GROUNDWATER:
THE MYTHS, THE TRUTHS AND THE BASICS

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WATER RESEARCH COMMISSION

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DEFINITIONS

Aquifer
An aquifer is an underground layer of water-bearing rock. Water-bearing rocks are permeable, meaning that they have openings that liquids and gases can pass through. Sedimentary rock such as sandstone, as well as sand and gravel, are examples of water-bearing rock. The top of the water level in an aquifer is called the water table.

Chert
Chert is a very hard and resistant microcrystalline variety of quarts (SiO_2). It is extremely resistant to weathering and remains in the soil that forms from the weathering of dolomite. As the soils are eroded and washed away, the chert remains or gets washed into the streams as gravel bars.

Coal
Coal is rock made from plants that have been buried and squeezed over millions of years.

Cone of depression
The zone around a well in an unconfined aquifer that is normally saturated, but becomes unsaturated as a well is pumped, leaving an area where the water table dips down to form a cone shape. The shape of the cone is influenced by porosity and the water yield or pumping rate of the well. The land surface overlying the cone of depression is referred to as the area of influence.

Confined aquifer
Aquifers (also known as artesian or pressure aquifers) that exist where the groundwater is bounded between layers of impermeable substances, such as clay or dense rock. When tapped by a borehole, water in confined aquifers is forced up, sometimes above the soil surface.

Contamination
The introduction of any substance into the environment by the action of man.

Discharge
An outflow of water from a stream, pipe, groundwater aquifer, or watershed; the opposite of recharge.

Dolomite
Dolomite is the name of a sedimentary carbonate rock and a mineral, both composed of calcium magnesium carbonate ($CaMg(CO_3)_2$) found in crystals.

Fracture
Any break in a rock, including cracks, joints and faults.

Gneiss
A rock formed by high-grade regional metamorphic processes from pre-existing formations that were originally either igneous or sedimentary rocks. It is a metamorphic rock, generally made up of bands that differ in colour and composition, some bands being rich in feldspar and quarts, others rich in hornblende or mica.

Groundwater
The water found underground, in the saturated zone, beneath the water table.

Infiltration
Flow of water from the land surface into the subsurface.

Leachate
Liquids that have percolated through a soil and that carry substances in solution or suspension.

Limestone
Limestone is a sedimentary rock composed largely of the mineral calcite (carcium carbonate or $CaCO_3$).

Permeability
Capable of transmitting water (porous rock, sediment or soil); the rate at which water moves through rocks or soil.

Porosity
Porosity of a rock or water-bearing formation refers to the fraction (or percentage) of voids or open spaces in the rock.

Quartzite
Quartzite is a tough stone composed mostly of quarts. It may be derived from sandstone or chert by regional metamorphism. Unlike sandstone, quartzites are free from pores and have a smooth fracture; when struck, they break through, not around, the sand grains, producing a smooth surface instead of a rough and granular one.

Recharge
The replenishment of an aquifer through the infiltration from precipitation (rainfall, snow, hale etc.) downward to reach the water table.

Sandstone
This is a sedimentary rock composed mainly of sand-sized minerals or rock grains. Most sandstone is composed of quartz and/or feldspar, the most common minerals in the Earth's crust.

Saturated zone
The zone beneath the water table where all the openings are filled with water.

Slate
Slate forms when shale, which consists of clay minerals, is put under pressure with temperatures of a few hundred degrees. The clays then begin to revert to the mica minerals from which they are formed.

Specific yields
The volume of water that can be abstracted from a unit volume of the aquifer.

Spring
The emergence of groundwater at the land surface, usually at a clearly defined point; the water may flow strongly or just ooze or seep out.

Transmissivity
A measure of the capability of the entire thickness of an aquifer to transmit water.

Unconfined aquifer
This is an aquifer with no confining layer between the water table and the ground surface, where the water table is free to fluctuate.

Unsaturated zone
The zone above the water table where the openings are filled with air and water.

Water pollution
Defined as water that has been contaminated by some substance to a level where it is no longter fit for its intended uses.

Water table
The top of an unconfined aquifer; it indicates the level below which soil and rock are saturated with water. The upper surface of the saturation zone.

INTRODUCTION

ONE EARTH, ONE HYDROLOGICAL CYCLE, ONE WATER SOURCE

Nature has always fascinated mankind; from the vastness of the universe and the stars to the mystery of water 'disappearing' underground. Water is the one thing no living creature – man, plant, animal or organism – can live without.

Already in the year 3000 BC, the preacher in Eccleciates was puzzled: "All the rivers run into the sea; yet the sea is not full; unto the place from whence the rivers come, thither they return again."

In one drop of water are found all the secrets of all the oceans

– Kahlil Gibran

These words of Gibran capture the essence of the water cycle; taking one year, maybe ten years or even one million years. And in this journey lies the secret of all water on Earth; from river to rain and from aquifer to ocean.

Groundwater forms that part of the hydrological cycle that is underground. This important – sometimes neglected – part of the cycle has more impacts on humans and the environment than most people realise. Groundwater makes up 1.69% of all water found on Earth. Despite being a source of life-giving water for people all over the world, groundwater still receives comparatively little attention. Few recognise that today, about half the world's population drinks groundwater every day. Groundwater also irrigates about half the world's crops, it sustains rivers and wetlands, provides stability to the soil and prevents seawater intrusion.

This book explores where groundwater comes from, its main characteristics and concepts.

The publication contains basic information and addresses questions such as:

- How does groundwater move?
- Is groundwater really safe to drink?
- How can groundwater be polluted?
- Can a borehole really dry up?
- Can my neighbour's groundwater use affect my groundwater source?
- How do we find groundwater?
- Where do we use groundwater in South Africa?

The book also provides some insight into groundwater's role in South Africa. Some case studies are presented. Finally, a list of useful links are provided to enable the reader to find out more about this fascinating, but misunderstood resource. In the end, we need to take care of all of our water resources.

For in the end, we will conserve only what we love, we will love only what we understand and we will understand only what we are taught

– Baba Dioum

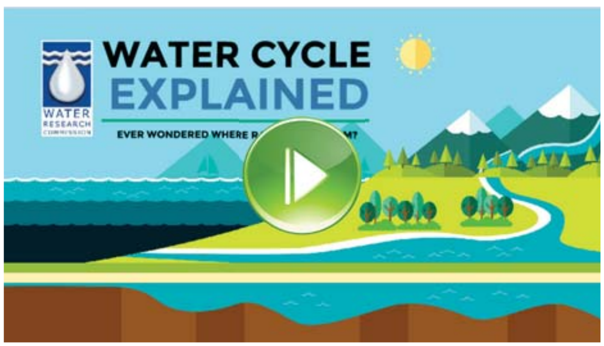
CHAPTER 1: OUR BLUE PLANET

Imagine you are in space. You are amazed by the vastness and beauty of all the stars and the planets. Then you spot her: Mother Earth. You immediately recognise the continents and see a light, white cloud covering parts of the Northern Hemisphere. Then the dominance of the deep blue oceans catch your eye and you ask yourself: is that the same planet where we are constantly hearing about water shortages and crises? Why – it consists of much more water than land? And you start wondering – if we as humans cannot use the water in our oceans for our daily needs, where is the water that we use every day?

Althea Grundling

THE HYDROLOGICAL OR WATER CYCLE

THE WATER CYCLE



Click to view the video.

The hydrologic or water cycle is a never-ending cycle whereby water moves in its three different forms (liquid, gas or solid) through the atmosphere, soils, plants, rivers, oceans and rocks. Water drops are made up of two atoms of hydrogen and one of oxygen (H_20). An individual water molecule may move through the water cycle in a few days or may be in storage (for example as ice or groundwater) for hundreds of years.

This ongoing cycle is kept in motion by the sun's energy. Water evaporates from a surface water source such as the ocean, a lake or through transpiration from plants. As the water vapour rises, it condenses to form clouds that return water to the land through precipitation, which includes rain, snow, hail, few and mist. This precipitation falls on Earth where it follows on of two routes: the precipitation either moves downward through the soil (known as infiltration), or flows across the land (surface runoff).

Surface runoff eventually reaches a river or other surface water body from where it is again eventually evaporated into the atmosphere. Some of the infiltrated water will be transpired by plants and returned to the atmosphere, while some will cling to particles filling some pore spaces in the subsurface, remaining in the unsaturated zone. The rest of the infiltrated water will move gradually under the influence of gravity into the saturated zone of the subsurface, reaching the water table and becoming groundwater. From here, groundwater may remain underground for hundreds or thousands of years or flow and discharge as springs, rivers, lakes or to the ocean to continue the cycle.

GROUNDWATER IN THE HYDROLOGICAL CYCLE

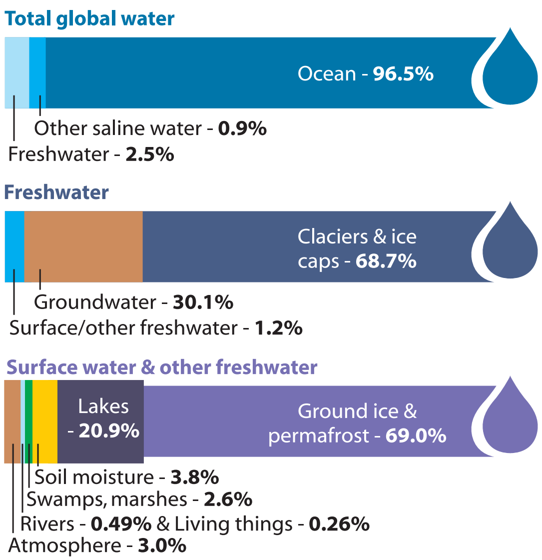
When asked to draw a diagram of the water cycle it is easy to get going. Evaporation from the ocean and rivers rises high up in the air to condense, forms clouds and then falls to the Earth as precipitation. Then the plants take up some of the water and runoff to the rivers and oceans occurs. Then the cycle starts again. Right? Wrong!

Many people do not add the groundwater part of the water cycle (often due to a lack of knowledge). So let's look a bit closer at this very important part of the water cycle – where most of the Earth's freshwater is stored.

Click to view the video.

The importance of groundwater in the hydrological cycle is illustrated by considering the distribution of the world's water supply. More than 97% of all Earth's water occurs as saline water in the oceans. Of the world's freshwater, almost 75% is held in polar ice caps and glaciers, which leaves a very small amount of freshwater readily available for use. Groundwater accounts for nearly all of the remaining freshwater. The freshwater stored in the world's rivers and lakes accounts for less than 1% of the world's available freshwater.

The groundwater portion of the Earth's freshwater.



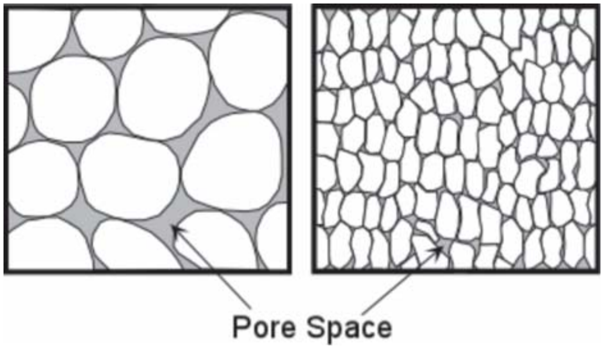
People are often under the impression that groundwater occurs in large underground dams or lakes or underground rivers. Groundwater really is the water that fills the natural openings that are present in rocks or sand.

WET FACT

97.5% of the Earth's water is saltwater. If all water on the earth water could fit in a bucket, only one teaspoonful would be drinkable.

