huge range of solution, dissolution and ion-exchange processes. Many compounds are more soluble in acidic waters than in neutral or alkaline waters, pH also affects the solubility of heavy metals in water.

The pH of the wet area around roots affects nutrient uptake by the plants. All animals and plants are adapted to specific pH ranges, generally between 6.5 and 8.0. If the pH is outside the normal range for an organism it can cause stress or even death to that organism.

### pH in groundwater

Groundwater pH is a fundamental property that describes the acidity and alkalinity of groundwater and largely controls the amount and chemical form of many organic and inorganic substances dissolved in groundwater. Many important properties of water are determined by pH; for example, both the suitability of groundwater for domestic and commercial uses and the ability of water to transport potentially harmful chemicals are controlled by pH.

There are no health-based drinking water guidelines for pH in the *Australian Drinking Water Guidelines* (1996), however there is an aesthetic guideline range of 6.5 to 8.5, based on the need to reduce corrosion and encrustation in pipes and fittings. The World Health Organization has also set a guideline range of between 6.5 and 8.5. Water with a pH outside the range

6.5 to 8.5 can lead to high concentrations of some dissolved metals, that are potentially harmful and for which there are drinking water standards.

pH values in groundwater are primarily controlled by the type of geological formation in which the water is stored and the soil overlying the aquifer. To some extent pH is affected by the pH of the recharge water. Rainfall is slightly acidic because of the carbon dioxide (CO<sub>2</sub>) dissolved in it; water running off limestone areas has relatively high pH. Streams and lakes in coastal dunes may have a very low pH (even less than 5) due to the presence of naturally occurring humic acids. In coastal regions with acid-sulphate soil problems, naturally occurring groundwater can have a pH below 2 due to the presence of sulphuric acid.

The value of pH is highly sensitive to dissolved gasses, in particular to CO<sub>2</sub>. The duration of sample storage, degree of aeration during sampling and water pressure all influence the dissolved CO<sub>2</sub> content, therefore the method of sampling as well as when and how the sample was tested can have a considerable bearing upon the pH value. Prolonged storage tends to create large errors in the order of a pH unit. Samples that have had time to degas CO<sub>2</sub> to the atmosphere show a consistent increase in pH. The loss of CO<sub>2</sub> is especially characteristic of groundwater, which has been rapidly pumped to the surface, in particular from an aquifer under pressure.

It is therefore recommended that pH be measured in the field, as soon as possible after obtaining the water sample. A pH measurement can be delayed by up to 24 hours, but only if the sample is refrigerated immediately and the sample bottle is filled completely, with no air at the top.

### Suggested methods and equipment

To measure pH, you can use either **pH strips** (often called indicator paper) or a **pH meter**.

#### pH strips method

pH strips are coated paper strips that change colour according to the pH of the sample. The colour can be compared to a colour scale to estimate the pH value. pH strips have a long shelf life (3 years) if stored in cool dry conditions; and give reliable results for monitoring groups. The sensitivity of this method however is reliable only within 0.5 pH units. Choose pH strips that can detect changes of 0.5 units in water samples and are suitable for weakly buffered waters.

### Equipment

The equipment you will need for this method includes:

- La Motte pHDrion pH test kit
- sample bottle
- deionised water.

### Procedure

1. Rinse the pH tube with sample water.
2. Tear off a piece of indicator strip that is slightly longer than the tube. Leave half a centimetre of the strip sticking out the top when the tube is recapped. This enables you to easily remove the indicator strip when the test is complete.
3. Fill the tube with sample water, put the cap on and swirl the water around the indicator paper.
4. Wait for one minute for the full colour to develop.
5. Place the tube on the black strip running through the middle of the pH colour indicator levels on the inside lid of the pH test box.
6. Compare the colour on the indicator paper with the pH colours on the lid to find the pH reading.
7. Repeat test on a replicate water sample.
8. Record both readings on the Water Quality Result sheet (see Record sheets).

### Maintenance

Pour the water into the liquid waste bottle and place the pH paper in the solid waste container.

Rinse the tube with deionised water and dry it before returning it to the kit.

### Calibration

You cannot calibrate pH paper, but you can check it against known reference solutions. Prolonged storage may make the paper less accurate.

### **pH meter method**

A pH meter measures pH and temperature, and it adjusts the readings according to the temperature of the sample (pH varies with temperature). pH meters usually display results in pH units. Meters vary a great deal, but the most important part is the electrode. Buy a good, reliable electrode and follow the manufacturer's instructions for proper maintenance. Infrequently used or improperly maintained electrodes are subject to corrosion, which renders them highly inaccurate. The electrode tends to last only 1 or 2 years, so you may consider purchasing a meter with a replaceable electrode.

### Equipment

The equipment you will need for this method includes:

- pH meter
- Sample bottle
- Deionised water
- Calibration solutions and containers.

### Procedure

1. Rinse the electrode well with deionised water.
2. Place the electrode in the sample. Wait 2–3 minutes for the reading to stabilise but be aware that some change will occur as pH reacts with carbon dioxide dissolving from the air.
3. Record the result on the Water Quality Results sheet (see Record sheets).
4. Repeat test on a replicate sample and record the result on the Water Quality Results sheet.
5. Periodically measure the pH of the calibration solution to test accuracy. If it has drifted, recalibrate the electrode. Do not reuse buffer solutions.

### Maintenance

Rinse the electrode well with deionised water, replace cap when finished.

### Calibration

A good quality pH meter can detect minimum variations (sensitivity) of 0.1 pH units in water and can be calibrated at two pH levels. This type of instrument will give more accurate readings over a wider pH range than one-point calibration meters.

Meters must be calibrated with buffer solutions before each sampling and periodically during sampling, e.g. every fifth sample, to check if the meter has drifted off calibration. Your check on the calibration standard should be within the sensitivity range, e.g.  $\pm 0.1$  pH units, of the equipment used. If you are using a two-point calibration meter, use two buffer solutions at 4.0 and 7.0. Buffer tablets can be purchased from test kit supply companies and must be used within their expiry date. A buffer solution of pH 4.0 will last 3 months, but a solution of pH 7.0 will last 6 months if stored in a cool dark place.

## Data confidence

### pH strips

- Minimise damage or staining of the colour chart by storing it in dark dry conditions – water reacts with dyes in the paper.
- Measure a field replicate after every tenth test.
- Test a Waterwatch mystery sample every six months.

### pH meter

- Test a Waterwatch mystery solution every 10 tests, or
- Set aside 10% of samples to be split and tested by a laboratory elsewhere, or an external field replicate sample to be tested by a water quality professional officer.

## Interpreting your results

Note the geology and soils and land use of the catchment you are monitoring, to help interpret your pH results.

For baseline monitoring, interpretation of pH values requires some knowledge of the natural ranges likely to be found in the aquifer. What is 'normal' in some systems may indicate a possible problem in others.

When monitoring a suspected point source of contamination a number of bores down-stream and up-stream of the source should be tested to enable a comparison.

Changes of more than 0.5 pH units from the expected values for the particular site should be investigated.

Contact your Waterwatch coordinator and ask about the relevant trigger values discussed in the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC/ARMCANZ 2000).

