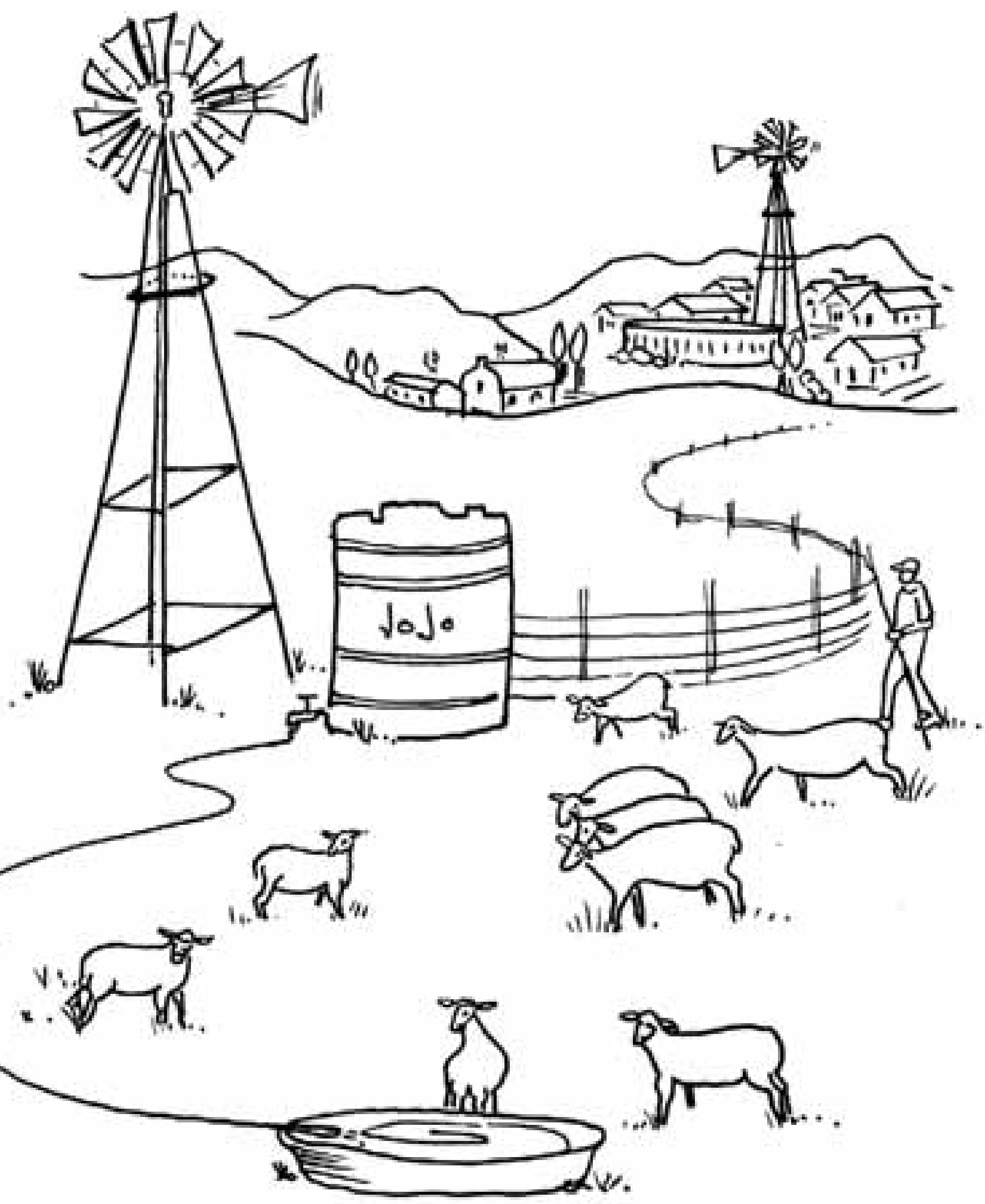
TAKING CARE OF

Groundwater

WHY AND HOW



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Preface and Acknowledgements

This booklet is part of a series to support a capacity-building initiative for Catchment Forums and Water Users Associations in the Olifants-Doorn Water Management Area (WMA). This initiative is a pilot, for possible implementation elsewhere in South Africa. The booklet is therefore designed to be used throughout the country. However, it serves a specific and limited purpose. It is a basic, practical introduction to groundwater resources, aimed at encouraging users to become involved in activities to better understand and manage a local water resources. As such the booklet is neither detailed nor comprehensive. It provides a bridge to more technical and regional materials available elsewhere.

WWF-SA initiated the project and produced the materials with partners including FETwater. The pilot programme is implemented by the Department of Water Affairs and Forestry (DWAF), Western Cape Region, with support from Danida.

For more information on the content and the capacity-building initiative, contact the office of the Olifants-Doorn WMA Manager in DWAF, Western Cape.

Artwork: Tammy Griffin

NASPERS FETWATER water & forestry Department: Water Affairs and Forestry REPUBLIC OF SOUTH AFRICA TLF

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What is Groundwater?

Groundwater is water located beneath the ground surface in soil pore spaces and in the fractures of geological formations. An aquifer is a geologic unit (or layer) of permeable material (like sand, gravel or fractured bedrock) that is capable of providing usable quantities of water to a borehole. Groundwater is normally brought to the surface through the development of **boreholes**, although it can flow to the surface at **natural springs**, **seeps and wetlands**. It is estimated that about 13% of all the water used by South Africans comes from groundwater.

Groundwater comes from rain, snow, sleet and hail that soak into the ground. The water moves down into the ground because of gravity, passing between particles of soil, sand, gravel, or rock, until it reaches a depth where the ground is filled, or saturated, with water. This process is known as groundwater recharge.

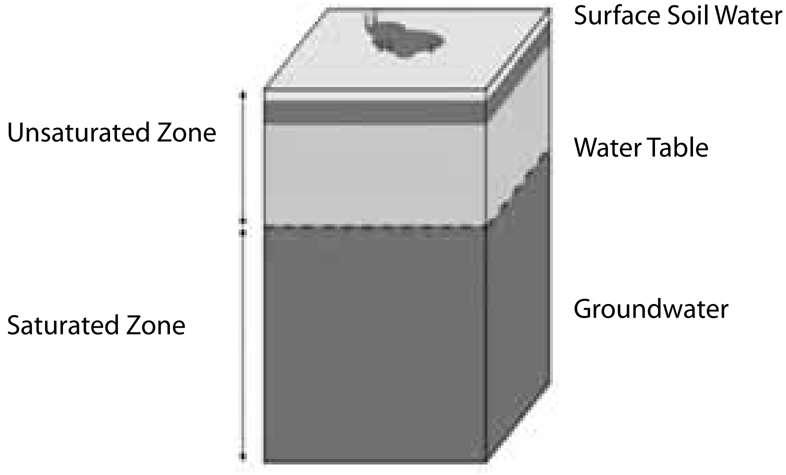

Figure 1: The Water Table
(Adapted from '*Guidelines for the management of groundwater to maintain wetland ecological character*', Ramsar Convention on Wetlands, 2005)

The area that is filled with water is called the **saturated zone** and the top of this zone is called the **water table**. The water table may be very near the ground's surface or it may be hundreds of metres below. The zone above the water table is known as the unsaturated zone.

It is estimated that the volume of groundwater comprises 30.1% of all freshwater resource on earth compared to 0.3% in surface freshwater. The icecaps and glaciers are the only larger sources of fresh water on earth at 68.7%.

Aquifers

An aquifer is an underground formation of permeable rock or loose (unconsolidated) material which can produce useful quantities of water when tapped by a borehole. These aquifers may be small, only a few hectares in area, or very large, underlying thousands of square kilometres of the earth's surface.

Primary Aquifers

Approximately 10% of groundwater in South Africa occurs in **'primary' aquifers**. Primary aquifers occur in porous sediments where groundwater is contained in the spaces between the 'sand' grains. Primary aquifers are found in river (alluvial) sediments, in coastal sand deposits and in the Kalahari deposits. These primary aquifers occur mostly in the coastal areas of the western and southern Cape, as well as the coastal areas of KwaZulu-Natal.

Secondary Aquifers

Over about 90% of the surface of South Africa, groundwater occurs in hard rock. Groundwater in these rocks is contained in fractures and in dolomite and limestone, in dissolved openings called 'fissures'. Hard rock aquifers are known as **'secondary' aquifers** because the groundwater occurs in openings which were formed after the rock was formed.

Karstic Aquifers

In South Africa there are significant areas of dolomite and limestone (known as karstic settings). Vast volumes of groundwater can occur in dissolved openings within the limestone and dolomites.

Groundwater Quality

As groundwater is found in many different situations, in association with different rock and sand types and minerals, the **quality of groundwater varies considerably**. Soluble parts of the surrounding materials are dissolved in the water and give each aquifer a unique quality. In the aquifers of the Table Mountain Group (TMG), which comprises a very clean (pure) quartzite, the chemistry of the groundwater recharge is essentially unaltered and the groundwater from the TMG is extremely pure.