These openings are the spaces in some sedimentary rocks (and in sediments such as sands and gravels) and in cracks and fractures in any type of solid rock. Some groundwater is tens of thousands of years old, but most groundwater used for drinking supplies has only been underground for a few months or years.

Groundwater moves through openings between soil or rock particles or along fractures. An aquifer is a subsurface geologic formation(s) that allows water to be accessible at a usable rate. Aquifer are permeable layers such as sand, gravel and fractured rock. 'Aquifer' is the correct technical term to describe water saturated rock formations. The definition adopted by the National Water Act (Act no. 36 of 1998) reads as follows: "A geological formation which has structures or textures that hold water or permit appreciable water movement through them." The water table is the surface underground where all the openings are filled with water, i.e. the saturated one. Above the water table, we find the unsaturated zone. Virtually all groundwater is slowly on the move and will eventually reach the ocean or a wetland, stream or lake. This water may even discharge at the surface as a spring – which can be either hot or cold.



The open spaces in rocks through which groundwater moves.

Most South African rivers receive about 40% of their flow from groundwater. Groundwater generally flows from higher-lying to low-lying areas. Therefore, groundwater in South Africa generally flows towards rivers and streams, which typically are the lowest points in the landscape.

This groundwater discharge that contributes to surface water flow is especially important during drier periods, when rainfall is scarce. With no rain falling in the dry season, the only water sustaining the riverflow is coming from groundwater.

It remains ironic that so many people face hardship daily because of a lack of water, yet metres below their feet is an untapped source of water

– Roger Parsons

A GROUNDWATER BUDGET TO BALANCE

The law of continuity applies to the hydrological cycle in all watersheds. Therefore, in a given period of time,

$$\text{Input} = \text{Output} \pm \Delta\text{Storage}$$

In the table below the sources for the Inputs and Outputs that affect the groundwater budget or system are summarised.

Inputs (recharge)	Outputs (discharge)
Natural areal recharge from precipitation that percolates through the unsaturated zone to reach the water table	Discharge to streams, lakes, wetlands, estuaries, oceans and springs
Artificial recharge through the injection of water in dedicated boreholes as part of a groundwater supply schemes	Groundwater evapotranspiration
Recharge from losing streams, lakes and wetlands and leaking infrastructure	Abstraction through boreholes

How does groundwater move?

Groundwater flows much more slowly than surface water (for example, rivers). Unlike surface water, which runs mostly in a straight line from high to low land, groundwater does not move through an open channel. Instead, groundwater moves between soil particles or through fractures in rock. Because groundwater flows through these spaces, the amount of time water stays in contact with the soil particles in much longer compared to surface water.

Groundwater moves under the influence of gravity from areas with a shallow water level to areas with a deeper water level. The speed at which groundwater moves depends on factors such as the gradient of the groundwater level (or hydraulic gradient) and the permeability characteristics of the rock formation through which it moves. In alluvial aquifers the flow may be up to several metres per day, but in most South African hard rock aquifers flow speeds are usually in terms of a few metres per year.

Water can travel just as fast as the geologic formation allows it to. Sand, gravel, rocks and clay are different types of earth materials. They also have very different 'openings' through which the water is able to move. Water can travel with relative ease around the individual particles of sand and gravel, but it is much more difficult for water to find its way around rocks or clay particles.

In the case of rocks, water must find a crack or hole, dissolve the rock, or simply go around the entire rock. In the case of clay, the particles are very small and situated close together, and these small open spaces are not connected, so water cannot easily find its way through it to soak further down into the Earth. Many times groundwater flow in the aquifers does not mirror the flow of water on the surface. Therefore, groundwater may move in different directions below the ground than the flowing of surface water.

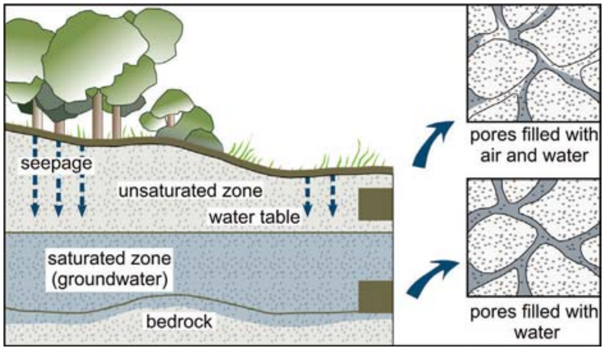


Diagram showing the difference between the unsaturated zone and the saturated zone.

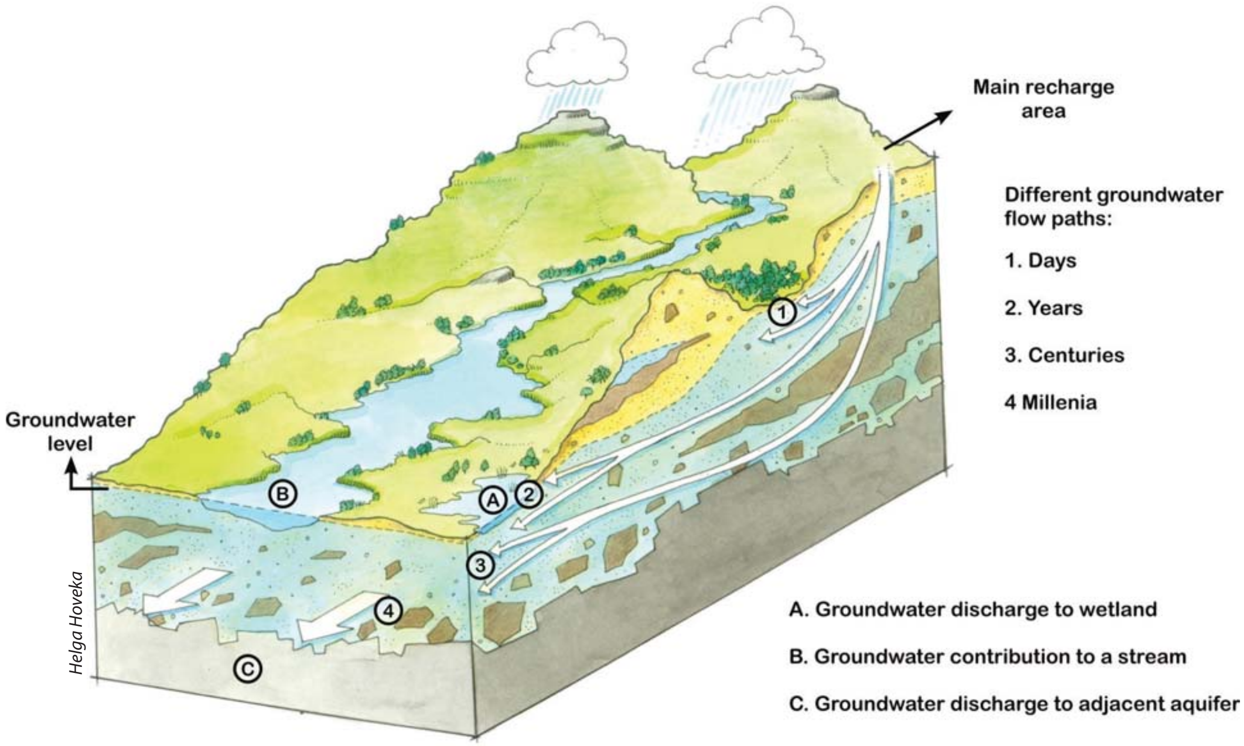


Diagram showing how groundwater follows different flowpaths in the subsurface.

AQUIFERS: WATER-CARRYING FORMATIONS

The word 'aquifer' is derived from two Latin words, ***aqua*** (water), and ***fer*** (to carry). This explains what some subsurface formations do: they carry water.

There are many different variations of geology and hydrology that may make an aquifer. Some aquifers extend over long distances and to great depths. However, many aquifers are small, only a few hectares in area. To understand these groundwater systems better, geological cross-sections are very useful. They help to form a picture of the subsurface by showing the different geological layers and their dimensions.

Are all aquifers the same?

No, aquifers mainly differ because the geology is not the same everywhere. All geologic material in the subsurface is either a potential aquifer or a confining layer/bed. A confining bed is a geologic unit which is relatively impermeable and does not yield usable quantities of water. Confining beds restrict the movement of groundwater into and out of the adjacent aquifers.

Groundwater occurs in aquifers under two conditions: confined and unconfined. A **confined** aquifer is overlain by a confining bed, such as an impermeable layer of rock or clay. An **unconfined** aquifer has no confining bed above it and is usually open to infiltration from the surface.

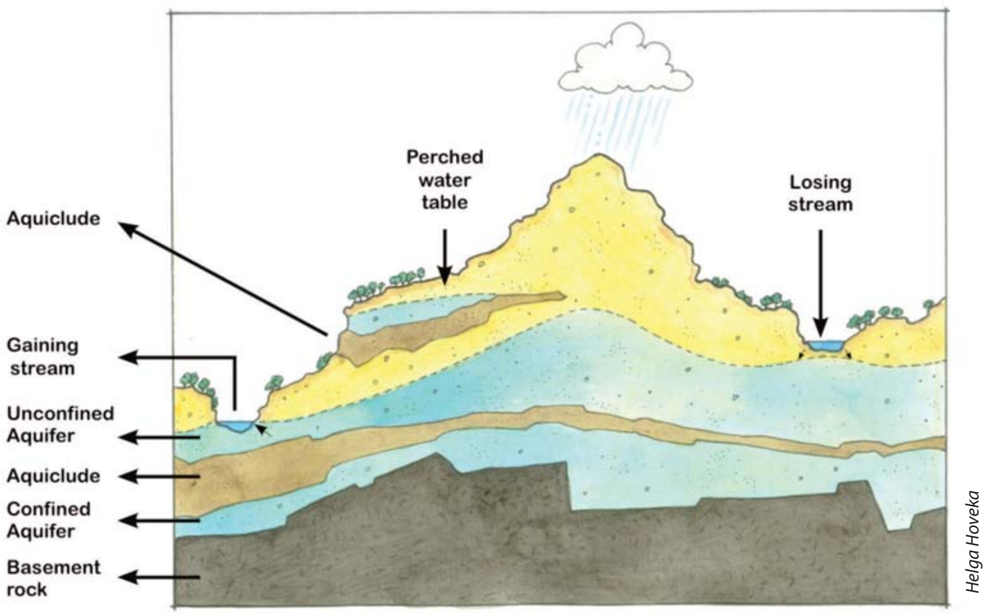


Diagram illustrating different kinds of aquifers.

Unconfined aquifers are often shallow and frequently overlie one or more confined aquifers. They are recharged through permeable soils and subsurface materials above the aquifer.

Confined aquifers usually occur at considerable depths. They are often recharged through cracks or openings in the impermeable layer above or below them. Confined aquifers may be exposed (e.g. due to secondary geological movement) at the land surface and are directly recharged from infiltrating recharge at that point. Water infiltrating fractured rock in a nearby mountain range my flow downward and then move laterally into confined aquifers.

The water level in a confined aquifer does not rise and fall freely because it is bounded by the confining layer – like a lid. This causes the water to become pressurised. In some cases, the pressure in a confined aquifer is sufficient for a borehole to spout water several meters above the ground. Such wells are called flowing artesian wells.

When a borehole is drilled into an unconfined aquifer, its water level is generally at the same level as the upper surface of the aquifer. This is, in most cases, the water table. On the other hand, when a borehole is drilled into a confined aquifer its water level will be at some height above the top of the aquifer and perhaps above the surface, depending on how much water is pressurised.

When the well is dry we know the worth of water

- Benjamin Franklin

An artesian borehole where groundwater spontaneously flows to the surface due to high pressure.

Groundwater recharge – How does the water get underground?