## Safety and waste considerations when measuring pH

- Let someone know where you are going and when you will return.
- Don't work alone.
- Students must be fully supervised by their teacher in accordance with Education Department guidelines.
- Ensure safe and easy access. Beware of possible presence of snakes in long grass surrounding a bore.
- If sampling near a road be wary of passing traffic.
- Avoid contact with contaminated water. Use gloves while sampling, but take them off as soon as you've finished. Don't touch your skin with wet gloves.
- Keep a first aid kit available.
- Feet should be covered; remember sunblock, hat and t-shirt.
- Take some clean water with you for washing down chemical spills on your skin and clothes.
- Have a squirt bottle ready to wash down eyes in case of chemical exposure.
- Hold all test bottles over a wide-mouthed liquid waste bottle while adding the reagents or calibration solutions.
- Place all used gloves, used paper towels, empty reagent packaging and any other rubbish from testing into a plastic garbage bag with no tears in it, and take it with you when you leave. Try to leave the site cleaner and tidier than you found it – pick up and transport out any rubbish.
- Consult your Waterwatch coordinator about disposal of liquid wastes.

# Electrical conductivity

## What is it and why does it matter?

**Electrical conductivity (EC) is the property of a material to conduct electricity. The ease with which electrical current passes through water is proportional to the salt concentration in the water, therefore, the higher the EC, the greater the salt concentration.**

Electrical conductivity is an indirect measure of water salinity, and one of the most common and convenient methods used to test water.

Electrical conductivity is significantly affected by the temperature, so all results should be normalised to a standard temperature of 25°C. The EC is also strongly dependent upon the ionic composition of water. Chloride (Cl<sup>-</sup>) and sodium (Na<sup>+</sup>) are the main ions influencing groundwater EC. Other ions that contribute to salinity are carbonates, sulphates, magnesium, calcium and potassium.

While an appropriate concentration of salts is vital for aquatic plants and animals, salinity that is beyond the normal range for any species of organism will cause stress or even death to that organism. Salinity also affects the availability of nutrients to plant roots. The fact that EC is mostly influenced by chloride and slightly less by sulphate is useful when interpreting the suitability of water for agriculture since most crops are more sensitive to chloride than to sulphate.

## Electrical conductivity in groundwater

As a result of chemical and biochemical interactions between groundwater and materials through which it flows, groundwater contains a variety of chemical constituents at different concentrations, with the two dominant ions being sodium and chloride (see 'Groundwater chemistry'). That is why all groundwaters exhibit varying levels of salinity (i.e. electrical conductivity).

Most of earth's vast groundwater resources have high to very high salt content (high EC); only about 8% of groundwater is suitable for human consumption and other uses (agriculture and industry). Increasing salinity (increasing EC) of usable groundwater resources is one of the most significant and widespread forms of groundwater pollution. In some areas it is a natural phenomenon in the landscape within soil formation and water movement (e.g. in inland salt pans,

brackish streams, coastal salt marshes and naturally saline soils). In other areas, increasing salinity is the result of a particular land use practice, such as over-clearing of vegetation, and unsuitable practices associated with urban development, irrigation or cultivation of crops and pastures.

Much of Australia's landscape is also naturally saline. Many of our agricultural lands contain vast reservoirs of salt, but normally these are held deep within the soil profile where they do not affect plant growth. Groundwater has the ability to mobilise and transport soluble salts when it moves through the soil. Problems occur when this salt is brought to the soil surface by rising water tables.

It has been recognised that salinity of groundwater (expressed as TDS or EC) is a useful indicator of the land area at risk from salinity. It becomes especially important once the water table rises to within 2 metres below ground surface because of the salinisation of the root zone. It is also important in places where groundwater is used for irrigation. Salinity of irrigation water should be monitored at least twice during each irrigation season (at the start and at the end of the season). Along with depth to water table, EC has been included in the *National Natural Resource Management Standards and Targets Framework*.

Contamination of the aquifer also can change the water's electrical conductivity in various ways. For example, a failing sewage system raises conductivity because of its chloride, phosphate, and nitrate content, but an oil spill would lower conductivity. Discharge of heavy metals can also raise the conductivity as metallic ions are introduced.

## Suggested methods and equipment

The electrical conductivity of water samples should be measured as soon as the sample is obtained (after temperature and pH). If this is not possible the measurement can be delayed by up to 1 month if the sample is refrigerated (but not frozen) immediately on being taken, and if the sample bottle is filled completely, with no air gap at the top.

### Equipment

The equipment you will need for this method includes:

- electrical conductivity meter
- calibration solution
- deionised water.

A good conductivity meter should have, apart from EC electrode, a temperature probe that enables measurement of temperature and automatic compensation for temperature in the conductivity reading. If you have a non-compensating meter, you must measure the water temperature at the same time as the electrical conductivity and use compensation tables to be able to standardise your EC reading and report it as electrical conductivity at 25°C.

Be aware that meters with different EC ranges are available, e.g. 0–1990 µS/cm (0–1275 mg/L) and 0–19 900 µS/cm, (0–12 800 mg/L) so select one that matches the expected conductivity range in the aquifer you will be monitoring.

**Procedure**

1. Before going to the site, calibrate your meter.
2. On site, rinse the electrode in deionised water.
3. Dip the electrode into the sample and, if necessary, select the appropriate conductivity range.
4. Do not immerse the probe too far (some probes/meters are not waterproof above a certain point).
5. Move the electrode slowly in a circle for one minute until the digital readout stabilises or continually jumps between two numbers.
6. Repeat the test on a replicate sample.
7. Record both results in a Water Quality Results sheet (see Record sheets).
8. Rinse the electrode with deionised water before testing the next sample.

**Maintenance**

Rinse the electrodes with deionised water from a squeeze bottle. Dry the electrodes with a paper towel; replace the cap and place the meter back in your kit. The electrodes need to be kept clean and dry.

To ensure accurate readings, you should periodically clean the meter with methylated spirits. Put the electrodes into a beaker with enough methylated spirits to just cover them, and leave them to stand for 15–20 minutes. Remove the electrodes and wipe them with a soft tissue soaked in methylated spirits. Finally rinse them thoroughly with distilled water.

**Calibration**

Use a conductivity calibration solution (usually potassium chloride) to calibrate the meter to the range you will need. For example, a 0.01 molar KCl solution has a conductivity of 1413 µS/cm, and a 0.001 molar KCl solution has a conductivity of 147 µS/cm.

To prepare a 0.01 molar conductivity solution, dissolve 0.7456 g of KCl (that has been dried overnight at 105°C) in deionised water and dilute to 1 L (can be stored for 6 months). To prepare a 0.001 molar solution, use only 0.0746 g of KCl (can be stored for 3 months). Store solutions in a dry, dark and cool room.

If your EC meter does not have an inbuilt temperature probe (i.e. no automatic temperature compensation) make sure your calibration solution is brought to a temperature of 25°C before calibration, otherwise significant errors can result, e.g. if the meter is calibrated using a solution at 15°C, it will give erroneous water sample readings that are 20% too high.

Tip a small volume of calibration solution into a small clean container for use when calibrating the meter. Discard used solution (do not return it to the bottle). Do not immerse the EC probe in the stock solution container. Rinse the electrodes with deionised water.

**Data confidence**

For quality control, calibrate the meter with a standard before each sampling run. The standard used for calibration must be of similar concentration to expected concentrations of test samples. Check that the meter has held its calibration at the end of the sampling run.

Test a Waterwatch mystery sample (available from your coordinator) every six months.

**Maximum recommended EC values in water**

Water use	EC (µS/cm)
Human drinking water	800
Chicken	3000
Dairy cattle	3700
Pigs	6000
Horses	6500
Beef cattle	7000
Sheep	7500

## Interpreting your results

Natural conductivity of groundwater varies significantly. You should know what baseline conductivities are expected in the area where you conduct your monitoring program. Interpret your results according to the objectives of the monitoring plan and suspected problems (e.g. seawater intrusion, contamination from septic tank, salinisation of groundwater and rising water tables, etc.).

Significant changes in conductivity may indicate that a discharge or some other source of contamination has entered the aquifer. Long-term regular monitoring may show a steady increase in salinity that may be due to a variety of different causes.