However, in some deep primary aquifers, such as in the Kalahari and the sands of the Western and Northern Cape. there is a considerable amount of salt (sodium chloride). Water from these aquifers can be **extremely saline**. In addition, groundwater recharge is low and there is not frequent replenishing of groundwater with good quality precipitation. Such water is described as 'brack'. One story tells of two Kalahari San being taken to the Atlantic Ocean for the first time. They scoop the water up in their hands and drink it, exclaiming how wonderfully fresh it is! This is perhaps not an entirely true story, but indicates that the Kalahari aquifers are very salty indeed, but animals and people have adapted to this. The situation is less extreme in other areas, but many communities, such as in Loeriesfontein in the Northern Cape, have become used to water that would be considered too salty by most people.

In some of the secondary aquifers, especially in sandstone and quartzite rocks, such as in the Eastern Cape, the water dissolves a number of mineral salts, especially iron. When the water is brought to the surface, and comes into contact with oxygen, iron oxidizes and forms an orange precipitate which slowly settles out. Until this settlement happens, the water, although safe to drink, is very discoloured – not good for washing white clothes! The taste, even after the water clears is often quite bitter.

Apart from the changes in the water caused by the different salts that can be dissolved in it, groundwater, in its natural condition, is generally considered safe for humans and livestock to drink. An analysis of water from an aquifer in the Eastern Cape showed that, apart from the iron salts it contained, it was healthier in terms of its pH, proportion of other dissolved salts, and absence of potentially dangerous bacteria than the local municipal water.

Apart from the changes in the water caused by the different salts that can be dissolved in it, groundwater, **in its natural condition**, is generally **considered safe** for humans and livestock to drink. An analysis of water from an aquifer in the Eastern Cape showed that, apart from the iron salts it contained, it was **healthier in terms of its PH, proportion of other dissolved salts, and absence of potentially dangerous bacteria, than the local municipal water**.

Why Care About Groundwater?

Importance for Human Livelihoods and Development

Groundwater, despite its relatively small contribution to bulk water supply (13%), represents an **important and strategic water resource** in South Africa. Owing to the lack of perennial streams in the semi-desert to desert areas, two-thirds of South Africa's surface area is largely dependent on groundwater. In these water-scarce areas, groundwater is more valuable than gold.

Recent work by the Department of Water Affairs and Forestry (DWAF) suggests that almost **60 out of every 100 rural communities are dependent on groundwater** for drinking, cooking, hygiene, and watering their crops and animals. About 320 towns and villages are dependant on groundwater.

Agriculture in the desert and semi-desert areas of the country, away from rivers such as the Orange and Great Fish which run through such areas, is dependent almost entirely on groundwater.

Although irrigation is the largest user, the supply to more than 300 towns and smaller settlements is also extremely important. Groundwater has become a strategic resource for village water supply even in the wetter parts of the country, because it is a more **cost-effective way of providing water** for widely scattered small communities.

In total, about **15 million South Africans** rely on groundwater to some degree, particularly in the drier western portion of the country. As part of the Reconstruction and Development Programme, **the basic water needs of some 4 million South Africans have been met in the last six years by groundwater supplies.**

Groundwater may become even more important in the future as demands for water increase. Although there is no absolute agreement among hydrogeologists (groundwater scientists) as to exactly how much groundwater there is in South Africa, it is estimated that **less than 20%**

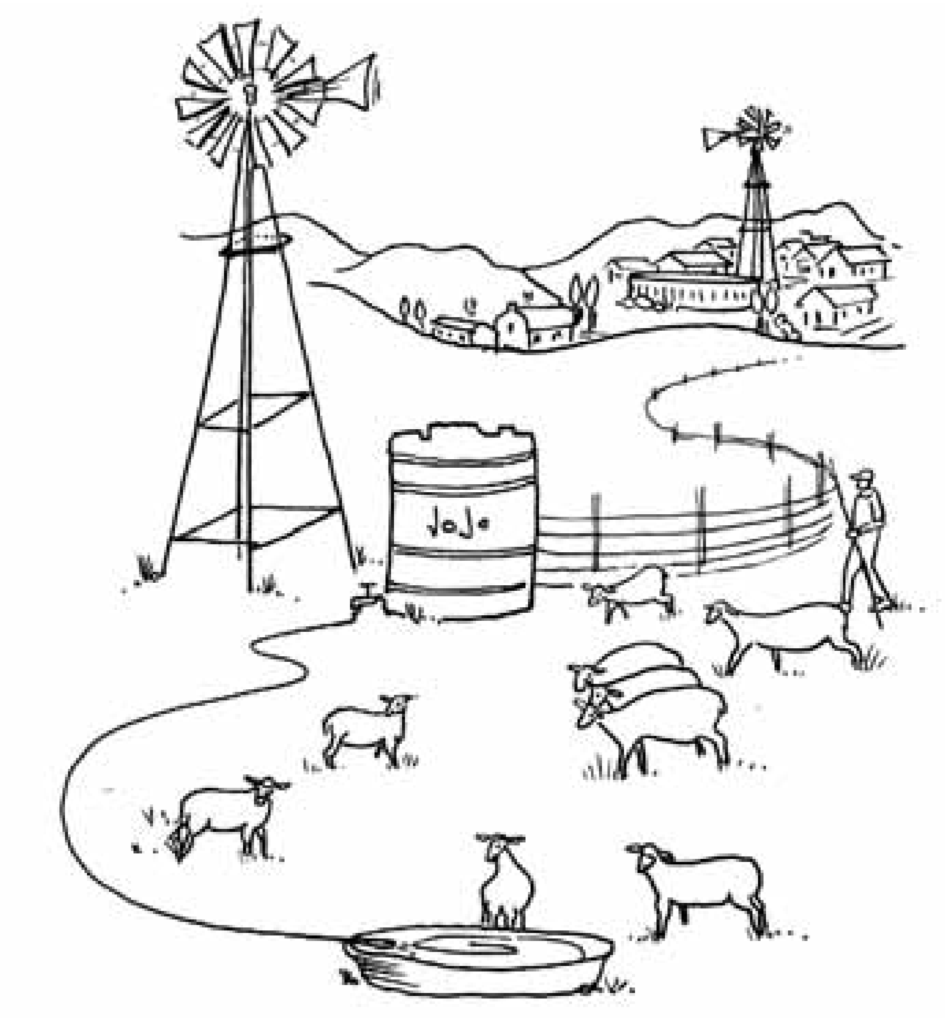

Figure 2: Aquifers Bring Life

of South Africa's available groundwater resources are currently used. This suggests that that there remains considerable scope for further exploitation of these resources, without impacting on the Ecological Reserve. As it is unlikely that there will be any increase in availability of surface water (in fact, given climate change this may reduce) **water from aquifers is likely to become extremely important for the future of the country**.

One estimate suggests that the maximum quantity of groundwater that can be developed economically is about 6 000 million cubic metres a year. Currently approximately 2 000 million cubic metres a year are abstracted from groundwater.

Ecological Importance

Water Quantity

Although groundwater is often seen as separate to surface water systems it is inextricably linked with them. The **sources of most rivers** are **natural springs**. These arise from **shallow aquifers** high in the catchment, often in mountains and hills. In many cases **tributaries** occur throughout the length of the catchment, also fed by **groundwater derived springs**.

It is clear that the functioning and the ecology of entire catchments can be dependent to a large extent on the proper functioning of the groundwater systems.

Most **wetlands are also fed by such springs** arising from **groundwater aquifers**. These can be at any point in the catchment, even in low-lying coastal areas, such as the vleis along the Western and Northern Cape coasts. Correct functioning requires that there must be sufficient water, from intermittent rainfall and seepage from rivers, to maintain a high enough water table in the aquifer to periodically inundate the wetlands.