Aquifer recharge (or replenishment) occurs through rainfall on the Earth's surface and by surface water (e.g. rivers, lakes and dams) that infiltrates into the ground. Precipitation in the form of snow also recharges groundwater. Snowmelt occurs slowly, allowing water to infiltrate rather than it forming runoff as surface flow.

geological environments, groundwater may move hundreds of kilometres from the point of recharge to where it eventually reaches the surface. It is possible to have rock layers with groundwater of recent origin overlaying rock layers containing much older groundwater. A borehole drilled in such geologic situations will contain a 'cocktail' of groundwater of different ages. Hydrogeologists can study these different ages with the help of chemistry. This helps them make recommendations regarding the safe pump rate of a borehole.

Does recharge not take place everywhere?

South Africa has a very sporadic rainfall pattern. Some parts of the country receives in excess of 1 000 mm a year, however, the average annual rainfall is only around 470 mm a year (this is only about half of the world average annual rainfall). A small percentage of that rainfall is the water that infiltrates the soil and actually reaches the water table to replenish our aquifers. So while recharge does take place everywhere the type of rock and soil controls the type of recharge and causes it to be different from one geological environment to the next.

Some topographical areas allow more water to infiltrate the subsurface than others. They are typically higher-lying areas with exposed permeable fractured rock or low-lying areas with loose topsoil and a permeable unsaturated zone (e.g. alluvial sand). Within a groundwater system it is important to identify this specific recharge zone to ensure this area stays undisturbed as far as possible.

GEOLOGY

Rocks: the home of groundwater

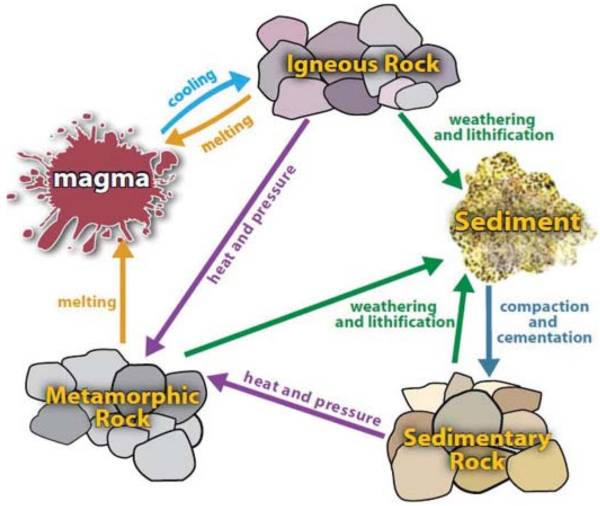
The study – or even the understanding – of groundwater requires knowledge of many of the basic principles of geology, physics, chemistry and mathematics. For example, the flow of groundwater in the natural environment is strongly dependent on the three-dimensional design of the geology deposits through which the flow takes place.

Before we can try and answer some questions about groundwater, such as how fast it moves or how it is accessed, we first need to look at the environment that provides a 'home' to groundwater. This environment does not only create the landscape and scenery we cherish, but also encompasses the fascinating world of groundwater.

The whole Earth is made up of rocks and minerals. Inside the Earth there is a liquid core of molten rock, and on the outside there is a hard crust. The rocks you see around you – the mountains, canyons and riverbeds, are all made up of minerals. A rock is made up of two or more minerals.

A mineral is composed of the same substance throughout. If you were to cut a mineral sample, it would look the same throughout. Minerals are made up of chemicals – either a single chemical or a combination of chemicals. There are 103 known chemical elements and minerals can be sorted into eight categories. Here are the categories, with some common examples of each:

1. **Native elements** – copper, silver, gold, diamonds
2. **Sulphides** – sphalerite, pyrite
3. **Haildes** – halite, fluorite
4. **Oxides and hydroxides** – corundum, hematite
5. **Nitrates, carbonates, borates** – calcite, dolomite, malachite
6. **Sulphates, chromates, molybdates, tungstates** – barite, gypsum
7. **Phosphates, arsenates, vanadates** – apatite, turquoise
8. **Silicates** – quartz,topas, talc



A diagram of the rock cycle showing the formation and transformation of rocks.

When rocks break down into smaller and smaller pieces, they turn into sand. If you look at the sand under a microscope, you will see that sand is made up of the same minerals as the rocks that the sand came from.

Rocks are constantly being formed, worn down and then formed again. This is known as the rock cycle. It is like the water cycle, but it takes even longer and takes thousands and millions of years for rocks to change.

Rocks are divided into three main types:

1. Igneous rocks
2. Sedimentary rocks
3. Metamorphic rocks

Igneous rocks form when molten lava (magma) from the Earth's core cools and turn to solid rock. There are five kinds of igneous rocks, depending on the mix of minerals in the rocks:

- Granite contains quartz, feldspar and mica

- Diorite contains feldspar and one or more dark mineral but the feldspar is dominant
- Gabbro contains feldspar and one or more dark mineral where the dark mineral is dominant
- Periodotite contains iron and is black or dark
- Pegmatite is a coarse-grained granite with large crystals of quartz, feldspar and mica.

When rocks are exposed to the elements – air, rain, sun, freeze/thaw cycle, plants – erosion occurs, and the little bits of rock worn away get deposited as sediments. Over time, these sediments harden as they get buried by more sediments and turn into **sedimentary** rocks. Sedimentary rocks are usually formed in layers (strata), and they cover 75% of the Earth's surface.

There are six main kinds of sedimentary rocks; depending on the appearance of the rock:

- Conglomerate rock has rounded rocks (pebbles, boulders) cemented together in a matrix.
- Sandstone is a soft stone that is made when sand grains cement together. Sometimes the sandstone is deposited in layers of different coloured sand.
- Shale is clay that has been hardened and turned into rock. It often breaks apart in large, flat sections.
- Limestone is a rock that contains many fossils and is made of calcium carbonate and/or microscopic shells.
- Gypsum, common salt or Epsom salt is found where seawater precipitates the salt as the water evaporates.
- Porphyry rock is when jagged bits of rock are cemented together in a matric.

The Golden Gate National Park is known for its beautiful sandstone formations.

Metamorphic is derived from the ancient Greek word ***meta*** (change) and ***morph*** (form). When rocks are heated or compressed, this type of rock forms. **Metamorphic** rocks were originally igneous or sedimentary, but due to movement of the Earth's crust, were changed. When the Earth's crust moves, it causes rocks to get squeezed so hard that the heat causes the rock to change. Marble is an example of a sedimentary rock that has been changed into a metamorphic rock. Here are some more examples of metamorphic rocks:

- Slate is transformed shale, and splits into smooth slabs.
- Schist is the most common metamorphic rock.
- Gneiss has a streaky look because of alternating layers of minerals.
- Marble is transformed limestone.

GEOLOGY AND GROUNDWATER

You might not realise how strong water is, but just think how easily it dissolves hard grains of salt, or cuts a path through sand or mud. Rain is not pure water. It is slightly acidic, because it dissolves chemicals from the air. This means that it can slowly dissolve rock. Acid rain, which has extra acid in it from polluted air, can 'eat' the nose off a stone statue in just a few years! Rushing water, such as what is found in rivers, or strong waves on the shore of oceans, roll rocks around. This cases the sharp edges of the rock to get knocked off and that is why river rocks are so smooth and by beach pebbles look so polished. The presence of water on Earth is of great importance for the rock cycle. Most obvious perhaps are the water driven processes of weathering and erosion. Water in the form of precipitation and acidic soil water and groundwater is quite effective at dissolving minerals and rocks. The water carries away the ions dissolved in solution and the broken down fragments that are products of weathering. Running water carries vast amounts of sediment in rivers back to the ocean and inland basins.

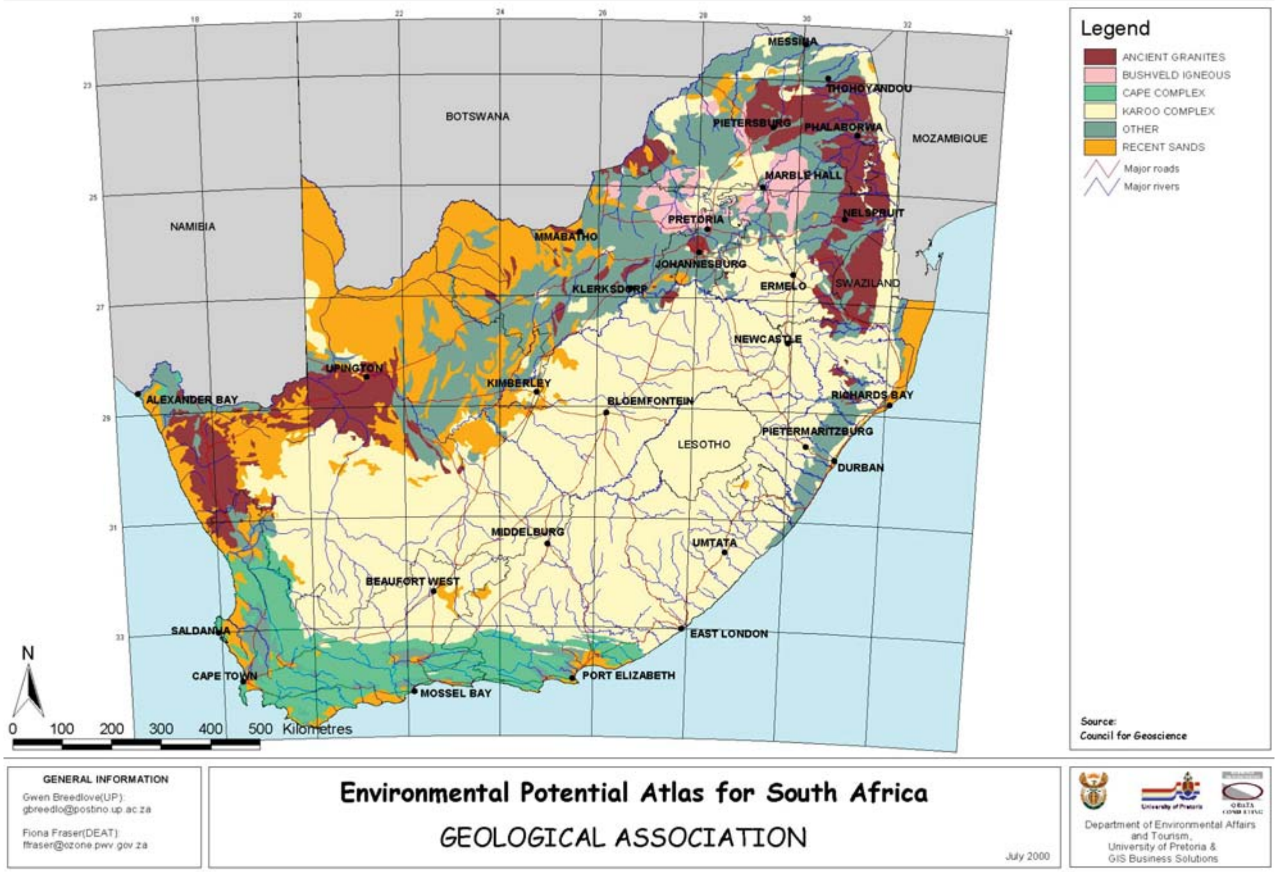
Water is strong enough to steadily cut through the hardest rock as illustrated by Bourke's Luck potholes, in Mpumalanga.