Discuss your results with your local Waterwatch coordinator. Compare your results with acceptable limits for water use in agriculture (different animals and crops).

If the aim of your monitoring plan is measuring salinity (EC) in order to assess risk of land salinisation, adoption of the procedures suggested in the National Standards and Targets Framework will ensure your results will be of high quality. Following the advice on choosing monitoring locations and frequency, measurement procedures, data analysis and interpretation will ensure your data will be comparable with the data collected by other groups or organisations and can be used in more than just the local context.

### Safety considerations when measuring electrical conductivity

Let someone know where you are going and when you will return. Don't work alone.

Students must be fully supervised by their teacher in accordance with Education Department guidelines.

Ensure safe and easy access.

Avoid contact with contaminated water. Use gloves while measuring, but take them off as soon as you've finished. Don't touch your skin with wet gloves.

Keep a first aid kit available.

Feet should be covered; remember sunblock, hat, t-shirt.

After each piece of used equipment has been rinsed with distilled water, pour the rinse water into the liquid waste bottle.

Do not put solid waste into the liquid waste bottle.

Place all used gloves, used paper towels, empty reagent packaging and any other rubbish from testing into a plastic garbage bag with no tears in it, and take it with you when you leave. Try to leave the site cleaner and tidier than you found it—pick up and transport out any rubbish.

Consult your Waterwatch coordinator about disposing of liquid waste.

# Nitrogen

## What is it and why does it matter?

**Nitrogen (chemical symbol N) is an element that is essential for all forms of life.**

Nitrogen is derived from the atmosphere, where nitrogen gas (N<sub>2</sub>) is the main constituent. Few living things can use gaseous nitrogen, but most depend on compounds of nitrogen.

The most common nitrogen compounds are:

- Nitrate (NO<sub>3</sub>-) is soluble in water and is easily adsorbed by plants and aquatic organisms.
- Ammonia (NH<sub>3</sub>) is a product of the decomposition of organic waste and can be used as an indicator of the amount of organic matter in the water.
- Nitrite (NO<sub>2</sub>-) is toxic to humans and animals.

Nitrogen is recycled continually by plants and animals, and is present in freshwaters at higher concentrations than phosphate. Although both nutrients are required for plant growth, phosphate is considered to be the limiting factor in fresh water. In saltwater ecosystems, however, nitrogen is much less abundant, and it becomes the nutrient that limits algal growth.

The importance of controlling nitrogen levels in aquatic environments has been recognised as one of the main elements when aiming at maintaining and improving water quality of these environments. Nitrogen in aquatic ecosystems, measured as 'total nitrogen' (sum of the concentrations of all forms of nitrogen present in water), has been included as a resource condition indicator of the *National Natural Resources Management Standards and Targets Framework*. In different environments it is, however, appropriate to measure particular components of total nitrogen, such as nitrate (expressed in µg/L of nitrogen) in groundwater.

### Nitrogen in groundwater

Nitrogen occurs in groundwater in a number of oxidation stages. Nitrate (NO<sub>3</sub>-) is the most common N-species.

Nitrate (and to lesser extent other nitrogen species) is probably the most important indicator of organic pollution or of biological activity in aquifers. Typical examples of high nitrate levels are:

- In wetter environments, excessive use of soluble nitrogenous fertilisers can result in leaching to the water table. This process is strongly influenced by seasonal microbial activity in the unsaturated zone. However, a clear long-term correlation exists between fertiliser application and rising concentrations of nitrate in groundwater.
- Both point and dispersed sources of pollution occur from animal wastes in farms and abattoirs. Various other food and industrial processes, including cheese factories, can also create nitrate pollution.
- A serious global industrial pollution problem is that of various oxides of nitrogen (NO<sub>x</sub>), which are derived mainly from vehicle and power station exhausts. The emitted nitrogen oxides are further oxidised to nitric acid, enter the soils with precipitation, react with bases in the soil and enter the aquifer as nitrate.
- In arid Australia, groundwater can contain very high values of nitrate in excess of 300 mg/L. This nitrate occurs naturally due to bacteria associated with termite mounds.

Groundwater can be the most important drinking water source available for many rural communities. Because of intensive agriculture, the groundwater in rural areas may have elevated concentrations of nitrate and other nutrients. Nitrate can persist in groundwater for a long time and accumulate to high levels as more nitrogenous fertilisers are applied to the land. To reduce the potentially adverse impacts of nitrate in surface and groundwater some particular land and water management practices can be adopted.

### Guideline values for nitrate-n

NHMRC Health Guideline	11.3 mg/L as N (or 50 mg/L as nitrate)
Livestock Water Guideline	90.0 mg/L as N (or 400 mg/L as nitrate)

## Suggested methods and equipment

Waterwatch groups that have chosen to test for nitrate usually use either the cadmium reduction (colour comparator) method or the zinc reduction (colorimeter/spectrophotometer) method. Both produce a colour reaction that is then measured either by comparison to colours on a colour comparator or by use of a colorimeter.

The cadmium reduction method appears to be more accurate at lower concentrations of nitrate than the zinc reduction method but is far more hazardous because cadmium is very toxic.

Monitoring nitrate is challenging because it can involve measuring very low concentrations – down to 0.01 mg/L as N. Your first consideration should be the purpose of monitoring for nitrate and the concentrations likely to be found. For example, if your group is monitoring for background changes in nitrate concentrations in the aquifer, environmentally significant changes in nitrate may occur but be undetected if they are smaller than the detection limit of your equipment. There is little to be gained if the concentrations of nitrate are persistently less than the detection limit of your equipment, or if the concentrations are right on the detection limit, where accuracy is often less than for mid-range values.

### Cadmium reduction (colour comparator) method

A colour comparator is a low cost, simple piece of equipment with a colour wheel or colour bar. The degree of redness of the solution is measured using the colour comparator – the redder the solution the higher the concentration of nitrates. Turbid water can, however, make this measurement difficult.

Matching the colour of a treated sample to a comparator can be subjective, especially at low concentrations, and can lead to variable results. Colour comparators are useful for identifying the high concentrations (greater than 1 mg/L) that can be expected at heavily polluted sites in the aquifer (e.g. a bore polluted by leakage from a septic tank).

The cadmium reduction method requires that the water samples are not turbid. Ideally all samples (not only turbid) should be filtered. If copper, iron, or other metals are present in concentrations above several mg/L, the reaction with the cadmium will be slowed and the reaction time will have to be increased.

The reagents used for this method are often pre-packaged for various concentration ranges of nitrate in water. It is not possible to know the appropriate range for your samples, unless other measurements have been made previously. Therefore, make some trial measurements with reagents for one range (perhaps chosen according to the trigger values for the designated uses) and then, once you get a feel for the

values likely for your samples, move to a more suitable range of reagents if necessary.

Your Waterwatch coordinator may have access to local values for nitrate for the aquifer you will be testing, and will be able to discuss the appropriate trigger values for nitrate suggested by the water quality guidelines (ANZECC/ARMCANZ 2000).

### Equipment

The equipment you will need for this method includes:

- acid-washed sample bottles or disposable Whirl-pak® bags
- latex gloves, safety glasses
- colour comparator and its glassware
- prepacked reagents
- deionised water to rinse the sample tubes between uses
- wash bottle to hold rinse water
- clean, lint-free cloth to clean and dry the outside of sample tubes
- filtration equipment: syringe (25 or 50 mL), disposable filters holders with 0.45 µm filters
- waste chemical bottle with secure lid for holding cadmium, clearly labelled.