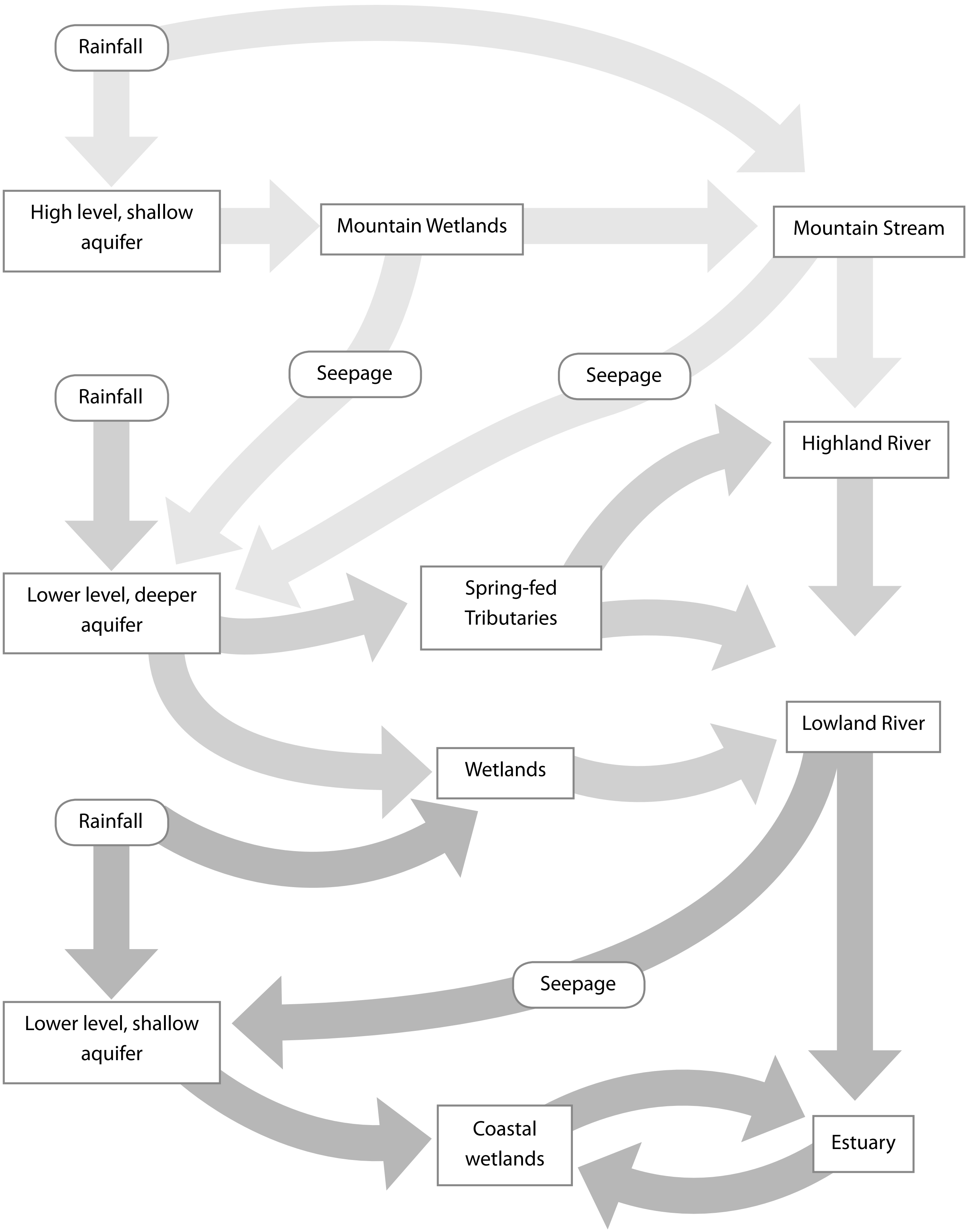

Figure 3: Typical Pattern of Water Exchange/Transfer between Catchment Components

There can also be exchange of water between **coastal wetlands** and **estuaries** where they occur close to one another. When estuaries are full from either high freshwater inputs (during floods) or high tides (with salt water), they can seep into wetlands and the aquifers that feed them. At low water, wetlands and their aquifers can seep into the estuaries.

Similarly, groundwater systems are themselves often fed by rivers and by wetlands, so the **natural 'recharge'** of aquifers can be dependent on sufficient water being released by these.

Catchment systems are therefore characterised by patterns of **water exchange or transfer** between the different components. A typical pattern of water exchange/transfer is shown in Figure 3.

Water Quality

Groundwater not only has a critical role to play in the quantity of water available for ecological functioning of the catchment, but also influences the particular quality of the water in various components. In turn this can influence the biological communities in these components. This is particularly the case with wetlands dependent on groundwater.

As water flows through an aquifer it dissolves minerals in the rock, such as calcium, sodium, bicarbonate and chloride, and the temperature becomes equal to that of the rocks. As a result, the chemical and thermal properties of groundwater are often quite different from those of surface water. So groundwater-fed wetlands often have different plant and animal communities than those fed purely by surface water. Indeed, in some cases the presence or absence of particular species known to be groundwater-reliant can be an indicator of whether or not a wetland is strongly dependent on groundwater.

Groundwater in aquifers itself supports some very specialised organisms, and these are being studied by researchers.

The following is adapted from *The WaterWheel*, January/February 2005:

There's Life in Groundwater

Modern technology has enabled scientists to discover thriving communities of tiny living organisms in groundwater beneath the surface of the Earth, including aquifers in parts of southern Africa. And, as subterranean karst wetlands are defined as groundwater-dependent systems (Ramsar Convention, Iran 1971), these ecosystems should be protected.

Dr Heather MacKay, research manager at the Water Research Commission (WRC), says scientists, already armed with knowledge of the unusual animals in aquatic habitats, are focusing on the small fauna (micro- organisms and invertebrates) living in aquifers. Sometimes these organisms occur in small fractures within rock strata or in the interstitial spaces within shallow, unconsolidated rock just beneath the streambed.

Amphipods are sometimes found when a borehole is drilled. They appear at various depths within the borehole water – there are usually greater concentrations at the bottom of the borehole.

Drillers have often noted this as a curiosity: occasionally small animals would be found in water brought up from the borehole. But, as they are living organisms, they are not merely a "curiosity", even though their linkages with and importance to other aquatic and terrestrial ecosystems are not yet well understood at all.

According to Dr MacKay many of these underground aquatic habitats are very sensitive to impacts such as pollution seeping down from the land surface as a result of, for example, agriculture, urban development or overabstraction of groundwater.

Sayomi Tasaki, a freshwater invertebrate zoologist, focusing on groundwater ecology and working with the WRC and DWAF, has found various groundwater-related invertebrates (scientifically referred to as stygoxen, stygophyle and stygobite), including the blind Sternophysinx amphipod group, in the area around The Cradle of Humankind (the Kromdraai Conservancy region).

The Sternophysinx calceola, which does not have eyes, senses movement by detecting sound waves via phonoreceptor appendages on its antennae. It has thus evolved to survive in groundwater habitats devoid of light.

> ***"In South Africa, these eyeless crustaceans can be found in water up to 170 m below ground," says Tasaki. "These stygobites are aquatic animals totally adapted to live their entire life cycles in absolute darkness, below ground," she explains. "Because of the fine nature of their evolutionary development, they are extremely well tuned to their environments, becoming a sort of natural indicator of system integrity."***

There is a good possibility that the study of these very specialised animals will give us a valuable monitoring tool for assessing the quality of our groundwater.

How Do Groundwater Systems Work?

As described in the sections and the model in Figure 3, groundwater systems work by:

- **Precipitation** generating groundwater recharge through both vertical percolation and lateral (sideways) inflow. **Groundwater is also replenished by seepage** from wetlands, streams and rivers.
- Aquifers then **store this water**, either between grains of sand or silt (primary aquifers) or in fissures (cracks and holes) in impermeable rock (secondary aquifers).
- Some of this groundwater then flows horizontally through the surrounding materials to **emerge as springs, feeding other catchment components, such as wetlands or rivers**. This happens most especially when there is surplus water in the aquifer after rains, but in well functioning systems they provide an almost constant, regulated supply.
- Some recharge makes its way **through underground channels to feed into deeper aquifers**. Again, this happens mostly in times of surplus water.
- Some groundwater emerges after sufficient rainfall or seepage has raised the water table to **inundate wetlands such as coastal wetlands**.
- Much of the groundwater remains in the aquifers for extremely long periods of time – even for thousands of years. This water is only released by dramatic changes in the structure of the surrounding material, such as through earthquakes or shifts in tectonic plates, or by human intervention, through wells or boreholes. Groundwater flow rates are typically very low, unlike surface water.

Aquifers can be seen as natural, permanent and (relatively) secure water storage facilities, and groundwater as the foundation of our water resource base.

Fossil Groundwater

Water that has been in aquifers for very long periods is known as 'fossil groundwater'. It is often in aquifers that were filled long ago but have been naturally sealed and have extremely slow recharge rates. Water taken from these aquifers is therefore not replaceable.