"Dripping water hollows out stone, not through force but through persistence"
- Ovid

South Africa's unique geology and its associated mineral riches have had a fundamental impact on the country's economic development since the late 1800s, when the first diamonds were discovered around Kimberley, and gold was found in the Witwatersrand. A major part of the country is covered by sediments and lavas of the Karoo system of rocks, deposited when the ancestors of the dinosaurs first emerged on land. Major volcanic events affected our continent in the distant past, leaving a record of the deep earth processes that occurred then (taken from ***Geological Journeys***).

In his classic study of minerals and metals, *De Re Metallica* (1556), the German, Georg Agricola, supposed that mineral veins are formed when groundwater percolating through the rocks, carrying dissolved salts, is "baked by subterranean heat to a certain denseness". Converted into modern terms, his idea becomes a demonstrable truth: many ores are formed when groundwater dissolves minerals in the soil and rocks and then precipitates them elsewhere in new combinations of elements.

THE GEOLOGY OF SOUTH AFRICA



Council of Geoscience

This map illustrates the simplified geology of South Africa.

Geology can be described as the complex structure of rock formations, which occur in specific locations and sequences. Geology has a major influence on most other features of the landscape, such as land form, soil, topography and vegetation and, of course, on groundwater as well.

South Africa has a very complex geological history dating back millions of years, and some of the oldest rocks on Earth have been found here. Many geological formations in South Africa are rich in mineral deposits, and some formations have become world renowned, such as the Witwatersrand quartzites (gold), the Bushveld Igneous Complex (platinum) and the coal deposits found in formations of the Karoo sediment. The Karoo complex covers about half of the surface area of South Africa. A prominent feature of South African geology is the Cape Folded Mountains. These mountains cover most of the southern tip of South Africa, and were formed as a result of continental movement millions of years ago. Large areas of sand cover the northern and central parts of the country, where Kalahari deposits have been transplanted by wind to cover major portions of land north of the Molopo and Orange River drainage systems (taken from www.environment.gov.za)

Geologic activity of groundwater

As groundwater moves through the geological environment, it interacts with the rocks and then any of the following can happen:

- **Dissolution**: Water is the main agent of chemical weathering. Groundwater is an active weathering agent and can leach ions from rock, and, in the case of carbonate rocks such as limestone, can completely dissolve the rock.
- **Chemical cementation and replacement** – Water carries ions which can precipitate to form chemical cements that hold sedimentary rocks together. Groundwater can also replace other molecules in matter on a molecule-by-molecule basis, often preserving the original structure, such as in fossilisation or petrified wood.
- **Caves and caverns**: If large areas of limestone underground are dissolved by the action of groundwater, these cavities can become caves or caverns (caves with interconnected chambers) once the water table is lowered. Once a cave forms, it is open to the atmosphere and water percolating in can precipitate new material, such as the stalactites (hang from the ceiling) and stalagmites (grow from the floor upward).
- **Sinkholes** – If the roof of a cave or cavern collapses, this results in a sinkhole. Sinkholes, like caves, are common in areas underlain by limestones.
- **Karts topography** – In an area where the main type of weathering is dissolution (such as in limestone terrains), caves and sinkholes form. These can collapse, resulting in a highly irregular topography called karst topography.

Thus, just as rivers can shape the landscape into beautiful canyons or steep valleys, groundwater also shapes the underground landscape.

In 2004, a sinkhole developed at Bapsfontein, Gauteng.

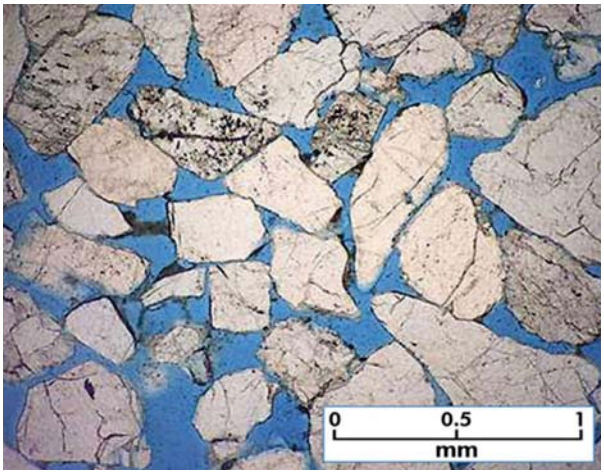
The geological environment sets the scene for groundwater; the volume of water that can be stored, the ease with which it can move and the unique chemistry of groundwater at a specific location.

The rate of groundwater flow is controlled by two properties of the rock: porosity and permeability.

Porosity is the percentage of the volume of the rock that is made up of open space (pore space). This determines the amount of water that a rock can contain. Well-rounded, coarse-grained sediments usually have a higher porosity than fine-grained sediments, because the grains do not fit together well. Poorly sorted sediments usually have a lower porosity as the fine-grained fragments tend to fill in the open space. In igneous and metamorphic rocks porosity is usually low because the minerals tend to be intergrown, leaving little free space. Highly fractured igneous and metamorphic rocks, however, could have high porosity.

Permeability is a measure of the degree to which the pore spaces are interconnected, and the size of the interconnections. Low porosity usually results in low permeability. However, high porosity does not necessarily translate into high permeability. It is possible to have a highly porous rock with little or no interconnections between pores.

Examples of high porosity materials include sand, sandstone, some limestones and basalt. These formations usually have a high permeability as well. Granite, gabbro and most metamorphic rocks have a low porosity. They may have a high permeability if fractures are present in the formation.



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A microscopic view of pore spaces in a rock .

THE HYDROGEOLOGY OF SOUTH AFRICA

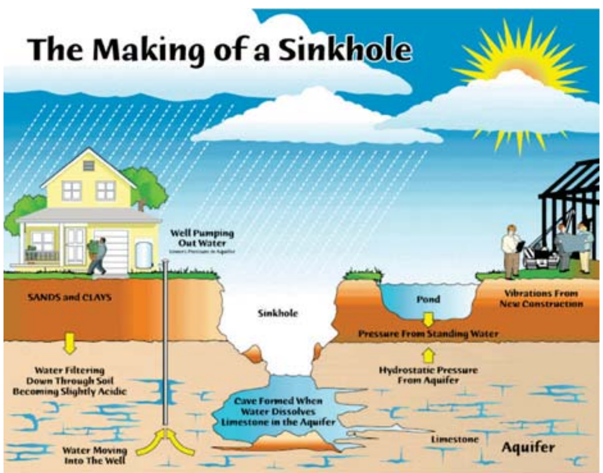
The hydrogeology (or the water-bearing formations) of South Africa has different properties from one area to the next. This is expected as the geology is different throughout the country.

In South Africa, the following main aquifer types can be distinguished:

- **Aquifers in the Karoo Sequence**: About 50% of the country surface consists of rocks belonging to the Karoo Sequence. These rocks comprise sandstone, shale and siltstones. They usually have low borehole yields and low permeabilities. This geological setting, however, also contains an irregular network of dolerite in the form of dykes and sills. These rocks are intrusions that create permeable, fractured zones which can yield large amounts of groundwater.
- **Dolomitic aquifers**: Dolomitic rocks only occupy about 5% of the land surface, but the groundwater potential of these rocks is significant. Dolomite has a high storage capacity as well as specific yield. Boreholes drilled in carefully selected areas can yield extremely large volumes of water.
- **Aquifers in igneous rocks and other hard rock formations**: Borehole yields can be significant in hard-rock areas where the rock is sufficiently weathered and/or fractured. Fault zones have a high porosity where water can be stored. Groundwater also moves faster in these zones compared to adjacent solid hard-rock.
- **Aquifers in unconsolidated sands**: These aquifers are found along our coastal areas, in the Kalahari, in alluvium-filled riverbeds and in the alluvial plains of rivers. These aquifers consist of unconsolidated, porous sediments and have a high specific yield.

A geological discontinuity, with layered shale on the left and a dolerite intrusion on the right. Groundwater occurrence and movement is enhanced by structures such as these.

Sinkholes – A (w)hole lot of nothing



www.swfwmd.state.fl.us/hydrology/sinkholes/SinkholePoster.gif

Sinkhole formation.

Sinkholes are depressions or holes in the land surface that occur in some parts of South Africa, mainly the Gauteng and North West provinces. These holes can be shallow or deep, small or large, but all are a result of the dissolving of the underlying limestone.

Hydrologic conditions, including lack of rainfall, lowered water levels, or, conversely, excessive rainfall in a short period of time, can contribute to sinkhole formation. Sinkholes are a common feature where the rock below the land surface is limestone, carbonate rocks or rocks that can naturally be dissolved by groundwater circulating through them. As the rock dissolves, spaces and caverns develop underground. If there is not enough support for the land above these open spaces, then a sudden collapse of the land surface can occur.

The water below ground is actually helping to keep the surface soil in place. Groundwater pumping for urban water-supply and for irrigation can produce new sinkholes in sinkhole-prone areas. If pumping results in a lowering of groundwater levels, then underground structural failure, and thus, sinkholes, can occur.

WET FACT
Over the past 50 years there have been around 1 300 sinkholes in the greater Gauteng area.

Wondergat, outside Mahikeng in the North West province, is South Africa's deepest sinkhole.

GROUNDWATER CHEMISTRY

We often think of water quality as a matter of taste, clarity and odour, and in terms of other properties which determine whether water is fit for drinking. However, for other uses than drinking; different properties may be important. Most of these properties depend on the kinds of substances that are dissolved or suspended in the water. Water for most industrial uses, for instance, must not be corrosive and must not contain dissolved solids that might precipitate on the surfaces of machinery and equipment.

Scientists assess water quality by measuring the amounts of the various constituents contained in the water. These amounts are often expressed as milligrams per litre (mg/L), which is equivalent to the number of grams of a substance per million grams of water.

The chemical nature of water continually evolves as it moves through the hydrological cycle. The kinds of chemical constituents found in groundwater depend, in part, on the chemistry of the precipitation and recharge water. Near coastlines, precipitation contains higher concentrations of sodium chloride, and downwind of industrial areas, airborne sulphur and nitrogen compounds make precipitation acidic.
One of the most important natural changes in groundwater chemistry occurs in the soil. Soils contain high concentrations of carbon dioxide, which dissolves in the groundwater, creating a weak acid capable of dissolving many silicate minerals. In its passage from recharge to discharge area, groundwater may dissolve substances it encounters or it may deposit some of its constituents along the way. The eventual quality of the groundwater depends on temperature and pressure conditions, as well as one the kind of rock and soil formations through which the groundwater flows, and possibly on the residence time.

As a result, the groundwater chemistry in South Africa could differ from place to place, depending on the geology of the aquifer in which it is found. This natural chemistry of the groundwater could render it unsuitable for certain uses. For example, water from the Malmesbury shales in the Western and Eastern Cape is unsuitable for most uses due to the presence of high total dissolved salts. Groundwater in granites (e.g. in Limpopo) often contains fluoride in high concentrations, whereas water from dolomites is usually a good drinking water, but classified as 'hard' water. 'Soft' water, on the other hand, comes from aquifers that pass through rocks such as slate and granite, which contain little or no calcium and magnesium.

All water has a perfect memory and is forever trying to get back to where it was.

Toni Morrison.

HOW CAN WATER BE 'HARD'?

Unless it is frozen, it is not easy to picture water as being hard. Yet, this is a term used frequently to describe the quality of one's tap water. So what does this mean? Water can dissolve many different substances. That includes the many minerals underground that water comes into contact with before it is pumped from the ground. The most common minerals found in hard water are calcium and magnesium. When water is high in calcium and magnesium content, it can be considered hard.

Unless it is really hard, you cannot really notice any difference in taste and it won't cause you any harm. Though the water itself may not have an unpleasant taste, the minerals can affect the taste of your coffee or your tea. Coffee can develop a bitter undertone when brewed with hard water, while delicate green teas can end up with a completely different flavour altogether.