### Procedure

1. Collect your sample using the standard technique and using dedicated sample bottles.
2. Filter an aliquot of the sample needed for nitrate test (50 mL will be sufficient), use disposable filter holders with filters made from nitrate free material.
3. If not testing nitrate in the field, keep the filtered samples on ice and test them in the laboratory as soon as possible (within 24 hours).
4. Use safety glasses and gloves to minimise risk of harm from reagents.
5. Follow the manufacturer's directions for your particular kit to analyse the sample.
6. Record your reading on the Water Quality Results sheet (see Record sheets).
7. Pour the treated samples into the waste chemical bottle for disposal as a hazardous toxic waste.
8. Thoroughly rinse all containers with deionised water before testing the next sample.

### Maintenance

If reusing sample containers follow normal acid wash procedures between sampling runs (see 'Acid-wash cleaning method').

## Zinc reduction (colorimeter/spectrophotometer) method

Colorimeters and spectrophotometers measure the intensity of red colour of the treated sample electronically. They measure the amount of light transmitted through the solution or absorbed by it. The light used is at a wavelength of 543 nanometres (nm).

Use of one of these instruments reduces the subjectivity of determining colour and is much more accurate than other instruments. However, colorimeters and spectrophotometers need maintenance and regular calibration.

At very high transmittance (above 90%) the presence of moisture, fingerprints or variable positioning of the sample cells can cause a significant change in readings. Some meters require you to prepare and analyse known standard concentrations before testing in order to convert the transmittance readings of your groundwater sample to milligrams per litre. Other meters read percentage transmittance of light that passed through the sample, which can then be converted to milligrams per litre as N, using a chart. The most convenient meters directly display the sample concentration as mg/L of N.

For many groundwater systems, environmentally significant changes in nitrate concentrations are very low. As a guide, a field colorimeter or spectrophotometer should have a minimum detection concentration of 0.02 mg/L as N and an accuracy of within 20% of the true value. Measuring lower concentrations can be achieved by sending a sample to a commercial laboratory for testing.

### Equipment

The equipment you will need for this method includes:

- dedicated sample bottles
- field colorimeter with sample tubes
- prepacked reagents
- deionised water to rinse the sample tubes between uses
- wash bottle to hold rinse water
- clean, lint-free cloth to clean and dry the sample tubes
- clean sample containers
- filtration equipment: syringe (25 or 50 mL), disposable filters holders with 0.45 µm filters
- safety glasses
- latex gloves
- chemical waste bottle clearly marked.

### Procedure

These instructions are generalised for a variety of colorimeters. Follow the manufacturer's instructions for your model.

1. Collect your sample as per standard technique using dedicated sample bottles.
2. Filter an aliquot of the sample needed for nitrate test (50 mL will be sufficient), use disposable filter holders with filters made from nitrate free material.
3. If not testing nitrate in the field, keep the samples on ice and test them in the laboratory as soon as possible (within 24 hours).
4. 'Zero' the meter using a blank (the sample without reagents added to it, following the manufacturer's directions).
5. Pour the recommended sample volume into a mixing container and add reagent powder. Swirl to mix. Wait the recommended time (usually a minimum of 10 minutes) before proceeding.
6. Pour the first water sample into the sample cell test tube. Wipe the tube with a lint-free cloth to be sure it is clean and free of smudges or water droplets. Insert the tube into the sample cell of the colorimeter.
7. Place the cover over the sample cell. Read the concentration of the sample or percentage transmittance, and convert to mg/L as N on the chart provided.
8. Record your reading on the Water Quality Result sheet.  
**Note:** if the sample concentration is below the minimum detection limit of your instrument, e.g. 0.05 mg/L, report the result as <0.05 mg/L as N.
9. Pour the treated samples into the liquid waste bottle.
10. Rinse the sample cell test tube and mixing container three times with deionised water. Avoid touching the lower portion of the sample cell test tube. Wipe with a clean, lint-free cloth. Be sure that the lower part of the sample cell test tube is clean and free of smudges or water droplets. Be sure to use the same sample cell test tube for each sample. If the test tube breaks, use a new one and repeat step 1 to zero the meter.

### Maintenance

Follow normal acid-wash procedures for sample bottles between sampling runs (see information box 'Cleaning sample containers').

### Calibration

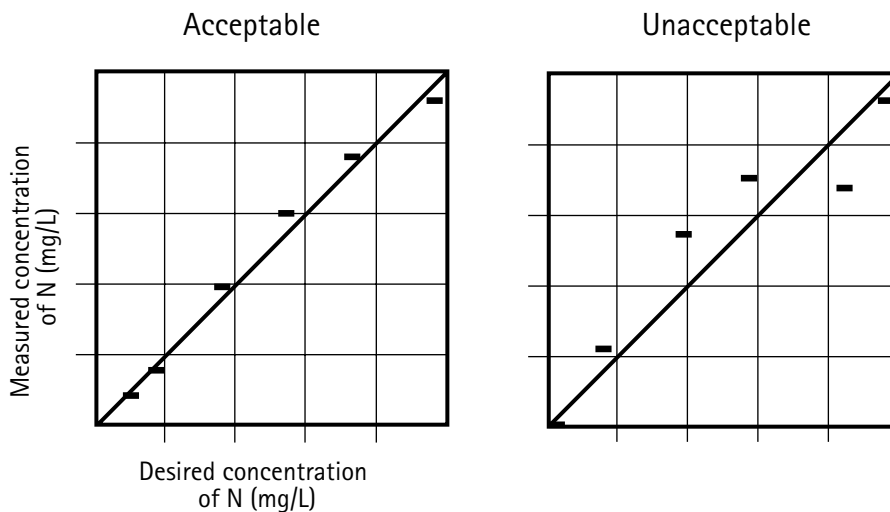
To calibrate a colorimeter you will need:

- standard stock solution of 1 mg of N/L concentration (best if purchased)
- six 25 mL volumetric flasks
- small beaker
- 1 mL accurate pipette.

The procedure for calibrating a colorimeter is:

- Six standard solutions that are in the range of the results expected have to be prepared. Generally 0.00 mg/L, 0.04 mg/L, 0.08 mg/L, 0.12 mg/L, 0.16 mg/L and 0.20 mg/L of N will be suitable concentrations.
- Label six 25 mL volumetric flasks, one for each new standard solution.
- Pour about 30 mL of a nitrate standard stock solution containing 1 mg N/L into a small beaker.
- Using an accurate pipette transfer appropriate volume (from 0 to 5 mL, see information box) of the stock solution from the beaker to the volumetric flasks.
- Fill the volumetric flasks to the line. Swirl.
- Analyse a portion of each of these new standard solutions in a colorimeter, as described above, and record the results.
- Construct a standard curve from your measured concentrations (mg N/L), with measured concentration on the y axis and desired concentration on the x axis. The points should fall on a straight line (see Figure 6.12).

Figure 6.12: Acceptable and unacceptable calibration curves for nitrate



**Proportion of stock standard solution (1 mgN/l) to concentration of new standard solution**

Concentration of new standard solution (mg/L)	Volume of standard stock solution (mL)
0.00	0
0.04	1
0.08	2
0.12	3
0.16	4
0.20	5

**Note:** Volume of stock solution needed to make each standard solution is calculated using the following formula:

$$\text{Volume of stock solution needed} = \frac{\text{Desired concentration of new standard} \times \text{final volume of new standard}}{\text{Concentration of stock solution}}$$

## Data confidence

### Colour comparator

- Check for contamination by testing a calibration blank (deionised water) before testing a sample. Always use the same type of light and from the same direction when comparing colours.
- The light source should be in the same position relative to the colour comparator when matching colours for each sample.
- As a quality control check, ask someone else to read the comparator after you.
- Test a field replicate every 10 samples.
- Test a Waterwatch mystery sample every six months.
- Colours of the comparator must be free of scratches and contaminants.