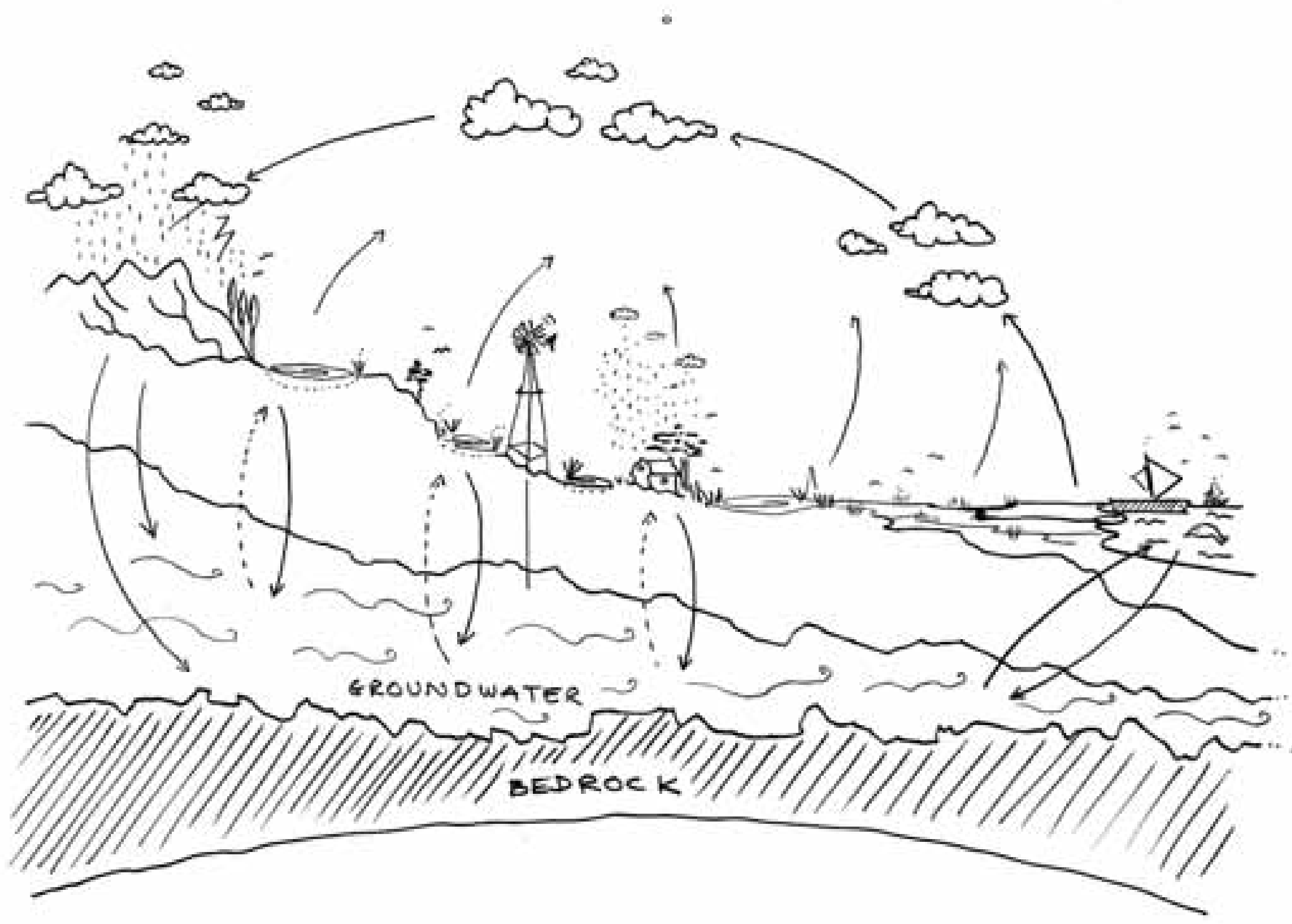

Figure 4: Some Possible Groundwater Interactions

What Can Go Wrong?

When pollutants are 'flushed out' this does not mean that they disappear. In fact they are carried down rivers to the estuaries and the sea, where they can do great damage.

As with all other water resources, groundwater is vulnerable to two key influences:

- **Over-abstraction** – this impacts on the **quantity** of water available for both ecological processes and for human requirements. Even if abstraction is generally at an acceptable level, during times of prolonged drought there may be too little water available for adequate recharge and the quantity of water available is reduced.
- **Pollution** – this impacts on the **quality** of the water, and can make it unsuitable for either supporting ecological processes or for supplying human needs. Once an aquifer has been polluted, it is extremely difficult and very costly to clean the water. Unlike rivers, where the water is constantly being changed and in which pollutants can be flushed out by heavy rains, groundwater retains pollutants for a very long time.

Over-abstraction

One of the biggest challenges in managing groundwater is deciding how much water can safely be taken out of any aquifer. This decision must be based on a good understanding of:

- How 'big' the aquifer is – how much water it can hold.
- How much of this water is essential to maintain ecological processes – the Ecological Reserve requirment (see the booklet *Catchments*, *Sustainability and The Reserve*).
- How quickly water is replaced – the 'rate of recharge'.
- When abstraction and recharge takes place.

Ideally, water should not be removed from an aquifer faster than it can be replaced so the **abstraction rate** matches the **recharge rate** with the aquifer being kept relatively full all the time. However, as recharge often only takes place at particular times of the year (in the rainy seasons), and abstraction takes place constantly, and often more in dry periods, matching the rates is not easy. This means that during periods of high abstraction and low recharge – dry conditions – the water levels fall. In a well-managed groundwater system this is compensated for in the wet seasons when abstraction drops and recharge increases, raising the water levels again.

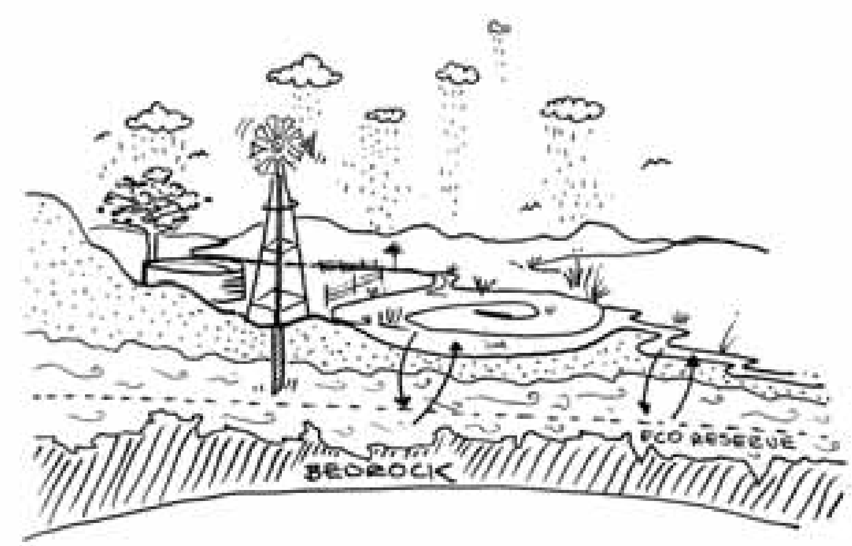

Figure 5a: Wet Season – Aquifer Recharges

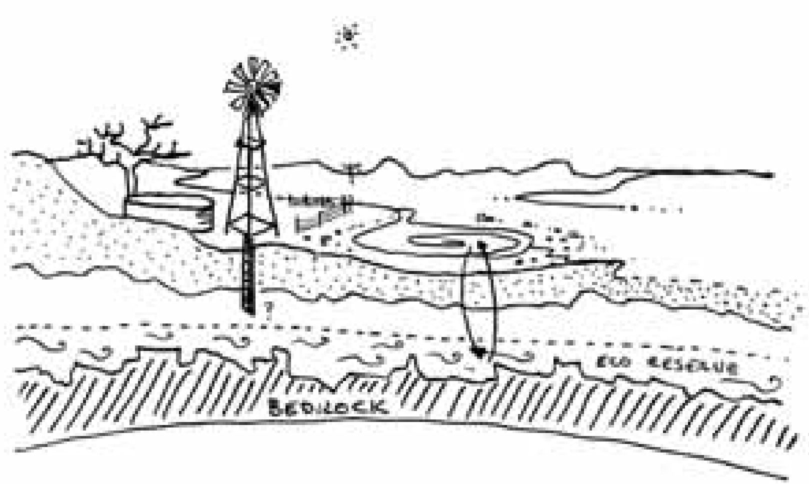

Figure 5b: Dry Season – Aquifer Water Levels Fall

There are two critical considerations:

- Even at the times of greatest abstraction and lowest recharge, the basic Ecological Reserve must not be compromised.
- At the end of each recharge season the aquifer should be full – so no more water should be abstracted over a full year than the expected recharge can replace.

The first point above implies that if the equivalent amount of recharge is removed by abstraction, there will be no groundwater left to maintain ecological functioning. There is debate as to how much of groundwater recharge should be permitted to be abstracted. Where groundwater plays a key role in supporting domestic supply or economic development, the equivalent of 50% of groundwater recharge may be abstracted. However, it would be good practice to permit the removal of less than 25% of groundwater recharge. Some ecologists believe that the permitted amount of groundwater abstracted should be calculated according to a percentage of groundwater discharge! The groundwater discharge value is lower than recharge and such an approach would afford greater protection to groundwater dependent ecosystems (including baseflow to rivers, inflow to wetlands, seeps and groundwater dependent vegetation).

Throughout the country there are very many farm boreholes that have been 'pumped dry', and farmers have had to drill deeper and deeper to find water. This is particularly so in areas with numbers of small isolated aquifers with very slow rates of natural recharge. When aquifers are depleted, the water table is so low that groundwater recharge never reaches the saturated zone and the aquifer never recovers.

Such a situation could occur under the previous Water Act where landowners had a right to use the water under their land. Under the new National Water Act (1998), all water users need to apply for licences to abstract water from boreholes (except for Schedule 1 uses), and this should help ensure that aquifers are not over-utilised and depleted in this way.

Abstraction of water from aquifers must only be carried out on the basis of a thorough understanding of the system and its capacity to maintain its essential functioning and to replenish itself.

Over-abstraction in certain circumstances can lead to further problems:

- **Land subsidence** – this can be as a result of over-abstraction, lowering the water table and irreversibly reducing the space available for groundwater storage. his can also occur as a result of mining operations
- **Saline intrusion of the aquifer** – as a result of lowered water tables near the coast or where saline aquifers occur beneath a better quality aquifer.