There are several other negative effects that derive from using hard water, such as that detergents won't foam, which can make washing difficult. Another problem is that the insides of your coffee maker, expresso machine or kettle can get a crusty buildup of minerals. These deposits are called 'mineral scale'. It is essential to have the quality of the water from a borehole intended for domestic use tested before consumption. Even natural groundwater may contain substances which can make it unfit for consumption.

GROUNDWATER LINKS IN THE HYDROLOGICAL CYCLE

Let's consider the hydrological cycle again for a moment. Water evaporates from surface water bodies through the sun's heat, it condenses high up in the air, precipitation forms and then the water ends up on the Earth's surface again. Some of the water then infiltrates into the ground and becomes part of the groundwater component of the hydrological cycle. Groundwater accounts for a large part of the water within the cycle and is constantly on the move. Groundwater does not stay underground forever. Rather, groundwater circulates back to the surface. From the surface some water returns to the atmosphere through evaporation and transpiration.

So eventually, the groundwater reappears above the ground. This is called discharge. Groundwater may flow (discharge) into streams, rivers, wetlands, lakes and oceans. It may also discharge in the form of springs and through artesian (free-flowing) boreholes.

RESIDENCE TIME

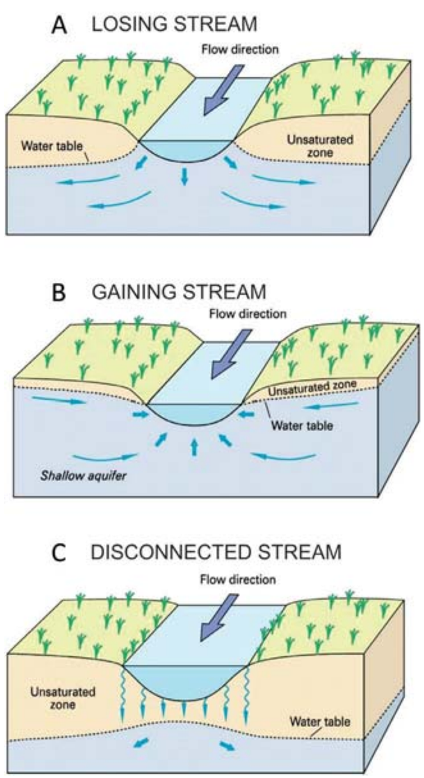
The residence time of groundwater, i.e. the length of time water spends in the groundwater portion of the hydrological cycle, varies enormously from system to system. Water may spend as little as days or weeks underground, or as much as 10 000 years. Residence times of tens, hundreds or even thousands of years are not unusual. By comparison, the average turnover time of river water, or the time it takes the water in rivers to completely replace itself, is about two weeks.

Groundwater and streams or rivers

The Pretoria fountains are the source of the Apies River.

Groundwater discharge can contribute significantly to surface water flow. In dry periods, the flow of some streams may be supplied entirely by groundwater. At all times of the year, in fact, the nature of underground formations has a profound effect on the volume of surface runoff. While the rate of discharge determines the volume of water moving from the saturated zone into streams, the rate of recharge determines the volume of water running over the surface. When it rains, for instance, the volume of water running into streams and rivers depends on how much rainfall the underground materials can absorb. When there is more water on the surface than can be absorbed into the groundwater zone, it runs off into streams and lakes.

This interaction between groundwater and surface water has a benefit, but also a drawback: because water flow can occur between the two water sources, they will support each other in dry periods, but once one of the sources gets polluted, it will inevitably lead to the pollution of the other resource as well. There are examples from around the world of people that got sick – or even died – from drinking polluted groundwater. However, it was not the groundwater that got polluted in the first place, but polluted surface water that got into contact with the groundwater and caused the disaster. Therefore, it is important that water managers understand these links between surface water and groundwater, and remember that the hydrological cycle implies that we actually need to manage our water sources as one single resource.



Diagrams illustrating the relationship between groundwater and streams.

Groundwater and wetlands

Wetlands are present in climates and landscapes that cause groundwater to discharge to the land surface or that prevent rapid drainage of water from the land surface. Similarly to streams and lakes, wetlands can receive groundwater inflow, recharge groundwater, or both.

According to the National Water Act, a wetland is defined as 'land which is transitionary between terrestrial and aquatic systems, where the water table is usually at or near the surface, or the land is periodically covered with shallow water, and which land in normal circumstances supports or would support vegetation typically adapted to life in saturated soil'.

Not all wetlands are entirely reliant on groundwater, but most have a dependency on groundwater. Wetlands are one of the discharge points of groundwater on the surface. Wetlands are important for a number of reasons. Apart from being rich in biodiversity they regulate streamflow and reduce floods; purify water and provide erosion control, among others.

Groundwater and lakes

The interaction between groundwater and lakes are very similar to that of the interaction between groundwater and streams or rivers. Where the water table is shallow and in contact with the water in the lake, groundwater will contribute to the lake, especially in the dry season. Freshwater lakes are not a common feature in South Africa. In fact, Lake Fundudzi, in Limpopo, is the only inland lake in the country.

Groundwater and the ocean

The ocean is another place where groundwater discharges to the surface. Depending on the slope of the geology, fresh groundwater discharges close to the beach or even kilometres from shore. Interesting research on this zone of interaction close to the beach have been done in recent years. At the Langebaan lagoon, on the West Coast, there is such a research site where the CSIR has been making interesting discoveries.

The ecology of St Lucia estuary, in iSimangaliso Wetland Park on the northern KwaZulu-Natal coast, is of unique international importance. During droughts the estuary experiences high salinities, with values above that of seawater. Ion-poor groundwater flowing into the estuary from prominent sand aquifers along its eastern shoreline forms low-salinity habitats for salt-sensitive biota. During droughts, plants and animals can take refuge in the groundwater discharge zone until the condition in the estuary regains tolerable salinity. Simulations of the groundwater discharge indicate that the flow can persist during droughts over at least a decade, and be of great importance for the resilience of the estuary. Anthropogenic activities have reduced the river inflow, and made St Lucia estuary more sensitive to droughts. The groundwater has therefore become increasingly important for the estuary's ecology. Protection of the groundwater discharge along the shoreline itself, and actions to increase the groundwater recharge are therefore important management tasks.

Hydrogeologists, ecologists and water managers often do not sufficiently understand how, when and where ecosystems are dependent on groundwater. Groundwater dependent ecosystems are often critical in supporting sustainable livelihoods and biodiversity. Sustainable use of groundwater should account for the vital role that groundwater plays in maintaining the natural environment.

iSimangaliso Wetland Park, in KwaZulu-Natal.

Groundwater: the missing link?

Groundwater degradation and depletion has far-reaching consequences for the environment, economy and society in general. For example, over-abstraction can reduce habitat for species dependent on groundwater during the dry season. Pressure on groundwater sources can also reduce irrigation capacity, compromising food security, and further impoverishing the vulnerable sectors of society.

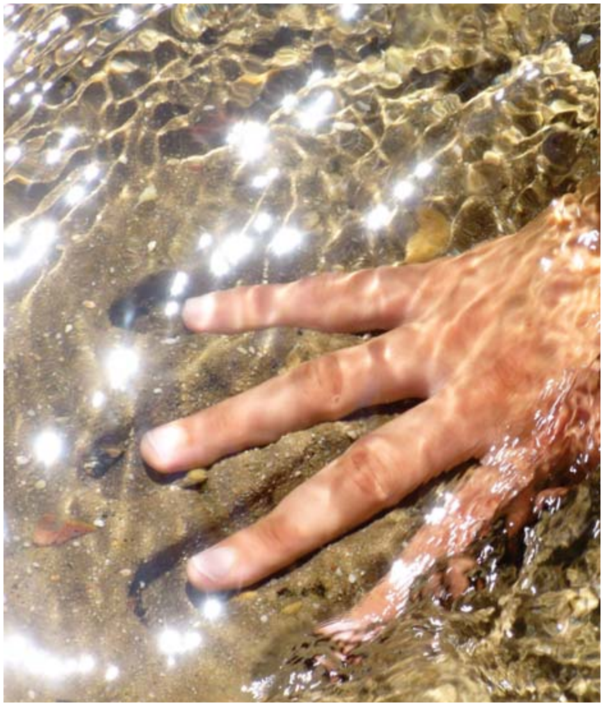
Groundwater may be the missing link sometimes when we try to understand environmental systems, but is not missing at all!

CHAPTER 2: FINDING THE GROUNDWATER – GETTING DOWN AND DIRTY

The man with the dusty boots and faded jeans walks diligently, yet cautiously. It is hot here on the Free State plains and he has been walking in a cross-cross pattern for hours now. He takes another few steps and then stops suddenly. Slowly he takes a few steps back, resetting his hands on the dowsing rod. Then he starts walking forwards again. The rod suddenly twitches and he shouts: "Right here gentlemen, right here! Bring the drilling machine; this is where you will find lots of water!"

The forked stick is probably the oldest tool used to locate water and underground riches. This method has been used since Greek and Roman times. But it was only around 1830 that this method found its way to South Africa. Since then there has been a dispute between water dowsers and water scientists about the validity and successes of their different (sometimes controversial) methods of finding underground water.

How do we find groundwater?



As fingers find their way through the cool sand, so does groundwater find its way through small openings.

The existence of this mysterious and precious natural resource called groundwater is non-disputable. Evidence is plentiful throughout a landscape: springs bubbling out in often unexpected places, plant communities thriving in areas of low rainfall or wetlands and marshes appearing in dry, sandy areas.

With the quality of groundwater of such good standard, it is then no surprise that mankind wants to utilise this water resource for different activities and needs. But how do we go about to identify and abstract this groundwater?

Let's look at a few of the investigation methods to determine where exactly a usable amount of groundwater is located:

- **Water divining** – This method dates back hundreds of years. Diviners use this method to locate oil, minerals, treasures and also water. No one know how or why this method works, but most people are sceptical of this approach. However, some successes have been achieved with this method.
- **Random guess** – This approach assumes that you can drill anywhere and still find the same amount of water. Groundwater is everywhere, but it is not necessarily available everywhere in quantities that are economical to abstract.
- **Scientific** – This is by far the most reliable method. Various scientific methods are used today. These include the magnetic method, the seismic refraction method, electro-magnetic method and the electrical resistivity method. Hydrogeologists and geophysicists use one or a combination of these methods, interpret the data and combine it with some visual indicators as well as experience to determine the optimal drilling position.

Dowsing/divining

Dowsing is a controversial practice where dowsers claim power to find water, metals, gem stones and hidden objects by carrying or waving a stick or other apparatus over a piece of land and watching for any movement. Repeated tests under controlled conditions have, however, not supported this claim. Dowsers (also known as diviners) may also use a forked branch of a tree, bent pieces of metal or plastic wire, or a small pendulum, while others use no pointing device at all.

People remain sceptical of the water divining approach to finding groundwater.

More accurate and reliable methods

There is no single method with which the exact quantities and depths of groundwater occurrences can be located. There are, however, scientific methods, which, with the correct use, vastly improve the chances for the successful sighting of a borehole or most favourable drilling conditions.