### Colorimeter

- Calibrate the colorimeter with a reagent blank before each use.
- To check if sample bottles are contaminating a sample, test a field blank.
- Test a field replicate after every tenth sample.
- Every six months, measure a mystery solution supplied by your Waterwatch coordinator.
- Check the calibration of the colorimeter at least twice yearly with prepared standards as described above. Some colorimeters require calibrating with prepared standards before each use.
- For an external quality control check on 10% of samples, split every tenth sample, measure one part and send the other part to another laboratory. Alternatively, during field sampling, make every tenth sample a replicate. On measurement, the two samples should give the same results.

## Interpreting your results

Nitrate concentrations in natural groundwater are generally less than 2 mg/L. It is a good idea to determine typical background concentrations of nitrate in the aquifer you are testing. Your findings will be interpreted according to the potential problem you are trying to monitor (e.g. pollution by point source such as a leaking septic tank or widespread pollution from application of nitrogenous fertilisers).

In excessive amounts, nitrates can cause significant water quality problems.

Adoption of the procedures suggested in the National Standards and Targets Framework will ensure your results will be of high quality.

Your Waterwatch coordinator will be able to discuss the relevant trigger values for designated uses, as suggested by the revised water quality guidelines (ANZECC/ARMCANZ 2000).

**Safety considerations and waste disposal tips when sampling and measuring nitrate**

- Let someone know where you are going and when you will return.
- Don't work alone.
- Students must be fully supervised by their teacher in accordance with Education Department guidelines.
- Ensure safe and easy access. Beware of possible presence of snakes in long grass surrounding a bore.
- If sampling near a road, be wary of passing traffic. Avoid contact with contaminated water. Use plastic disposable gloves while sampling, or analysing, but take them off as soon as you've finished. Don't touch your skin with wet gloves.
- Keep a first aid kit available.
- Feet should be covered; and remember sunblock, hat and t-shirt.
- Take some clean water with you for washing down chemical spills on your skin and clothes.
- Have a squirt bottle ready to wash out eyes in case of chemical exposure.
- Use methods that minimise your possible contact with chemicals.
- To avoid contamination and contact with possibly toxic chemicals, never put your thumb over the test tubes when you shake or swirl them.
- Never pipette with your mouth; always use a pipette bulb.
- Use goggles and gloves when handling reagents.
- Be very careful if you are testing nitrate with the cadmium reduction method. Cadmium is present in the reagent powder and precipitates to the bottom of the test tube at the end of the test. Waste from this test should not be poured down the drain but stored separately in a hazardous waste jar labelled 'toxic waste'. This jar must be disposed of as 'special waste'.
- Hold all test bottles over a wide-mouthed liquid waste bottle while adding the liquid and powder reagents.
- Place all used gloves, used paper towels, empty reagent packaging and any other rubbish from testing into a plastic garbage bag with no tears in it, and take it with you when you leave the field site.
- After each piece of used equipment has been rinsed with distilled water, pour the rinse water into the liquid waste bottle.
- Don't put solid waste into the liquid waste bottle.
- Consult your Waterwatch coordinator before disposing of liquid wastes.

**Extra safety tips for testing nitrate**

Always wear plastic disposable gloves and goggles when analysing samples. They protect you from the reagents and samples, and also protect the samples from contamination by the nitrates and phosphorus that are typically present on the hands of smokers. Be very careful when you are testing nitrate with the cadmium reduction method. Cadmium is present in the reagent powder and precipitates to the bottom of the test tube at the end of the test. Waste from this test should not be poured down the drain but instead should be stored separately in a hazardous waste jar labelled 'toxic waste'. This jar must be disposed of as 'special waste'.

# Phosphorus

## What is it and why does it matter?

**Phosphorus (chemical symbol P):**  
a mineral nutrient that is essential  
for all forms of life.

The phosphorus found in both surface water and groundwater is in a form called phosphate (chemical formula,  $\text{PO}_4^{-3}$ ). It is naturally derived from the weathering of rocks and the decomposition of organic material, but it can also enter waterbodies in runoff or discharges – soil and fertiliser particles can carry phosphorus.

Phosphates available to plants and animals are called orthophosphates, and exist in waterbodies as dissolved and particulate (suspended) and colloidal forms. Dissolved orthophosphate is immediately available to plants and animals. Particulate orthophosphate is potentially available to plants and animals. Colloidal polyphosphates are not immediately available to plants.

Plant growth is limited by the availability of dissolved orthophosphate. A sudden increase in orthophosphate in waters can stimulate great increases in the growth of algae, as well as other aquatic plants. Algal blooms potentially produce toxins and also can cause large deficits of dissolved oxygen. Phosphates do not pose a human or animal health risk, so are not regulated in drinking water.

The importance of controlling phosphorus levels in aquatic environments has been recognised as one of the main elements when aiming at maintaining and improving water quality of these environments. Phosphorus measured as total phosphorus (sum of the concentrations of all forms of phosphorus present in the water) has been included in the resource condition indicator list of the *National Natural Resources Management Standards and Targets Framework*.

## Phosphorus in groundwater

Phosphate is a component of sewage and other household effluents (mainly from detergents), as well as being another important constituent of fertiliser.

Phosphate dissolves less readily than nitrate. Phosphate is not considered to be a primary water quality indicator in groundwater because it tends to bind to soil particles – it is not mobile in soil–water. However, in areas where soil is saturated with phosphate, there is an increased chance of phosphate reaching groundwater. In particular, this may

happen in sandy soils and in areas with shallow water tables. In situations like that phosphorus may serve as a water quality indicator.

The phosphorus concentration in groundwater is generally low (0.1 mg/L or less).

## Suggested methods and equipment

Phosphate concentration is measured in milligrams per litre (mg/L). Since most results are reported in terms of phosphorus (rather than phosphate), Waterwatch has adopted the convention of reporting results as P. To convert phosphate ( $\text{PO}_4$ ) to phosphorus (P), divide by 3 (e.g. 0.06 mg  $\text{PO}_4$ /L is equivalent to only 0.02 mg P/L).

Existing field equipment cannot detect phosphate at concentrations below about 0.02 mg/L. There is little to be gained from monitoring if concentrations of phosphate are consistently lower than the detection limit of your equipment.

Phosphate concentration does not have to be measured onsite in the field, provided the samples can be refrigerated immediately, or frozen. The phosphate in refrigerated samples must be measured within 24 hours of sampling, and in frozen samples within one month of sampling. The sample bottle should be filled to three-quarters capacity.

The **dissolved (or filterable) reactive test** measures only dissolved orthophosphate and provides a measure of the immediately available phosphate in the system at the time of sampling.

The **total phosphorus test** measures the immediately and potentially bio-available forms of phosphorus in the sample. Total phosphorus concentrations are often many times higher than orthophosphate reported as phosphorus in the same sample. Therefore total phosphorus readings are more likely to come within the measuring range of your instrument.

## Filterable reactive phosphate method

Filterable reactive phosphate is usually measured by the ascorbic acid method. It is best to filter the sample, but some Waterwatch groups do not have access to filters. If the sample can be filtered, the **ascorbic acid method** measures dissolved orthophosphate only (also known as filterable reactive phosphate). This is a useful value.

**Note:** In an unfiltered sample, the ascorbic acid method is likely to give inconsistent results, because the reagents are also reacting with other substances attached to the unfiltered particles.

For measurement of total phosphorus, all the forms of phosphorus in the sample are first converted to orthophosphate by treating the sample with suitable reagents. The sample is then neutralised and the orthophosphate is measured by the standard ascorbic acid method.

The need for a heat source means the total phosphorus test is better done in a laboratory. Even then, it is difficult for inexperienced operator to get accurate results.