Making the calculations to decide on the levels of abstraction that are possible from any groundwater system is an extremely complicated and highly technical exercise. This can only be carried out by experienced hydrogeologists, and one of the roles of the Groundwater Co-ordinator (see below) is to call on these specialists to work with CMAs and WUAs in developing water abstraction plans for each groundwater system.

Pollution

A polluted groundwater system is a danger to the ecology, the livestock and the people of the area, and it can pose this danger for a very long time. Once pollutants enter a groundwater system, they stay, at least until they decay, which can take a very long time.

Figure 6: Pollution Risks To Groundwater

Groundwater systems are also particularly vulnerable to pollution as they receive water in different ways from different sources, often over very large drainage areas:

- Rainfall/surface runoff – this can be from enormous areas, often many thousands of hectares
- Seepage from rivers and wetlands – more restricted in area, but these are also fed by surface runoff over areas far larger than they themselves cover.

Any pollution occurring in the area from which an aquifer is fed can make its way into the groundwater.

When polluted, groundwater ceases to be an essential supporter of life and can become a serious threat to life.

There are many types of pollution that can affect groundwater systems:

- **Agricultural pollutants** – pesticides (herbicides, insecticides, fungicides), many of which are highly toxic; fertilisers (organic and inorganic) which increase the nutrient levels in the water and encourage the growth of algae and other plants. (Since groundwater is filtered to some extent as it passes through the soil layers, siltation is not considered a major problem in aquifers.)
- **Industrial/commercial pollutants** – a very wide range of different chemicals with different impacts; heavy metals (lead, mercury, cadmium, chromium, tungsten and many more), many of which can be toxic to wildlife and humans; oils (fuel and lubricating) can disrupt entire ecosystems and are toxic to all life.
- **Domestic pollutants** – in particular sewage, can contain dangerous pathogens (harmful organisms) such as *coliform* bacteria and other sources of disease.

How Do We Take More Care?

The Precautionary and Preventative Principles

It is evident that groundwater systems cannot provide an infinite supply of water, any more than rivers can. Although it is possible to artificially recharge aquifers, by transferring water from other components in the catchment or from other catchments (see below), it is clearly better to manage our water demands within the limitations of the groundwater systems themselves. If too much water is abstracted irreversible damage may be done to the systems. It is equally clear that once water in aquifers is polluted it is almost impossible to clean it up.

In order to take proper care of our groundwater systems it is essential to apply the **precautionary principle.**

This states, in essence, that whatever we do we must **act with caution** and assume that any action may have damaging consequences.

What this means in terms of abstraction from aquifers is that **ideally no abstraction** should take place until the extent and capacity of the aquifer is known. More **practically** it means that **no further abstraction** should take place until these are known.

In terms of avoiding pollution the precautionary principle simply means that we must all **take every possible precaution** to avoid any pollutants entering any water resource, including and especially groundwater systems. A further implication of this principle is that, as groundwater can come from any part of its drainage area (see below), this entire area must be considered a potential source of pollution and managed appropriately.

The **preventative principle** is an extension of this. In relation to systems such as groundwater where it is almost **impossible to repair damage** it is essential to do everything possible to **prevent damage**, either by over-abstraction or by polluting.

Caring for groundwater systems is based on these principles.

A document on Groundwater Management (DWAF-DANCED, 2002) suggests the following as key elements in a groundwater protection strategy:

- Improve public awareness and involvement as a guard against degradation of groundwater resources. The public must be empowered to understand groundwater issues and appreciate the value of the resource.
- Protect water resources using instruments such as land-use zoning, classification of aquifers, environmental management plans and EIA (Environmental Impact Assessment).
- Involve groundwater institutions and specialists in the debate and decision-making processes regarding South Africa's resources and environment.

Groundwater Drainage Areas

As management of groundwater systems cannot be carried out 'inside' the aquifer it must be done throughout the surface recharge area. In these areas there will be obvious features such as rivers and wetlands that seep into the aquifers, but the bulk of the groundwater often derives from surface runoff and can therefore come from almost anywhere, and from any land-use taking place. This can include agricultural and industrial use, housing and waste and sewage disposal. In addition, mining operations below ground can have a serious impact on the integrity of groundwater systems through pollution of the water, drainage of tunnels, subsidence, and abstraction of large volumes of water.

In order to provide protection for the groundwater resource it is essential to have a good idea of the extent of the drainage area feeding any aquifer. Here again the expertise of a hydrogeologist will be required to help map out this area.

Roleplayers

The need to protect the water resource over large areas means that many people must be involved. All land-uses – agriculture, industry, tourism, housing, etc. – have the potential to impact negatively on the water resource and everyone involved have responsibilities to ensure that the resource is protected. Key role-players include municipalities, national and provincial government departments, and agricultural and industrial concerns.

The institutions charged with the greatest responsibilities for protection of the water resources are the Catchment Management Agencies and the Water User Associations, but they cannot do this alone and must collaborate with the other roleplayers. Ideally the different interest groups should be represented on both the CMAs and the WUAs in their areas.

One key roleplayer is the groundwater coordinator who should be appointed by the CMA to coordinate all groundwater management and protection in the Water Management Area (WMA) (see below).

Types of Groundwater Users

All groundwater users have responsibilities for managing and monitoring their resource. However the larger scale users will have more formal responsibilities.

The different types of users are listed in Table 1:

Type of user	Limits	Typically	Monitoring requirements
Unregistered	Schedule 1 use, or less than 10 kilolitres per property on any given day.	Private borehole used for domestic and domestic garden use.	None. Good practice but not a legal requirement.
Registered	More than 10 kilolitres per property on any given day. Use within General Authorisations.	Most municipal production boreholes and farm boreholes supplying water for irrigation will need to be registered.	*Abstraction on the last day of each month. Water levels and chemistry. Good practice but not a legal requirement.
Licenced	Use exceeds General Authorisations.	High-yielding production boreholes.	*Abstraction on the last day of each month. Monitoring as per licence conditions would typically include chemistry and water levels.

Table 1: Groundwater Users (adapted from DWAF, 2004)
* Total volumes abstracted for each month must be recorded and submitted to the CMA (See Monitoring below).

Direct and Indirect Actions

There are a number of direct and indirect actions that can be carried out by roleplayers to ensure the best care of the groundwater systems in their areas. These are outlined in Table 2.

Threat	Direct action	Indirect action
Pollution		
Industrial/ commercial, including petrol stations (chemicals, oils etc.) and mines	• Continuously monitor all industrial outfalls (including via streams and storm drains) within groundwater drainage area • Report any incidents or concerns immediately to the appropriate authorities • Follow through to ensure appropriate action is taken • **If owner or manager of industrial or commercial concern**, ensure that all pollution control measures are in place and checked regularly • Comply fully with requirements of NEMA and other legislation.	• Establish groundwater forum, WUA (or similar) • Involve owners and managers of industrial and agricultural concerns in groundwater forum or WUA • Work with groundwater coordinator and hydrogeologists to develop groundwater abstraction/management plan • Integrate groundwater abstraction/ management plan into Integrated Water Resource Management Strategy (IWRMS) • Involve municipality and community representatives in groundwater forum or WUA • Work with municipality to ensure only appropriate industrial and commercial development in Spacial Development Forum (SDF) and Integrated Development Plan (IDP) in groundwater drainage area • Work with municipality to ensure only appropriate housing and infrastructure development in SDF and IDP in groundwater drainage area • Work with municipality to ensure appropriate siting and design of waste disposal facilities, including landfill sites • Work with municipality to establish continuous monitoring of all outfalls from sanitation and other water services infrastructure.
Agricultural (fertilizers/ pesticides/oils)	• Report any incidents or concerns immediately to the appropriate authorities • Follow through to ensure appropriate action is taken • **If a farmer**, avoid over-application of fertilizers and pesticides in groundwater drainage area (or anywhere) • Do not exceed recommended application rates anywhere • Dispose of containers in appropriate registered sites • Comply fully with requirements of NEMA and other legislation.	
Domestic (sewage, waste disposal etc.)	• Continuously monitor all outfalls from water treatment works and other sanitation infrastructure (including via streams and storm drains) • Continuously monitor waste disposal sites, including landfills, for seepages, especially after heavy rains.	

Threat	Direct action	Indirect action
Pollution		
		• Work with Department of Agriculture and Department of Water Affairs and Forestry to establish monitoring of farm run-offs and of groundwater systems in general • Ensure that groundwater forum and/or WUA contributes to Catchment Management Strategy developed by CMA • Work with DWAF and water research institution to develop water monitoring programmes • Involve water users in monitoring programmes • Work with municipality and other stakeholders to develop disaster management plans.
Subsidence	• Avoid over-abstraction • Avoid mining in areas close to major groundwater systems.	• As above with the addition of: • Work with National Department of Minerals and Energy to ensure that issuing of mining licences does not threaten the integrity of groundwater systems.
Over-abstraction	• Everyone except Schedule 1 water users must register their water use and seek licences • Comply fully with the conditions of the licence • Continuous monitoring/policing of water use by registered (and other) users • Ensure that all abstraction infrastructure (well-heads, pipes, pumps, storage tanks etc.) operate effectively and efficiently and are continuously maintained to avoid loss though leakages or faulty equipment • Ensure that water usage by all users is efficient.	• Establish groundwater forum, WUA (or similar) • Involve water users, farmers, industrial and mineral concerns and municipalities in forum/WUA • Ensure that groundwater forum and/or WUA contributes to Catchment Management Strategy developed by CMA • Work with DWAF and water research institution to develop water monitoring programmes.