John Weaver, a South African hydrogeologist, has the following to say when it comes to borehole sighting: "We use a number of tools, first and foremost are geological maps, aerial photographs, and satellite images. Unless I have these available, I will decline to go out to site a borehole. Quite often I get a call from a farmer who has drilled on-site, and wants me to come out to site the next day to locate a new drill-site. The temptation is high to pop out to site and charge a stiff consulting fee, but so far I have always been able to persuade the fellow to let the drill-rig move on, and for me to locate a new drill-site after having

EXTRACT FROM "DIVINING. THE SUPERNATURAL STATE: WATER DIVINING AND THE CAPE UNDERGROUND WATER RUSH, 1891-1910", ARTICLE IN *JOURNAL OF SOCIETY HISTORY*, SUMMER 2004, BY LANCE VAN SITTERT

The existence of underground water in the Karoo had long been known and its presence commemorated through place names in which the Dutch word Fontein [fountain] is made liberal use of…[and] the Hottentot and word Kamma [water] is not less frequently found in the composition of the aboriginal names. In the absence of cultural markers, Karoo water could also be detected through close observation of birds, animals and flora.

Burchell advised watching for circling swallows, captive baboons were fed salt and set to the task and folk-botany recognised an aabosje (literally a "vein shrub") for its water-finding capabilities. Folk-geology was similarly attuned to reading the landscape for water, prospecting dry river beds for "graafwater" (spade water) trapped by "seekoeigate" (hippopotamus holes) and dolerite dykes and everywhere else seeking out the dolerate "water klip" (water stone), "keerbanke" or "keerdamme" (weirs) indicating and catching underground water.

obtained air-photos from the Surveyor-General. The air-photos take about ten days to process, the geology maps are available off the shelf and satellite images are obtained either from Google Earth or from the Satellite Application Centre at Hartebeeshoek. The next important tool is existing groundwater information. This we obtain from local knowledge of successful and unsuccessful drilling, from existing groundwater reports from that area or nearby areas, and from the Department of Water and Sanitation National Groundwater Database. For some geological terrains it is only these tools that are needed to be able to properly interpret the geology. In other terrains we will use one or more geophysical instruments."

Different rocks (geological formations) exhibit different characteristics, such as magnetic intensity and/or electrical resistivity. These characteristics are observed and then interpreted to site a borehole.

The following methods, also called geophysical methods, generally apply to South African conditions:

- **Magnetic method**: This is probably one of the most commonly used geophysical surveys that are used to assist with the location of positions to drill boreholes. This method measures the changes in the normal magnetic field of the Earth, and it is used to pick up contacts between different geological formations, such as dolerite dykes, which are a typical feature in the Karoo geological environment.
- **Electrical resistivity**: With this method an electrical current is passed through the underlying rock, and the difference in the passing of this electrical current through the different rock formations is measured. The differences in the resistivities of rock types can be measured, which can then be correlated to water-bearing zones. Because water conductivity is the most important cause of electrical conductivity in rock formations, this method is directly related to groundwater occurrences. An advantage of this method is that the resistivity is not measured laterally (horizontally) only over an area, but also in depth at a specific point. The electrical resistance is influenced by water, salt and rock type and density.
- **Electromagnetic method**: This method uses the difference in electromagnetic conducting abilities of rocks. This method is used increasingly in groundwater exploration, with the advantage of the speed with which the survey can be carried out. The area of application of this method is similar to the electrical resistivity method.
- **Gravimetric method**: The Earth's natural force of gravity forms the basis of this method. The changes in the Earth's gravitational field, caused as a result of the different densities and mass of rock formations, are determined at different measurement points on the surface. When correctly interpreted, structures such as sinkholes and solution cavities and the thickness of alluvial sand can be determined with this method. For example, denser material has a higher gravity and weathered material will have a lower gravity reading.
- **Seismic refraction method**. This method is based

on the principle that shock waves move at different velocities through different rock formations. Sound travels faster in dense material and, therefore, reflects on formation boundaries. The arrival time of the reflected sound waves at different locations are measured. In this way, a picture can be formed of the underground strata. It is, therefore, also possible to locate areas where there is an increase in the thickness of weathered material. The more weathered an area, the higher the probability of finding a utilisable groundwater source.

Two students undertaking a magnetic survey.

Apart from these geophysical methods, there is also some additional 'help' from Mother Nature in trying to find usable quantities of groundwater:

- **Soil changes:** Normally in southern Africa, the hilltop areas are covered by a light yellow or grey sandy soil. These changes further down the slope into toil types that are richer in clay, finally ending in the black, surf-type soil at the bottom of valleys. A change in this normal sequence of soil deposition can indicate the presence of a geological feature associated with water.
- **Rock outcrops:** Quartz veins and dykes are often visible as straight lines in the landscape, and can form ridges or mark a break in the slope of the strata. Here, less erosion-resistant rock types can form shallow depressions, and are often associated with water-bearing fractures.
- **Vegetation changes:** In Limpopo this indicator is evident when thick bush and tree growth contrast with the otherwise grassy land. These greener, different vegetation (phreatophytes) line-like features are often associated with dykes. This straight-line change can be indicative of fracture zones that carry more water than the surrounding rock. In addition, the presence of a cluster of moisture-loving plants could suggest a seep or a spring.
- **Insects and animals:** Termits sometimes penetrate the soil to remarkable depths in search for water. Notice a strange line of mounds in the veld, and they're far too small for the doing of a mole? Well, in granite and hard-roc areas where water storage is mainly in narrow zones, termites can establish themselves along these zones (referred to as fractures or fissures). Colonies of meerkats and ground squirrels can also establish themselves in an environment along the contact of two rock types. This contact can be an indication of a deep lying water source. Their community of tunnels would then somewhere intersect this water underground, providing them with an important resource.

Vegetation in line features are often associated with dykes and, therefore, are possibly indicative of water-carrying zones.

In locating a site one has largely to be guided by first principles, by experience of local conditions and by knowledge of the results acquired during previous work upon adjoining ground, or in default thereof, in similar formation elsewhere having a comparable environment. That the surface configuration may have little influence upon the character of the subsurface supply has been demonstrated in practice, boring in pans or in laagtes having not infrequently failed, whereas water has readily been obtained in higher ground close by.

– Alex du Toit, 1928

Regardless of which method(s) are used to find water, the only way to be absolutely sure if groundwater is present in a usable quantity is to drill.

Once the drilling position has been located, the next step is the physical drilling of the borehole. For this one will need to approach a drilling contractor and obtain a quotation for the job. To help the potential groundwater user appoint an accredited driller and ensure that a successful borehole be drilled, it is advisable that the SABS standard document be used: ***SANS-10299. Development, maintenance and management of groundwater resources***, an initiative of the Borehole Water Association of South Africa.

How do we get the groundwater to the surface?

Quite a number of towns and cities in South Africa were founded where springs surged from the ground or on alluvial plains where wells could be dug easily. The development of pumps capable of raising water from great depths, together with technical advances in drilling machinery and technology, enabled the drilling of thousands of boreholes from the late nineteenth century.

Water-lifting technologies, such as the windpump, is still in use today.

The oldest way of using groundwater is to take it directly from springs and fountains, or to dig a well with pick and shovel. Prior to modern methods, people used pulleys or animal-powered systems (known as water wheels or donkeys pulling 'bakkiespompe') or even wind-powered mechanisms (including windpumps).

Water in aquifers is brought to the surface naturally by means of a spring, or can be discharged into wetlands, streams or the ocean. We can abstract groundwater through a borehole, which is drilled into an aquifer.

Once a successful borehole has been drilled, it can be equipped with any of the following equipment, the choice of which is influenced by the specific intended use of the water, e.g. as drinking water, municipal water supply, irrigation etc.:

- Handpump: especially if the yield of the borehole is low, mainly in rural areas.
- Windpump: Mainly on farms, can maintain higher yields.
- Electrical pump/diesel pump: Usually when borehole yield is higher, higher assurance of supply.
- Playpump: Effective when borehole yield is low, mainly for water supply at schools.

Some of the earliest methods of lifting water to the surface was with the use of a 'donkiepump' or animal-driven pump.

A playpump can be used to provide water to schools.

A handpump in rural KwaZulu-Natal.

Boreholes require sophisticated technology with the right appropriate technical design, together with proper knowledge of the aquifer. Unfortunately, the importance of good quality borehole design and construction is often underestimated. The lifetime of a borehole and the efficiency of its functioning depend directly on the materials and the technology used. Borehole 'failure' is often not linked to aquifer performance, but rather to the incorrect design and construction of the hole as well as poor operation and maintenance.

HOW A BOREHOLE IS DRILLED

When it comes to drilling, the proof is in the pudding. Depending on the thoroughness of the groundwork done by the hydrogeologist, the experience of that person and the specific area targeted, the success rate will still vary from as low as 60% to as high as 100%. An example of this type of success variation is the granites in the northern suburbs in Johannesburg where the drilling success rate is more than 90%, while the granites of Sir Lowry's Pass outside Somerset West have a success rate of only 15%.

The presence of boreholes in the front yard or just next to the driveway of a homeowner is no coincidence, neither a mysterious scientific phenomena. It is just simply the one place where the drill-rig has easy access! A drill-rig is quite a monstrous piece of machinery, usually weighing in excess of 10 tons.

The drilling process

There are often several rock layers in a single borehole; each may require different drilling pressures. Once water is encountered, the driller will need to keep a close watch on the drilling process. The most common methods used for drilling boreholes are rotary, air hammer and cable tool.

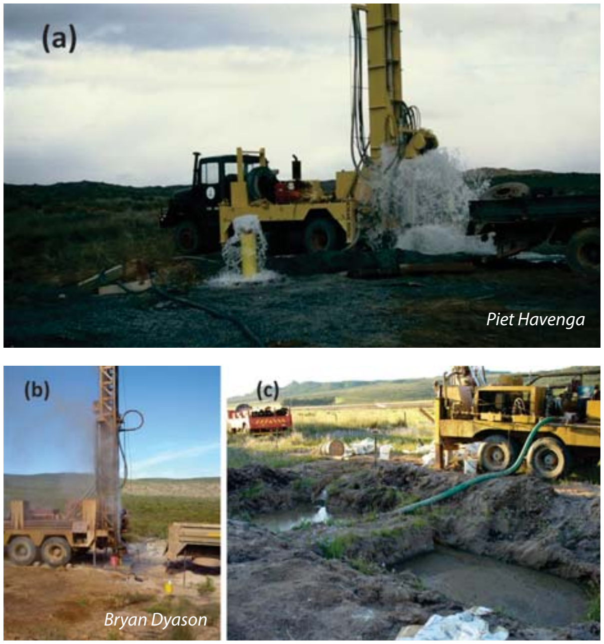
In rotary drilling, a drill bit is attached to a length of connected rill pipe. The drill bit is made of a tough metal, such as tungsten, and as the drill is rotated, the bit acts to grind up the rock. The broken pieces (called cuttings) are flushed upward and out of the hole by circulating a drilling fluid (sometimes called drilling mud) down through the drill pipe and back to the surface. This drilling fluid also serves to cool and lubricate the drill bit, and by stabilising the wall of the hole it can prevent possible cave-ins of unstable sands or crumbly rock before the well casing or well screen is installed. As the drill intersects water bearing rock formations water will flow into the hole. Most drillers carefully monitor the depth of water 'strikes' and keep note of the formations in which they occur.

In hard rock areas many drillers prefer to use a well drilling technique that uses compressed air to operate a down-hole air hammer on the end of the drill string that helps to break up the hard rocks. The compressed air also blows the crushed rock fragments out of the hole to the surface along with any water that flows in the hole during drilling. This is also the drilling method which is the most widely applied in South Africa.

Another drilling technique uses a 'crusher' machine, usually referred to as cable tool drilling. With this method, a heavy bit is attached to the end of a wire cable and is raised and dropped repeatedly, pounding its way downward. Periodically, cuttings are bailed out of the hole. The method is slow and, in most places, has been replaced by rotaring drilling.

In low-yielding boreholes it is sometimes possible to increase yield by using 'hydrofracturing' techniques. In this process, selected parts of the drilled hole are subjected to great pressure using special tools lowered from the surface. The expected result is that small existing fractures will be enlarged or opened up to allow the borehole to connect to additional water bearing fractures or fissures.