### Equipment

The equipment you will need for this method includes:

- dedicated sample bottles
- colour comparator or field colorimeter
- pre-packed reagents to turn the water blue
- deionised water to rinse the sample tubes between uses
- wash bottle to hold rinse water
- clean, lint-free cloth to clean and dry the sample tubes
- clean sample containers
- safety glasses
- latex gloves
- clearly marked 'chemical waste' bottle
- filtration equipment: syringe (25 or 50 mL), disposable filters holders with 0.45 µm filters

### Colour comparator and colorimeter

**Colour comparators** are appropriate for monitoring sites with expected high concentrations of phosphates (greater than 0.1 mg/L). A colour comparator is a low-cost simple piece of equipment consisting of a blue colour spectrum. Intensity of the blue is in direct proportion to the amount of orthophosphate present. Reagents react with the water sample to result in a blue colour. The colour is matched against the spectrum to determine mg/L of phosphorus.

The **colorimeter** is best used at sites where the expected concentrations of phosphates are relatively low (down to 0.02 mg/L). The colorimeter is a relatively expensive electronic device, which measures the degree of 'blueness'. The colorimeter measures the amount of light transmitted or absorbed at a nominated wavelength.

### Procedure

#### Field procedure for a colour comparator

1. Collect sample.
2. Filter it (if filters are available). If you are not filtering, you are measuring total reactive phosphate. It is important to note which method you are using so your data can be interpreted with the method your group is using.
3. Follow manufacturer's instructions for your colour comparator.
4. Make the closest possible colour match between the treated sample and the colour scale of the colour comparator.
5. Record the value in orthophosphate as P on your Water Quality Results sheet (see Record sheets).

#### Field procedure for a colorimeter

1. Follow the manufacturer's instructions for your model.
2. 'Zero' the meter using a blank (sample minus reagents) following the manufacturer's directions. Most manufacturers will instruct you to zero the meter using a reagent blank. The blank you use will depend on what you are testing. When testing your groundwater samples your blank will be the sample without any reagents added to it; when testing glassware or reagents for data confidence, your blank will be deionised water plus the reagent powder.
3. Pour the recommended sample volume into a mixing container and add reagent powder. Swirl to mix. Wait the recommended time (usually a minimum of 10 minutes) before proceeding.
4. Pour the first water sample into the sample cell test tube. Wipe the tube with a lint-free cloth to be sure it is clean and free of smudges or water droplets. Insert the tube into the sample cell of the colorimeter.
5. Place the cover over the sample cell. Read the concentration of the sample, or percentage transmittance and convert to mg/L as P on the chart provided. Record your reading on the Water Quality Result sheet (see Record sheets).
 

**Note:** if the sample concentration is below the minimum detection limit of your instrument, say 0.05 mg/L, report it as '<0.05 mg/L as P'.
6. Pour the used samples into a designated waste bottle.
7. Rinse the sample cell test tube and mixing container three times with deionised water. Avoid touching the lower portion of the sample cell test tube. Wipe with a clean, lint-free cloth. Be sure the lower part of the sample cell test tube is clean and free of smudges or water droplets.

- 8. Be sure to use the same sample cell test tube for each sample. If the test tube breaks, use a new one and repeat step 1 to re-zero the meter.

**Calibration**

To calibrate a colorimeter you will need:

- Standard stock solution of 1 mg of P/L concentration (best if purchased)
- Six 25 mL volumetric flasks
- Small beaker
- 1 mL accurate pipette

The procedure for calibrating a colorimeter is:

- Six standard solutions that are in the range of the expected results have to be prepared. Generally 0.00 mg/L, 0.04 mg/L, 0.08 mg/L, 0.12 mg/L, 0.16 mg/L and 0.20 mg/L will be suitable concentrations.

- Label six 25 mL volumetric flasks, one for each new standard solution.
- Pour about 30 mL of a phosphate standard stock solution containing 1 mg P/L into a small beaker.
- Using an accurate pipette transfer appropriate volume (from 0 to 5 mL, see Table below) of the stock solution from the beaker to the volumetric flasks.
- Fill the volumetric flasks to the line; swirl.
- Analyse a portion of each of these new standard solutions in a colorimeter, as described above, and record the results.
- Construct a standard curve from your measured concentrations (mg P/L), with measured concentration on the y axis and desired concentration on the x axis. The points should fall on a straight line (see Figure 6.13).

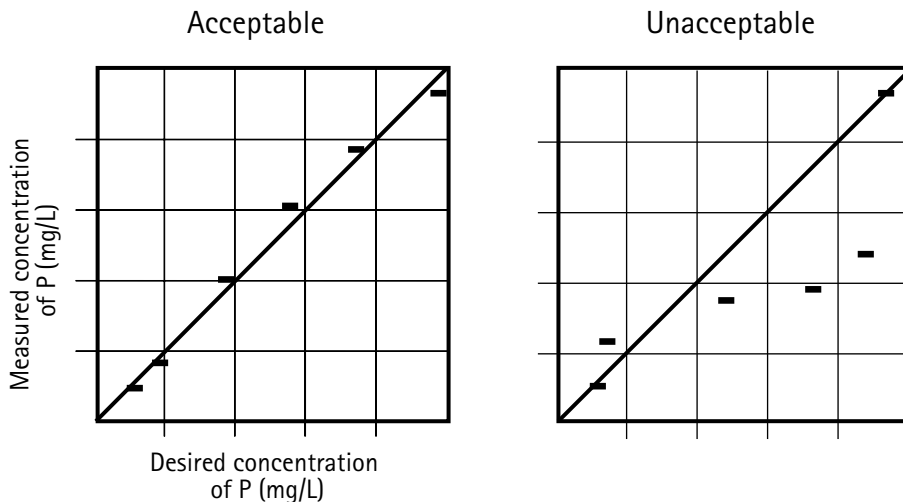
**Proportion of stock standard solution (1 mg P/L) to concentration of new standard solution**

Concentration of new standard solution (mg/L)	Volume of standard stock solution (mL)
0.00	0
0.04	1
0.08	2
0.12	3
0.16	4
0.20	5

Note: volume of stock solution needed to make each new standard sol. is calculated using the following formula:

$$\text{Volume of stock sol. needed} = \frac{\text{desired concentration of new standard} \times \text{final volume of new standard}}{\text{concentration of stock solution}}$$

Figure 6.13: Acceptable and unacceptable calibration curves for phosphate



## Total phosphorus method

It is very difficult to obtain results that agree with those measured in external laboratories.

### Equipment

The equipment you will need for this method includes:

- potassium persulphate
- a pressure cooker.

### Procedure

1. Follow the manufacturer's instructions for digesting and neutralising the sample before testing for orthophosphate with either a colour comparator or colorimeter, as described above.
2. Because of the digestion step, measurement of total P should be carried out in the laboratory. Extreme caution must be taken when carrying out the total P test. Also take care with the disposal of waste from the reactions.
3. Because of the extra equipment needed, use of acid and the much longer time needed to complete a total phosphorus test you should consider only testing for orthophosphate using the ascorbic acid method on an untreated sample.

### **Data confidence**

- Contamination can significantly affect the results in this test. All sampling equipment must be phosphorus-free; phosphorus molecules from samples have a tendency to attach to the inside surface of sample containers and bottles.
- Check for contamination by calibrating sample bottles with a reagent blank (deionised water) field sample in the comparator before each sampling run.
- Before testing samples, containers must be acid-washed to remove adsorbed phosphorus before re-use.
- The bottles must be able to withstand repeated contact with hydrochloric acid. Plastic bottles (high density polyethylene or polypropylene) are preferable to glass because they will better withstand breakage. Many laboratories now use phosphate-free detergents, so contamination during washing is no longer a common problem. However, phosphate contamination can still occur from other samples.