Table 2: Direct and Indirect Actions

Water Use Efficiency

The total natural runoff in South Africa is estimated at 55 billion m^3 per year, of which only 33 billion m^3 is utilizable. It is estimated that water use will increase from a current level of 18 billion m^3 (1996 estimate) to 30 billion m^3 per year in 2030. From this it is apparent that an action plan is urgently needed to ensure wise supply and use of water. The first step in such a process should be to ensure more efficient and productive use of current water supply. The Department of Water Affairs and Forestry (DWAF) has embarked upon a process to develop sectoral action plans for improving water use efficiency and productivity. These plans are generically referred to as Water Conservation & Demand Management (WCDM) Strategies (DWAF, 2000).

One of the most important approaches to reducing pressure on our water resources is that of efficient usage. This is particularly critical in areas with very limited water, such as those areas reliant on groundwater.

WCDM Strategies are considered essential in all water use contexts.

Guidance on efficient water use is available for different sectors, including optimising the efficiency of water delivery and storage equipment and infrastructure.

The following guidelines are from DWAF (2002).

On Delivery and Storage Infrastructure

Are leaks detectable at the well head which are leading to long term significant losses?

The wellhead may be inadequately designed for the operating conditions (corrosive water chemistry, high pressures, high temperatures, large abstraction volumes). If leaks are evident, characterise the known operating conditions and repair the wellhead to the necessary standard. Flow metering at the abstraction point as well as at the point of delivery can be useful for detecting leakage losses in the system.

Is the pump operating optimally or is groundwater ever being pumped to waste or overflow?

This will require the application of appropriate technology in terms of timing pumping hours or retraining pump attendants to schedule abstraction more carefully to actual requirements.

Is surface storage of groundwater in a dam leading to unnecessary evaporative losses or deterioration of water quality due to contamination?

Studies have demonstrated how groundwater resources are contaminated during above ground storage, reticulation and at point of use. An examination of as much of the system as possible and an audit balance of abstraction volumes versus consumed volumes should indicate points of loss. Over much of South Africa, potential evaporation exceeds precipitation and the potential for water losses from open water bodies is high. Dam losses are common and may be reduced by covering the dam with a roof, shade cloth or even floating bottles on the surface of the water. Inevitable losses at communal taps can be channeled towards garden areas or trees.

On Agriculture

Agriculture is the largest consumer of groundwater in South Africa. In many areas water efficiency could be improved through:

- Selection of water efficient crops
- Use of more water efficient irrigation technology
- Optimal or minimal irrigation scheduling.

Much information on determining crop coefficients and implementation of WCDM for agriculture is available in the DWAF guidelines on the development of water management plans for irrigation. Key role players in implementation of these plans are the former Irrigation Boards who are transforming into Water User Associations.

If a farmer requires water for irrigation in excess of the general authorisations for the particular groundwater abstraction zone under consideration, for example, it may be a condition of the licence that the water is only irrigated on lands where optimum crop yields per cubic metre of water are obtained.

On Industry

Industries requiring licences for groundwater use could also be required to demonstrate water use efficiency in their industrial process. Environmental and water auditing of large industrial water users should form part of the licensing conditions for an individual or compulsory allocation. Water use efficiency should also form part of the **Environmental Management Systems** being adopted by many South African industries in order to obtain internationally-recognised environmental accreditation under the SABS ISO 14001 code of practice.

On Homes and Gardens

Public education is the most effective means of assuring efficient use in **households**. Many of the large water boards and municipalities in South Africa have been actively involved in public education campaigns to encourage water-saving measures in the home, particularly in times of water shortage.

Water use awareness campaigns have been conducted through the print media and school projects, especially during National Water Week during March each year. Water Services Providers (WSPs) may go further and insist on bylaws to enforce water efficient building regulations, for instance the installation of dual flush toilets.

They may also introduce sliding tariffs as an additional incentive to reduce water consumption. In areas where shallower groundwater occurs, such as the Cape Town Metropole, households supplied with mains water may additionally tap groundwater through garden boreholes. This groundwater is primarily used for garden irrigation. Here a greater appreciation of **Water Wise Gardening** (as publicised by the Department) would help reduce inefficient use and public education on optimal irrigation scheduling and leak reduction would minimise losses. Rand Water, Umgeni Water and the National Botanical Institute all provide educational material for water saving measures in urban gardening.

Enhancement of Groundwater Resources

A further approach to making the most of the groundwater resources is through actively managing it to increase the availability of water. This can be done in a number of ways as described in DWAF, 2002:

- **Land-care programmes**, which typically aim to reduce negative impacts of development and agriculture and may include soil conservation, afforestation and alien vegetation removal.
- **Conjunctive use**, which is the simultaneous use of both surface- and groundwater resources to ensure the best yield spatially and temporally. It includes initiatives and schemes such as transfers of water between surface and groundwater resources, transfers of water between wet and dry periods and artificial recharge as a method of storing the water.
- **Artificial recharge**, by transferring surface waters into aquifers. Unused aquifer storage capacity can for the most part be developed at a significantly lower cost than surface storage facilities, and without the environmental and social problems frequently associated with surface storage.
- **Water-sensitive urban design**, which aims to reduce runoff loss in urban areas and promote the use of water as a resource rather than a waste product.

More detail is provided on these in Chapter 3 of the Groundwater Management document (DWAF, 2002):

Catchment land-care

Land-care programmes in catchments typically aim to reduce negative impacts of development and agriculture. These may include:

- soil conservation through terracing, contour-tilling, wind-breaks, mulching, etc.,
- afforestation (stabilising soil, and increasing utilisable catchment water yields), and
- alien vegetation removal (improving biodiversity and increasing recharge to groundwater and surface water).

In South Africa the Working for Water Programme is a well-established example of a land-care initiative that has been successful in creating jobs and removing alien vegetation. The programme was aimed at increasing runoff, enhanced groundwater recharge and baseflow to streams, and uplifting local communities.

Conjunctive Use

Conjunctive use management offers many opportunities to improve the volume and assurance of water supply, and to manage the water resource effectively.

Combinations of artificial recharge operations, exchanges and transfers of surface and groundwater supplies, as well as transfers or exchanges of water between wet and dry periods with other agencies provide many alternative designs for conjunctively managing a catchment's water system.

The general idea behind all these schemes is to maximize the use of surface water in wet years when it is available, and to reserve groundwater use as much as possible for dry periods and droughts.

Schemes developed under a conjunctive use management system could be used to address such problems as developing more groundwater-based urban water supplies; controlling subsidence, groundwater quality deterioration, and other overdraft-related problems, and maintaining adequate water supplies during multi-year droughts when shortages of surface water are severe.

The coordinated and integrated management of surface and groundwater resources, under a conjunctive use management program, would aim to optimise the joint use of all water resources in the country.

In general, greater benefits from the conjunctive management of all water supplies together can be achieved over the isolated management of each individual supply system.

Opportunities include:

- artificially enhancing groundwater recharge using excess surface water,
- adjusting the mix and match of supplies and demands through the exchange, redistribution or reallocation of water supplies,
- designing water transfers between catchments to contribute positively under a conjunctive use management approach, or
- putting substandard water resources to use by mixing with other resources.

Artificial Recharge

Excess surface water, under conjunctive use management, can be used to recharge groundwater basins to recover storage after a period of heavy groundwater use or to alleviate localized overdraft problems.

Artificial recharge schemes may be considered in areas where there are:

- surplus surface water resources at certain times of the year, and
- available unsaturated storage with sufficient permeability for injection/recovery.

In addition, opportunities for artificial recharge should be considered in areas where evaporative losses from open water bodies are high.

The first step in developing artificial recharge schemes is to identify possible sources of water and their availability.

Excess surface water

Rainy season runoff is theoretically available for artificial recharge. By appropriating some of this unmanaged water, artificial recharge schemes using excess water could be developed.

Treated urban wastewater

Treated wastewater from cities represents a potential water resource to be considered in a conjunctive use programme.

Surface water from distant source

Other sources of surface water for recharge activities are the large dams constructed in most parts of South Africa. Above average precipitation during the rainy season could be used.

Water Sensitive Urban Design

Urbanisation of the catchment often leads to a decrease in infiltration to aquifers due to increased paved surfaces and efficient drainage systems, which remove storm water from the recharge area.

Water sensitive urban design (WSUD) aims to reduce those losses by incorporating more vegetated surfaces and soak-aways to maintain groundwater recharge. WSUD incorporates water management systems into buildings, urban transport routes and public open spaces. Most importantly, water is treated as a resource rather than a waste product. At the same time there is a focus on addressing pollution problems at the source rather than through expensive engineered solutions.