It is important that the surface area around productive boreholes be equipped with a cement block to prevent potential contamination from surface water.



Air percussion drilling in the Karoo; b) Air percussion drilling in the West Coast region ; c) Mud rotary drilling.

The groundwater supply to Oudtshoorn.

A cement block around a completed borehole prevents contamination from the surface.

Is drilling a borehole the only option to get access to groundwater?

Well-points or tube wells are small diameter pipes (usually PVC or polyethylene) that are jetted into unconsolidated sand or gravel formations. The bottom of the pipe is slotted to allow just water, and not the sand, to flow into the well-point, from where the groundwater is pumped to the surface. Not surprisingly, well-points are mostly utilised for small-scale water supply.

The unconsolidated nature of the sand and shallow water table in the Cape Flats Aquifer Unit (CFAU) make for ideal well-point installations conditions. In Cape Town, a large number of home owners on the CFAU are using well-points for garden irrigation. These well-points are cheap to install and to operate.

Thanks to Mother Nature, there is an even easier way to get access to groundwater, namely natural springs. These are usually channelled and provide good quality water to a number of people in South Africa.

Grootfontein is one of the natural springs that provide water to parts of Pretoria.

USEFUL CONVERSIONS IN THE GROUNDWATER INDUSTRY

1 litre = 0,220 gallons
1 m^3 = 1 000 litres
1 m = 3,281 feet
1 foot = 0,30 metres
1 cm = 0,39 inches
1 inch = 2,54 cm
1 ha = 2,4711 acres = 1,1675 morgen

WET FACT

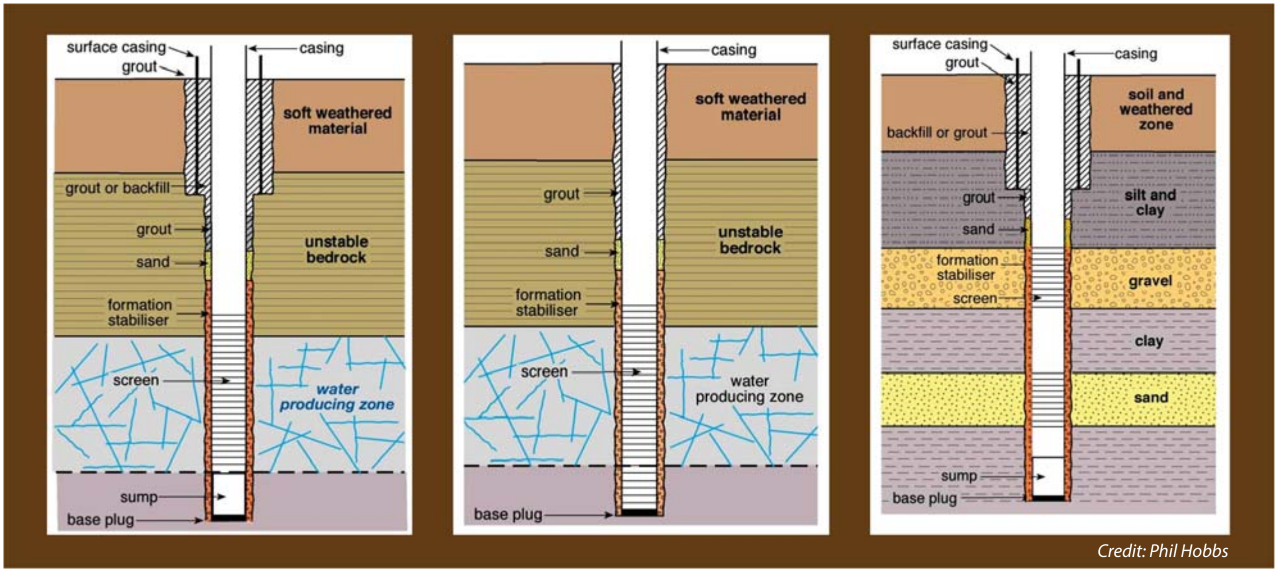
Between 1910 and 1984 the Department of Water and Sanitation sank a total of 125 000 boreholes in South Africa. This adds up to a total distance of 7,6 million metres!

BOREHOLE DESIGN

A modern borehole is much more than just a hole in the ground. No matter which method of drilling is used, the top part of the borehole is usually lined with steel or plastic well casing. The diameter of the drilled hole is usually an inch or two wider than the diameter of the casing. The space between the drilled hole and the casing has to be filled to prevent the chance of polluted surface water from migrating downward along the outside of the casing where it might contaminate the aquifer. This filling is called 'grout' and (depending on local regulations) it may either be cement or special volcanic clay (bentonite). Sometimes, most of the space is filled with the fine rock pieces from drilling and then the top ten metres or so is grouted.

In time and with water, everything changes.

Leonardo da Vinci



Diagrams to illustrate proper borehole construction design in different geological environments.

Make sure you acquire the services of a registered driller if you want to drill a borehole on your property. You will save yourself a lot of money (and several headaches). Visit www.bwa.co.za for more information.

Borehole equipment

Once a borehole has been drilled, access to water is still needed. This is achieved by equipping the borehole with a pump. There are various types of pumps, and the choice is critical for the optimal and sustainable use of the groundwater source.

Hand pumps are used to provide water to people all over the world.

Thousands of windpumps dot the South African landscape.

These different pumps include:

- **Hand pump**: Man has used various forms of human and animal driven pumps during the last two thousand years. Although the introduction of modern technology has almost entirely replaced this method, hand pumps still have a definitive role to play in remote rural areas where electricity and other infrastructure are not available. Hand pumps are perfect for supplying small quantities of drinking water to communities who otherwise might not have access to clean water at all.
- **Windpump**: A huge improvement on the hand pump was brought about with the introduction of the windpump. When driving through southern Africa, it is easy to see why the windpump is regarded by many as the unofficial South African landmark.
- **Submersible pump**: This type of pump is becoming increasingly popular in South Africa. The pump, complete with motor, is submerged into the borehole. These pumps are usually efficient in terms of power consumption, and are available for a wide range of applications. Once installed, the pump runs silently, and is virtually tamperproof, making a pump house generally unnecessary.
- **Screw type pumps**: Screw type pumps are well known for their reliability and ability to deliver water at high heads and large amounts. These pumps are also widely used throughout South Africa.
- **Turbine pumps**: Borehole turbine pumps work in a similar way as submersible pumps. Turbines are normally used where high capacities are required. Some farmers, as well as the mining industry, commonly use turbines of different sizes, depending on their specific needs.
- **Other pumps**: Some other pumps that are available include solar pumps and jet pumps. These are not so commonly used.

THE FIRST WINDPUMPS

The arrival of the windpump brought huge changes to the water business. The first pumps were rickety and crude. All parts were made of wood and nothing short of a gushing Cape southeaster wind was required to get them going. The windpump only became practical once an American company started making them with steel heads in 1888. The first windpumps were imported to South Africa in 1893 and their marketing slogan made quite an impact: "Wherever you go, you see them: wherever you see them, they go."

A UNIQUELY SOUTH AFRICAN INVENTION – THE PLAYPUMP

It is custom in rural South Africa for women and children to be responsible for fetching water for household needs. Some travel two to five kilometres to the closest water point, be it a river, pond or borehole. In the early 1990s, private organisation, Roundabout Outdoor, came up with a very innovative design. The playpump relies on the energy of children playing on a roundabout and couples this with a low maintenance pump. Each roundabout pump is capable of providing water for up to 2 500 people. The water is pumped from the borehole into a 2 500 litre tank, standing seven metres above the ground. A tap makes it easy for women and children to draw water.

THE BAKKIESPOMP – REVOLUTIONARY WATER-LIFT PATENT IN THE 1800S

A very important piece of water machinery saw the light in the second half of the nineteenth century. Before this invention, people had to lift water manually from hand-dug wells. According to the census of 1960, there were more than 20 000 of these wells spread across the country. The bakkiespomp caused a revolution in South Africa as it was the first piece of machinery that the farmer could use without manual labour. The pump simply had a horizontal wheel with a shaft. This was connected to an animal like a donkey or an ox who then turned the shaft. The wheel had gears that propelled a vertical wheel which was attached to a shaft that went down the hole and turned a wheel inside the water. This wheel inside the water was equipped with some dippers that transported the water to the surface and delivered a constant stream of water. As the patent improved, it was able to deliver a phenomenal volume of water of between 1 and 82 m^3 per hour from a depth of 9 metres.

Pumping groundwater at a sustainable rate

The borehole is drilled and the pump is equipped and can now be utilised as a water supply. The privilege of enjoying this precious resource now becomes the responsibility of the user; the water down there is neither guaranteed indefinitely nor is it there to be wasted. It is important to have, at least, a basic understanding of the specific groundwater system from which a specific borehole(s) is tapping.

This brings us to the concept of the water balance: what comes in has to be equal to what goes out; otherwise we are left with a deficit. By estimating how much groundwater is available for abstraction without depleting the resource and, as a consequence, lowering the water level, it is possible to ensure a long, safe supply for future use. One of the methods one can use to arrive at a sustainable pumping regime is to do a pumping test. The objective of a pumping test is to provide recommendations to ensure that the abstraction will be in equilibrium with nature: that recharge to the borehole is equal to or less than discharge.

Depending on the intended use and required volume of groundwater, the hydrogeologist will suggest a time duration for the pump test. For instance, a borehole supplying domestic water to a household will have a shorter duty period than an irrigation borehole or municipal supply borehole. As a result, the type and length of the test performed on a borehole for domestic use will be shorter than the test on a borehole for irrigation use. Time durations vary from 6 hours to 72 hours.

Water is the soul of the earth.
W.H.Auden

Typical volume requirements for different users

Small household, domestic use	1 L/s
Handpumps	>0.2 L/s
For irrigation (10 ha)	10 L/s
Municipal wellfield	30-100 L/s

WET FACT

The potential yield of an aquifer is mainly a function of two things, namely geology and aquifer parameters (e.g. porosity, permeability, transmissivity and recharge). Other factors that determine the volume of water that can be safely abstracted from a borehole are user-specific needs and the size of the pump.

Different types of pumping tests can be undertaken. An article in *Farmers Weekly* summed it up as follows:

Test pumping consists of pumping a borehole at a specified rate and recording the water level (and therefore the drawdown) in the pumping well as well as in nearby observation boreholes at specific time intervals. When these measurements are substituted in appropriate flow equations, certain hydraulic parameters can be calculated. These parameters, together with qualitative assessment of discharge-drawdown characteristics, are then used for the assessment of a recommended yield of the boreholes and/or aquifers.

There are three primary types of borehole yield tests commonly used by hydrogeologists, i.e. step test, constant rate test and a recovery test. Prior to any test, a calibration test exercise is carried out to adjust and calibrate the pumping equipment at various discharges.

Step test – During this test the pump rate is increased in steps at regular intervals. For example, a borehole may be pumped at a rate of 1 000 L/h for a period of an hour and increased thereafter to a rate of say 2 000 L/h for the next hour and so on for several more steps. This type of test is particularly useful to determine the effectiveness of the borehole, but not too useful in determining the long-term sustainable yield of a borehole. In this regard, the constant rate test is more applicable.

Constant rate test – in the constant rate test the borehole is pumped at a constant discharge rate over a period ranging from 8 to 48 hours (or longer) – the length of the test is normally proportional to the expected yield and importance of the borehole. The discharge is kept constant for the duration of the test, and water levels are recorded in the pumping borehole as well as observation boreholes (if any). The time-drawdown data obtained from the test is then analysed for quantitative (estimation of transmissivity, storativity and hydraulic parameters) and qualitative analyses of borehole and aquifer response to pumping. The analyses provides useful input to assess the sustainable yield of individual boreholes, and the potential of aquifers. Hydrogeologists are trained to use different mathematical equations to estimate a sustainable yield.