- The light source should be the same and in the same position relative to the colour comparator when matching colours for each sample.
- As a quality control check, ask someone else to read the comparator after you.
- Follow the manufacturer's directions for your colour comparator.
- Calibrate the colorimeter with prepared standards at least twice a year, or before each use, if so directed by the manufacturer.
- Always wear plastic disposable gloves when analysing samples. They protect you from the reagents and samples, and also protect the samples from contamination by the phosphorus and nitrogen that are typically present on the hands of smokers.
- Test field replicates for 10% of samples.
- Measure a Waterwatch mystery sample every six months.
- Arrange an external check on 10% of samples, by splitting them and sending half to another laboratory elsewhere.
- Make sure reagents are not out-of-date.
- Keep all glassware acid-washed and rinsed.

### **Interpreting your results**

When you have enough measurements of phosphate through time in your aquifer, especially in comparison with a local or regional baseline value, you will know when a particular phosphate value does not fit the usual pattern.

Contact your Waterwatch coordinator about the water quality guidelines' (ANZECC/ARMCANZ 2000) suggestions of relevant trigger values for specific designated uses.

Adoption of the procedures suggested in the National Standards and Targets Framework will ensure your results will be of high quality.

**Safety considerations and waste disposal tips when sampling and measuring phosphate**

- Let someone know where you are going and when you will return.
- Don't work alone.
- Students must be fully supervised by their teacher in accordance with Education Department guidelines.
- Ensure safe and easy access. Beware of possible presence of snakes in long grass surrounding a bore.
- If sampling near a road, be wary of passing traffic.
- Avoid contact with contaminated water. Use gloves while sampling, but take them off as soon as you've finished. Don't touch your skin with wet gloves.
- Keep a first aid kit available.
- Feet should be covered; remember sunblock, hat and t-shirt.
- Take some clean water with you for washing down chemical spills on your skin and clothes.
- Have a squirt bottle ready to wash down eyes in case of chemical exposure.
- Use methods that minimise your possible contact with chemicals.
- To avoid contamination and contact with possibly toxic chemicals, never put your thumb over the test tubes when you shake or swirl them.
- Never pipette with your mouth; always use a pipette bulb.
- Use goggles and gloves when handling reagents.
- Hold all test bottles over a wide-mouthed liquid waste bottle while adding the liquid and powder reagents.
- Place all used gloves, used paper towels, empty reagent packaging and any other rubbish from testing into a plastic garbage bag with no tears in it, and take it with you when you leave the field site.
- After each piece of used equipment has been rinsed with distilled water, pour the rinse water into the liquid waste bottle.
- Do not put solid waste into the liquid waste bottle.
- Consult your Waterwatch coordinator about disposal of liquid wastes.

**Extra safety tips for testing phosphate**

- Safety glasses and gloves must be worn at all times.
- The First Aid procedure for acid on skin is to flush it with plenty of water.
- Sulphuric acid and phosphate acid reagent are strong acids and can cause severe burns.
- Ammonium persulfate is harmful if swallowed; avoid contact with eyes and skin.
- Sodium hydroxide causes severe burns.
- Phosphate reducing reagent is an irritant.

# Appendixes

These appendixes consist of key terms you will need to understand to be able to effectively monitor groundwater, as well as how to construct and install a Piezometer.

## Key terms

<b>Aquifer</b>	A rock or soil formation capable of receiving, storing, transmitting and yielding significant quantities of water; aquifer types are confined, unconfined, and artesian.
<b>Aquitard</b>	See confined aquifer.
<b>Artesian aquifer</b>	A confined aquifer in which the pressure head of the groundwater rises above the upper confining layer of the aquifer. If the pressure is sufficient to cause the well to flow at the surface, it is called a flowing artesian aquifer.
<b>Artesian well</b>	A bore sunk into an artesian aquifer in which water rises from an underground water-containing layer under its own pressure.
<b>Bore, well</b>	A hole sunk into the ground for abstraction of water from an aquifer or for observation purposes. A well is generally of larger diameter than a borehole and dug rather than drilled.
<b>Casing</b>	A tube used as a temporary or permanent lining for a borehole in order to prevent the solid aquifer material from entering the borehole or to ensure groundwater only enters the borehole at specific depths through a screen.
<b>Catchment</b>	The area of land, which intercepts rainfall and contributes the collected water to surface water (streams, rivers, wetlands) or groundwater.
<b>Confined aquifer</b>	An aquifer that is sandwiched between two layers of relatively impermeable material (e.g. clay or unfractured granite) called aquitards. Groundwater in a confined aquifer is under pressure significantly greater than atmospheric pressure.
<b>Discharge</b>	Water flow from an aquifer (e.g. from a natural spring or water bore).
<b>Discharge zone</b>	Area where groundwater reaches the surface.
<b>Flow rate</b>	Speed with which groundwater moves through the ground.
<b>Flowing artesian well</b>	When the top of a well in a confined aquifer is below the <i>potentiometric surface</i> , water will flow out of the well under pressure.
<b>Hydraulic gradient</b>	Slope of the water surface between two points in an aquifer. The difference in hydraulic head between two measuring points within a porous medium, divided by the distance between the two points.
<b>Head</b>	The fluid potential for flow through porous media largely comprised of pressure head and elevation head. Hydraulic head has been defined as the water level above a zero datum (mean sea level) of water in a well tapping an aquifer that is open to the atmosphere.
<b>Permeable</b>	<i>Permeability</i> is a measure of the ease with which a fluid will move through a porous material (e.g. sand and gravel or rock). A geologic unit is permeable if groundwater moves easily through it.
<b>Permeability</b>	Ability of a material (generally an earth material) to transmit fluids (water) through its pores when subjected to pressure or a difference in head. Expressed in units of volume of fluid (water) per unit time per cross section area of material for a given hydraulic head.
<b>Piezometer</b>	Small diameter well open at a point or short length in the aquifer to allow measurement of hydraulic head at that point or short length.
<b>Potentiometric surface</b>	The level to which water in a confined aquifer would rise if unaffected by friction with the surrounding rocks and sediments.

<b>Precipitation</b>	Water falling onto the surface of the earth in the form of rain, hail or snow.
<b>Recharge</b>	Water infiltrating to replenish an aquifer, it can be either natural, through movement of precipitation into an aquifer, or artificial through pumping of water into an aquifer.
<b>Recharge area (recharge zone)</b>	An area through which water from a groundwater catchment percolates to replenish (recharge) an aquifer; an unconfined aquifer is recharged by rainfall throughout its distribution; confined aquifers are recharged in specific areas where water leaks from overlying aquifers, or where the aquifer rises to meet the surface; Recharge of confined artesian aquifers is often at some distance 'upflow' from points of extraction and discharge.
<b>Run-off</b>	The portion of rainfall, melted snow, or irrigation water that flows across the ground surface instead of soaking into the soil. Runoff can pick up pollutants from the air or land carry them to streams, lakes or oceans.
<b>Salinity</b>	The amount of salt dissolved in water. In the field, salinity measurements are usually expressed in terms of electrical conductivity either in $\mu\text{S}/\text{cm}$ or $\text{dS}/\text{m}$ . The measure of total dissolved (or soluble) salt, i.e. mineral constituents in water. Water resources are classified on the basis of salinity in terms of Total Dissolved Solids (TDS) or Total Soluble Salts (TSS). TDS and TSS are measured by different methods, but for most purposes they can be read as the same thing. Measurements are usually shown in milligrams per litre (mg/L) or parts per thousand (ppt). Measurements in ppt can be converted to mg/L by multiplying by 1000, e.g. seawater is approximately 35 ppt or 35 000 mg/L TDS. Water resources are classified as fresh, marginal, brackish or saline on the basis of salinity.
<b>Salinisation</b>	An increase in the level of salinity in soil or water, which impairs quality.
<b>Seawater intrusion</b>	The inland or up-gradient intrusion of seawater into a layer of fresh groundwater.
<b>Saturated zone</b>	Rock or soil, in which every available space is filled with water.
<b>Sustainable yield</b>	The volume of groundwater that can be annually extracted from a groundwater basin without causing adverse effects.
<b>Transpiration</b>	The process of absorption of water by plants, usually through the roots, the movement of water through plants, and the loss of the water to the atmosphere through small openings on the underside of leaves called stomata.
<b>Turbidity</b>	Turbidity is caused by the presence of fine suspended matter such as clay, silt or colloidal material. It gives water a muddy or milky appearance due to the scattering of light by the suspended material.
<b>Unconfined aquifer</b>	An aquifer whose upper boundary is made up of permeable material that transmits water readily.
<b>Water table</b>	The upper surface of groundwater within the unconfined aquifer. Swamps or lakes in low-lying areas may be surface expressions of the water table.
<b>Well</b>	See Bore