Monitoring of Groundwater

This is one of the most critical activities connected with protecting our groundwater resources and the DWAF-DANCED project (DWAF, 2002) has placed great emphasis on this. The proposal is for monitoring to be carried out at three levels:

Proposed Three Levels for Monitoring of Groundwater in South Africa

National Monitoring (Level 1)

Collection and analysis of groundwater data on a national scale. The monitoring points will be chosen based on conceptual models of major aquifers and selected to represent ambient groundwater conditions, not impacted by short term fluctuations caused by human activity. National monitoring will measure the natural response of aquifers to atmospheric conditions over the long term and will be used for resource planning and management purposes.

Catchment Monitoring (Level 2)

Groundwater levels and water quality monitoring of water resources on a catchment scale. Collection of appropriate data for the effective management of groundwater management units and to ensure compliance with Resource Quality Objectives (RQOs). Catchment monitoring may include:

- **quality monitoring**
  - impact monitoring of non-point sources in the catchment
- **quantity monitoring**
  - impact monitoring of abstraction over an area
  - quantification of groundwater – surface water interactions
  - recharge and discharge characterisation.

Local Monitoring (Level 3)

Project-specific and site-specific monitoring of potential human impacts on groundwater in the areas close to abstraction or potential contamination sources.

Examples of local groundwater monitoring include:

- **quality monitoring** at point sources of pollution
  - impact monitoring
  - detection monitoring
- **effectiveness of mitigation measures**
  - compliance monitoring
  - remediation monitoring
- **effectiveness of clean-up**
  - wellhead protection zone monitoring
- **precautionary measures**
- **quantity monitoring** at individual production boreholes or wellfields
  - compulsory recording of abstraction volumes
  - impact monitoring of water level drawdown
  - compliance monitoring where set as a condition of the abstraction licence.

The Groundwater Management document (DWAF, 2002) suggests that: *"It is the responsibility of DWAF to establish national monitoring systems, including the development of mechanisms and procedures to coordinate the monitoring of water resources. The responsibility for the **actual collection of water samples and data as well as data capture** will, in all likelihood, be devolved to the regional and local level. The national monitoring system will, therefore, incorporate information collected by:*

- water users
- water management institutions (Water Boards, WSPs, WSAs, WUAs)
- CMAs
- DWAF (regional offices)
- DWAF (national office) and
- other state organisations."

This clearly indicates that **water users, WUAs and CMAs** are expected to play central roles in the collection of monitoring data or information to feed into the monitoring systems, especially at local and catchment levels. **They will need to be trained and guided in this by the government agencies, particularly DWAF**, and by the groundwater coordinator and appropriate specialists.

Specific CMA responsibilities are likely to include:

- assisting DWAF (National) with the collection of data for national monitoring
- designing monitoring networks and carrying out all the activities associated with catchment monitoring
- overseeing and assessing information collected by water users for local monitoring and
- supplying the necessary information collected at all or any of these levels for the purposes of the National Monitoring Systems.

In addition the CMA will be responsible for:

- the design, installation, operation, maintenance and updating of monitoring systems;
- data collection, data capture and storage functions;
- the assessment and interpretation of the monitoring data; and
- the dissemination of monitoring information to stakeholders and the general public.

In order to fulfil these obligations the CMA may have:

- The authority to require that a water user
  - installs a recording or monitoring device to monitor storing, abstraction or use of water
  - establishes links with any monitoring or management system to monitor the storing, abstraction or use of water, and
  - keeps records on the storing, abstraction and use of water and submits the records to the CMA

- The power to undertake the installation or establishment of such links as required on the behalf of any water user, if the user has failed to comply with a written request from the CMA
- The power to recover any reasonable cost from the water user for such installation.

Water users drawing more than 10m^3 of water per day must register their use with DWAF, becoming a 'registered water user'. They are then required to:

- measure the quantity abstracted and record the total abstraction as at last day of each month, or
- calculate volumes of water irrigated using an approved method, in the case where no meter or gauge is used.

The CMA, as Responsible Authority, may also request in writing that a registered water user:

- ensures establishment of additional monitoring programmes, and
- appoints a competent person to assess water use measurements and submit the findings to the CMA.

Written records of groundwater abstraction must be kept for a period of at least five years and must be made available by the registered water user to the CMA upon written request.

It is likely that Water User Associations will be required to assist individual water users in meeting their monitoring obligations.

Water Quantity

Monitoring of the quantity of groundwater, and the rates of abstraction and recharge, is clearly vital for the effective management of the resource. Most of the information provided by water users will be concerned with how much water is being abstracted, but it will also be necessary to monitor the impact of abstraction on the resource itself. Monitoring of the water levels and of the recharge is therefore essential.

Monitoring **abstraction rates** is usually carried out by the use of flow meters at wellheads or other convenient points in the delivery system. These monitor the flow continuously, but usually need only to be read on a monthly basis, when the volumes recorded must be sent to the CMA.

Monitoring **water levels** in aquifers is conducted either manually using a dip meter, or with automatic 'data loggers' which can be read on a monthly basis, but provide a continuous record. Both of these monitor the depth below ground level of the water surface.

The frequency at which recordings should be taken varies according to the nature of the aquifer, the frequency of recharge and the abstraction pressures on it. Another constraint is the storage capacity of the recorders.

However the advice is that: *"To form a functional part of any monitoring network, the minimum frequency of observation of **water levels** in boreholes should be **two times per year**, ideally timed to coincide with annual peaks and troughs according to seasonal climatic changes" (Van Wyk, in prep.).*

Water Quality

As groundwater can be extremely vulnerable to pollution it is also essential that monitoring includes assessment of water quality. This however can be extremely complex as there is a wide range of pollutants that can contaminate aquifers.

The most basic water quality monitoring usually includes analysis of:

- **pH** – to ensure that this does not exceed limits of acidity or alkalinity appropriate for different uses. This is linked to the 'hardness' of water, with more acid water (often in granite aquifers in mountain areas) being 'soft', and alkaline water (in limestone aquifers) being 'hard. 'Hard' water is more liable to cause problems with both corrosion and scaling.

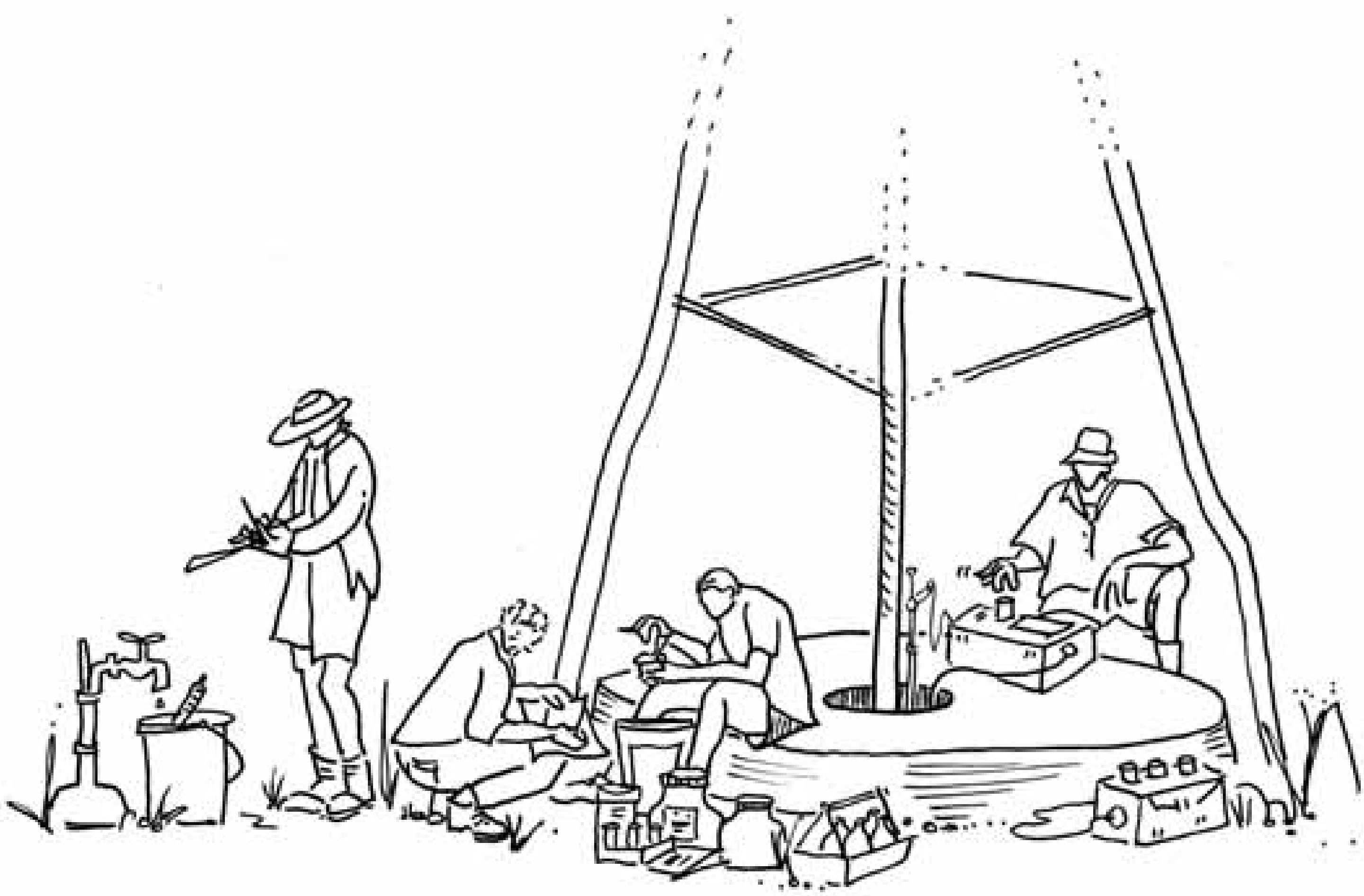

Figure 7: Monitoring our Water Quality and Quantity

- **Electrical Conductivity (EC)** – to measure the amounts of dissolved salts in the water, and to ensure that these are not above the legal limits for specific uses.
- **Microbiology (especially viruses and bacteria)** – to check for the presence of potentially harmful pathogens including parasites
- **Nutrients** – assessing the levels of plant nutrients to ensure that these are not above acceptable limits.

In addition to these a very wide range of specific metals, chemicals and other contaminants can be monitored for according to the local context (agricultural, industrial, urban etc.) and to how the water is to be used.

The Groundwater Management document (DWAF, 2002) informs us that:

"The South African Drinking Water Quality Guidelines (DWAF, 1996) provide detailed information on the variables that affect the quality of water for a range of end uses. Guidelines are available for:
Volume 1: Domestic use
Volume 2: Recreational use
Volume 3: Industrial use
Volume 4: Agricultural use: irrigation
Volume 5: Agricultural use: livestock watering
Volume 6: Agricultural use: aquaculture
Volume 7: Aquatic ecosystems".

While some water quality monitoring can only be carried out by specialists using sophisticated equipment, much of the more basic monitoring can be conducted by water users themselves using fairly simple water testing kits. Such testing kits are available for all the aspects described above.

The Groundwater Management document gives the following advice concerning the recommended **frequency for groundwater quality monitoring:**

Suggested Frequency for Groundwater Monitoring

Groundwater is a slow-moving medium and dramatic changes in the groundwater quality are not normally encountered within hours or days as can be found in surface water. The frequency at which groundwater samples are collected for quality analysis will depend on the sampling objectives and the aquifer behaviour.

Water quality monitoring is generally conducted at a lower frequency than water level (quantity) monitoring, chiefly because of the time and costs involved in sample collection and analysis.

National or catchment monitoring of resource quality away from potential sources of pollution: It is suggested that samples should be collected **twice per year**. For an aquifer that responds to seasonal rainfall patterns, these should correspond to the peaks and troughs of the water level measurements.

Local monitoring intervals should be more frequent, usually **monthly or quarterly**, depending on the type of impact anticipated and the rate of migration or decay of contaminants.

The document ***Minimum requirements for water monitoring at waste management facilities*** (DWAF, 1998) gives the following advice for groundwater sampling frequency, which is considered valid for local monitoring at other potential pollution sources:

> ***"Initial sampling should be done at a frequency high enough to obtain statistically valid background information. For any long-term monitoring facility, three initial sampling exercises, all within 90 days, but not less than 14 days apart are suggested. Depending on the variation amongst these values, future sampling may be planned. A three monthly sampling frequency will in most instances be sufficient."***

Boreholes used for **public drinking water** supply should be sampled **weekly** or even **daily**, if possible.

The Groundwater Coordinator

Given the challenges faced in managing groundwater resources the National Water Act makes provision for CMAs to employ Groundwater Coordinators (or Managers) in each WMA.

The Groundwater Management document (DWAF, 2002) states that the role of the co-ordinator will be to *"…form a key link in the chain, integrating* *not only with other water resource managers, but also with land-use and development planners and user groups. In order to operate effectively, groundwater coordinators will need to understand their local groundwater systems and the local institutional systems that interact with the resource."*

More detailed guidance on the proposed functions of the coordinator are given:

A further role of the groundwater coordinator is in relation to the National Water Resource Strategy (NWRS). The Groundwater Management document proposes that:

> *"Assuming the NWRS will have been gazetted by the time many CMAs come into existence**, the main role of the groundwater coordinator will be to provide relevant information for the review of the NWRS**… In addition to the specific sections of the NWRS, it is important that groundwater coordinators keep in mind the overall aims of the NWRS and the NWA…"*

Another very key role concerns monitoring, where it is proposed that: *"The groundwater coordinator in the CMA should play both an advisory and a policing role in the implementation of local groundwater monitoring by water users."*

It is clear that groundwater coordinators will be expected to play very central roles in the management of groundwater resources in each WMA, and that they will work very closely with both the CMAs (their employers) and the WUAs. It is the groundwater coordinators who will be responsible for commissioning the technical expertise required by CMAs and WUAs in deciding on groundwater allocations and groundwater conservation measures. They will also be responsible for coordinating the monitoring of the groundwater resources, in conjunction with the WUAs.

Agencies Involved

The principal agencies involved in the protection of the groundwater resources are the national government departments, in particular:

- **National Department of Water Affairs and Forestry (DWAF)** – who have prime responsibility for the management of all water resources in the country. This department has been working in close collaboration with the Danish Foreign Ministry and DANCED (lately Danida) in developing comprehensive guidelines for Groundwater Management, and for inclusion of Groundwater in the National Water Resource Strategy (NWRS). In addition DWAF have been responsible for the establishment of

Groundwater Coordinator Roles

Development of a Catchment Management Strategy (CMS)

The CMA is required to develop a CMS for the use, protection, development, conservation, management and control of the water resources in its WMA.

In order to develop such a CMS, a full appreciation of the groundwater resources is imperative. To achieve this, groundwater specialists will have to form part of the strategy development team, with sections of the strategy being developed by the groundwater specialists.

The implementation of the management strategies developed in the CMS will be largely the responsibility of the groundwater coordinator and the CMA geotechnicians.

Input Into Catchment Management Committee (CMC)

It is imperative that the CMC include representation of a groundwater specialist to provide technical input on groundwater management issues. This representation may either be through **participation of the groundwater coordinator** and/or an appointed groundwater specialist.

In order to elicit broader based groundwater specialist input, the CMC may decide to establish a groundwater management subcommittee. It is envisaged that **the groundwater coordinator will play a central role in the coordination of the functions of this committee**.

Relationship with the WUAs

The WUAs serve as a forum through which local communities can give input in the water resources planning process. **A close working relationship is therefore envisaged between the WUAs and the CMA groundwater coordinator**. The interaction of the groundwater coordinator with the WUAs will be both educational, and consultative. It is at the local level that a common vision and goals for water resources management can most effectively be developed.

Water Services Institutions

Water services providers will require some guidance on the development of their water resources. It is not envisaged that either the water service authorities or the water services providers will employ groundwater specialists. It is expected that they will rather outsource functions such as resource identification, development and monitoring to specialist consultants**. Some interaction and consultation with the CMA groundwater coordinator will still be necessary**.

Especially important will be the exchange of information on the distribution of the groundwater resources, its quality, the rates and volumes of abstraction, and other information required for efficient management of the resource.

the Working for Water programme, focusing particularly on the removal of water-demanding alien vegetation from catchment areas.

- **Department of Agriculture (NDA)** – the national Landcare programme administered by the NDA has focused on the control of soil erosion in catchments through rehabilitation and soil conservation projects. The NDA is also responsible for promoting water efficient agriculture, particularly through the adoption of appropriate and water efficient irrigation systems.
- **Department of Environmental Affairs and Tourism (DEA&T)** – although not directly concerned with groundwater this department has the responsibility to monitor and control pollution in all forms through enforcement of the National Environmental Management Act.
- **Local and District Municipalities** – these have responsibilities for development planning that is sensitive both to the use and availability of water and to the need to protect all water resources.

For More On Groundwater

References and Further Reading

This booklet drew heavily on the following documents:

DWAF/DANCED. 2001. **Groundwater Strategy for National Water Resource Strategy.** www.dwaf.gov.za

DWAF/DANCED. 2002. **Guidelines For Groundwater Management In Water Management Areas, South Africa.**

DWAF. 2004. **Implementing a Rural Groundwater Management System: A step-by-step guide.** (This is part of a comprehensive package of documents comprising the 'Toolkit for Water Services', developed between 2002 and 2004 by CSIR for DWAF, with funding from the Norwegian Agency for Development Co-operation, NORAD.)

Groundwater – More Valuable than Gold. Water Research Council. www.wrc.org.za

The Water Wheel, January/February 2005. www.wrc.org.za

Guidelines for the management of groundwater to maintain wetland ecological character. Ramsar Convention on Wetlands. 2005. www.ramsar.org

All of these above documents are included on the CD accompanying the training programme.

Weaver, JMC, Cavé, L and Talma, AS, 2007. **Groundwater sampling – A comprehensive guide for sampling methods** (Second Edition). Prepared for the Water Research Commission by Groundwater Sciences, CSIR, South Africa. WRC Report No TT 303/07.

Notes