# Piezometer construction and installation

Based on the Waterwatch Queensland, *Community Estuarine Monitoring Manual*.

Piezometers can be made easily from PVC pipe and installed using an auger.

## Construction

### Equipment

The equipment you will need to construct a piezometer includes:

- 2–3 m of 80 mm diameter PVC pipe
- two 80 mm PVC caps
- saw.

### Procedure

1. Dig test hole to determine the depth to groundwater, the piezometer should be 500 mm longer than the distance to the water table.
2. Using the saw, cut small slots along the bottom 500 mm of the piezometer to allow the groundwater to enter (see Figure 6.14).
3. Place a PVC cap over the bottom of the piezometer.

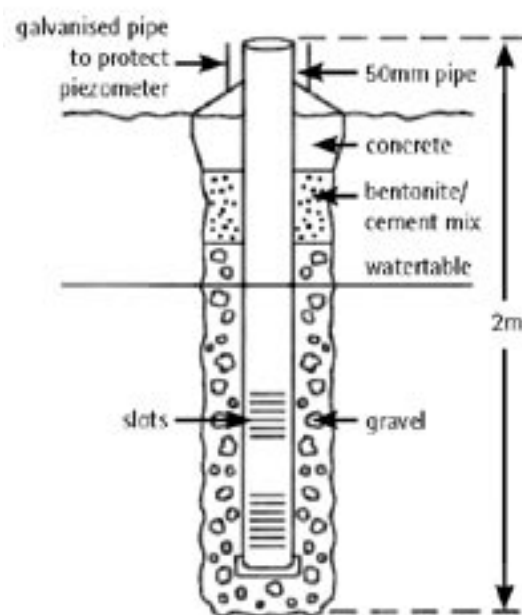
## Installation

### Equipment

The equipment you will need to install a piezometer includes:

- auger (extendable to 5 m) with a 100 mm tip
- bucket of gravel (3–5 mm rounded pebbles – do not use jagged pebbles as they do not pack down as well)
- bentonite pellets (pre-soaked)
- premixed concrete
- a capped galvanised or clay pipe (large enough to case the piezometer above the ground)
- extra PVC pipe and extension joint
- hacksaw.

Figure 6.14: Cross section of a piezometer



### Procedure

1. Use the auger to dig a hole to the length of the prepared piezometer. The depth should be at least equal to, but preferably greater than, the distance to the water table.
2. Put a small amount of gravel at the bottom of the hole. Place the piezometer in the centre of the hole, ensuring that it extends at least 100 mm above the ground.
3. Fill around the pipe with the remaining gravel, to within 400 mm of the surface.
4. Fill the next 300 mm with a concrete/bentonite slurry, and the remainder with a concrete mix. Slope the concrete so surface water flows away, reducing the likelihood of contamination of the piezometer with surface water.
5. Place galvanised case or clay pipe over the top of the piezometer to reduce the likelihood of damage.
6. Quite often when drilling or augering holes, the stratigraphic profile of the bore wall is smeared by the action of the drilling. To ensure the through-flow of groundwater it is recommended that the fully constructed bore is pumped or bailed for a period immediately after construction and before it is used for monitoring. This will remove debris and fine material from the annulus. It also induces the aquifer to perform reasonably as if the casing was part of the stratigraphy.

## Record sheets

This section includes the record sheets you will need to record your data. Make sufficient copies of each. The forms are:

- Equipment maintenance and calibration record
- Site registration form
- Bore information sheet
- Water quality results.



## Site registration form

Complete one form for each borehole you are monitoring

Waterwatch group name: \_\_\_\_\_

School: \_\_\_\_\_ Teacher: \_\_\_\_\_ Year level: \_\_\_\_\_

Landcare group: \_\_\_\_\_ Other group: \_\_\_\_\_

Eastings (6 figures)						Northings (7 figures)							Map no.	Map name	Map scale	Bore id. no.	Bore type	Site name	Bore location	
4	6	0	2	0	0	5	4	1	4	1	0	0	8215	Tamar	1:100 000		Production bore, equipped	Wilson's orchard	Side of the xxx Road, 100 m south of bridge	

\* Example

Contact address: \_\_\_\_\_

Phone: \_\_\_\_\_

Form completed by (please print): \_\_\_\_\_

Don't forget – send copy of this form to your Waterwatch coordinator

## Bore information sheet

Bore identification number: \_\_\_\_\_

Bore position: Alt = \_\_\_\_\_

S = \_\_\_\_\_

N = \_\_\_\_\_

Bore location:<sup>1</sup> \_\_\_\_\_

Bore owner/custodian: \_\_\_\_\_

Bore drilled (when, by whom): \_\_\_\_\_

Type of bore:<sup>2</sup> \_\_\_\_\_

Construction comments:<sup>3</sup> \_\_\_\_\_

Access to bore: \_\_\_\_\_

Bore surroundings: \_\_\_\_\_

Bore parameters: casing height (m): \_\_\_\_\_

casing radius (m): \_\_\_\_\_

slots/screen @ (m): \_\_\_\_\_

total depth (m):<sup>4</sup> \_\_\_\_\_

water level (m):<sup>5</sup> \_\_\_\_\_

water column (m):<sup>6</sup> \_\_\_\_\_

casing volume (L):<sup>7</sup> \_\_\_\_\_

Notes:

<sup>1</sup> catchment name, shire, property name,

<sup>2</sup> monitoring, production, piezometer, equipped, not equipped

<sup>3</sup> casing material, good condition, well maintained headworks, etc.

<sup>4</sup> total depth = measured total depth – casing height

<sup>5</sup> water level (depth to water table) = measured water level – casing height

<sup>6</sup> water column = total depth – water level

<sup>7</sup> casing volume =  $3.14 \times \text{radius}^2 \times \text{water column} \times 1000$

## Water quality results

This sheet is for recording your results. Photocopy the sheet for each collected sample.

Date: \_\_\_\_\_ Time: \_\_\_\_\_

Name of group: \_\_\_\_\_

Name of investigators: \_\_\_\_\_

Bore ID number: \_\_\_\_\_

Bore location: \_\_\_\_\_

Depth to water table (m): \_\_\_\_\_

Record your results and the type of equipment, method and preservation method used, mystery or replicate sample results.

Parameter	Equipment method	Sample result	Replicate sample result	Mystery sample result	Mystery code no.
Temperature °C					
Conductivity μS/cm					
pH					
Nitrate mg/L-N					
Dissolved reactive phosphate mg/L-P					
Total phosphate mg/L-P					