Recovery test – in this test, recovering water levels are measured in the pumping borehole immediately after the constant rate test, when the pump is switched off. This recovery test is very useful in qualitatively assessing the pumping effect and possible dewatering of aquifers that may result due to the limited extent of an aquifer. Furthermore, the recovery test will indicate the level to which the aquifer is actually dewatered by measuring the residual drawdown after the borehole was allowed to recover.

Obviously one will need a borehole to be tested. Then one will need a pump, a waste pipe to divert water away from site, manual and/or electronic dataloggers, time watches, pen and paper and (last but not least) a hat and a chair. It is preferable to have a hydrogeologist on site. This is not an exercise for one person, so there will be some technicians, possibly the driller, general labourers or even students to assist with the test.

To summarise, the following are the simplified steps of a pumping test:

- Measure static water level in borehole.
- Start pump for test. Make sure outlet of waste pipe is placed far enough from borehole, so as to not influence test.
- Measure water level drawdown at specific time intervals, as well as the discharge rate.
- Switch the pump off after pre-determined time.
- Measure water levels at specific time intervals as levels recover towards initial rest static level.

The recorded data is then interpreted with a relevant interpretation method; mainly considering slope of a graph, difference between static water level and pumped water level as well as the elapsed time of the test. After this interpretation a hydrogeologist can recommend a sustainable yield for that specific borehole. It is important to conduct a proper pumping test before commencing use of the borehole; neglecting to do so will end up in disaster – and a 'dry' borehole.

Can a borehole just be pumped indefinitely?

A flat-tape water level meter uses a flat 'measuring tape' to transmit a signal to a buzzer when water is encountered.

A safe yield was recommended for the borehole, so does that mean that the borehole can just be pumped indefinitely? No, unfortunately not. Constant measuring of the water level in the borehole is required to decide if the aquifer can really cope with this disturbance in natural equilibrium or not. This monitoring of the water level is relatively simple and can be done manually or with an electronic datalogger.

The measured data is then plotted on a simple X-Y graph, and steps can then be taken if needed, especially when the water level seems to drop too fast and/or too deep. It is impossible for a hydrogeologist to predict beyond doubt what the behaviour of the aquifer will be after abstraction starts. Chapter 4 take a more in-depth look at groundwater monitoring.

Can we run out of groundwater?

Groundwater supplies are naturally replenished, or recharged, by mainly rain and snow melt. In some areas of the world, people face water shortages because groundwater is used faster than it is recharged. Under natural conditions, without human activity, there is a balance between the amount of water entering an aquifer and the amount that is removed. In many areas of the world, groundwater is being pumped out faster than it is being replaced – this leads to groundwater depletion.

In essence, we can run out of groundwater at a specific moment in a local aquifer. This happens when groundwater depletion occurs due to over-abstraction. The good news is that, in the long run, the aquifer will replenish naturally if abstraction is ceased.

Hydrogeologists can calculate the volume of recharge to a specific aquifer. This helps them to make recommendations to current and future groundwater users of the aquifer regarding a sustainable yield and to ensure fair distribution of the water available.

Can neighbouring groundwater users affect one another?

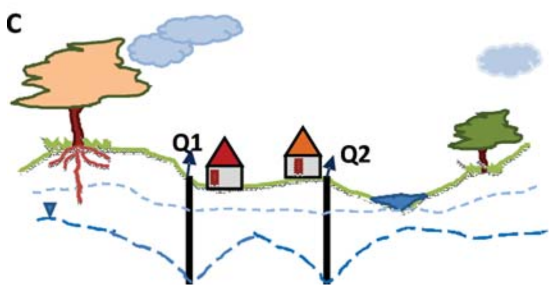


Diagram A – Boreholes are not pumped, therefor water level is static and follows topography. Groundwater connected to stream and vegetation.
Diagram B – Borehole pumps are switched on and pumped at rates Q1 and Q2. Cones of depression form in immediate vicinity of boreholes. Groundwater still connected to stream and vegetation.
Diagram C – After continued, long-term pumping, the regional water level drops. Cones of depression intersect. Groundwater not connected to stream and vegetation anymore, resulting in reduced streamflow and perished vegetation.

Fights – some ending in ugly court battles – between water users accusing each other of stealing each other's water is not a new thing. Today, thanks to science, it is actually possible to indicate exactly how much influence one groundwater user can have on another.

To understand if and how far one user's influence can reach, we need to understand what exactly happens when we switch on a pump in a borehole. From the diagrams it is clear that first there is an impact on the water level in the immediate vicinity of the borehole, and then the cone expands wider. The shape and extent of this cone of depression is dependent on the pump rate, the geology and the aquifer characteristics. In an aquifer with a low transmissivity the cone of depression will be narrow and deep, but in an aquifer with a high transmissivity the cone will be shallow and wide.

To influence a neighbouring groundwater user, the cone of depression a borehole creates needs to be wide/far enough to have an impact on the water level in the next user's borehole. It is possible to calculate the radius of influence and therefore support or deny claims of an upset groundwater user.

Groundwater contamination

What is the connection between groundwater and land use? Why do we need to be concerned about groundwater in planning for a community or municipal area? Since groundwater gets into the ground from the land surface, it makes sense that what happens on the land surface has an impact on the groundwater. In fact, it can affect both groundwater quality and quantity. Many land use activities have the potential to impact the natural quality of water, as shown in the table on the next page.

Place of origin	Potential groundwater contamination source			
	Municipal	**Industrial**	**Agricultural**	**Individual**
At or near the land surface	Air pollution Municipal waste Salt for de-icing streets Runoff from streets and parking lots	Air pollution' Chemicals storage and spills Fuels storage and spills Mine tailings	Air pollution Chemical spills Fertilizers Livestock waste Storage facilities and landspreading Pesticides	Air pollution Fertilizers Detergents Motor oil Paints Pesticides
Below the land surface	Landfills Leaky sewer lines	Pipelines Underground storage tanks	Underground storage tanks Poorly constructed or abandoned wells	Septic systems Poorly constructed or abandoned wells

Land use activities that have the potential to impact groundwater quality.

Groundwater contamination occurs when man-made products such as petrol, oil and other harmful substances get into groundwater supplies and cause it to become unsafe and unfit for human use. Sources of groundwater contamination include storage tanks, septic systems, waste sites (hazardous and domestic), pesticides and many more.

If not managed properly the leachates from landfills can pollute groundwater sources.

A waste site that was not designed properly may leach contaminants into the ground that could end up contaminating groundwater. Petrol may leak from an underground storage tank into groundwater. Fertilizers and pesticides can seep into the ground from application on farm fields, golf courses, or lawns. Intentional dumping or accidental spills of paint, used motor oil or other chemicals on the ground can result in contaminated groundwater. The list goes on and on. Groundwater quantity can also be impacted by a number of land uses, particularly population growth. As the population increases, there is an increased demand for water to supply new homes, businesses and industries.

As communities grow, land is paved over for roads, houses, shopping centres and parking lots. These land uses do not allow precipitation to recharge into the subsurface. Instead the water runs off into lakes, streams and wetlands, picking up contaminants as it goes. The result is threefold:

- First, there is less recharge to groundwater, thereby reducing the amount of groundwater that can be withdrawn from the aquifer at the same time that demand for water is increasing.

- Second, more runoff during precipitation events means more flooding than was the case before development. That water has to go somewhere. Those living near surface waters may find flooding of their properties that didn't occur before.
- Third, as precipitation runs off the land, it may pick up fertilizers or pesticides from lawns, golf courses or farm fields. It may pick up oil and other waste products from streets. This non-point source pollution can serious degrade the quality of the runoff as it moves towards a stream.

Can we prevent contamination? Unfortunately, many activities on the land surface cause groundwater contamination to some extent. We surely can prevent contamination of groundwater resources, but that could mean that no or restricted industrial and urban development can take place in the future.

In South Africa, the industrial and agriculture sectors can cause groundwater contamination. It is not only the large industries that pose a threat to groundwater quality. Small businesses and even individuals could be busy on a daily basis with activities that pose a threat to groundwater quality. It is therefore encouraging to note that there are campaigns to make small business owners, in particular, motor repair shops and car wash outlets, aware of the potential impacts of their activities on groundwater resources. Practical tips and advice are provided so that the business owner is able to have a 'groundwater-friendly' business set-up.

To most economical as well as environmental sustainable option would be to find ways not to only minimise groundwater pollution, but also implement groundwater resource protection measures. Groundwater moves so slowly that problems take a long time to appear. Because of this, and because it is so expensive to clean up a contaminated aquifer (if it is possible at all) it is much more preferable to prevent contamination from happening in the first place. For example, leaking underground storage tanks can be sited in locations and designed to limit leachate migration into the underlying groundwater; the impacts of spills of hazardous materials reduced by restricting access to recharge areas and sewer systems' infrastructure constructed properly and maintained to prevent the leaking of bacteria, viruses and household chemicals into the groundwater.

WET FACT

Groundwater dissolves many different compounds, and most of these substances have the potential to contaminate large quantities of water. For example, one litre of petrol can contaminate 1 000 000 litres of groundwater. In many cases, the problem is only noticed long after the aquifer is contaminated.

GROUNDWATER AND GEOLOGY

Groundwater does not only play a role as a potential water resource. Engineers must consider groundwater when planning any kind of structure, either above or below the ground. Ignoring the effect of groundwater on slope stability can be both costly and dangerous. Geologists, on the other hand, see groundwater as a major force in geological change. They also know that the movement of water through underground geologic formations controls the migration and the accumulation of petroleum and the formation of some ore deposits.

CHAPTER 3: BUSTING MYTHS

Much of South Africa's development has been as a result of water. The country's ancient communities made their migratory routes along the paths of rivers and fountains and knew the secrets of the landscape, and where to find hidden water sources. The sea explorers of days gone by could not pass the Cape on their journey; for the splendour of the scenery but mainly for the presence of sweet, freshwater springs on Table Mountain. As people moved further inland, it was water that determined their route. Towns and settlements grew around the presence of springs and fountains.

As in other parts of the world, the past 200 years have seen some changes in the ways we use groundwater. These changes have mainly been driven by the agricultural, mining and industrial industries of the nineteenth century. Prior to 1956, the legislation governing groundwater use was almost non-existent, and it was only after the promulgation of the National Water Act in 1998 that groundwater started taking its rightful place in legislation and policy.

After going through the main phases of siting and drilling, then quantification, expanding activities and now integrated management, the small- yet competent practicing group of hydrogeologists are placing an emphasis on groundwater quality, hydrogeological processes and sustainable use within an integrated environment.

TIMELINE OF GROUNDWATER DEVELOPMENT IN SOUTH AFRICA

1860s – The first recordings of windpumps in the country were around Graaff-Reinet and the 1869 census a 'windmill for irrigation at Adendorp', near Graaff-Reinet was recorded and the following year 'two windmills for irrigation' on the nearby farm of Buffelshoek were reported.

1874 – The first imported wooden windpump was set up on the farm of PJ du Toit of Hopetown.

1880 – The first imported drilling machine arrived in South Africa.

1892 – Thomas Bain wrote the first hydrogeological report in South Africa, *Report on the prospects of water boring on Government Ground in Bushmanland.*

1896 – The first imported steel windpumps were distributed through two firms in South Africa

1898 – Zuurbekom pumping station, in the North West Province, was installed and delivered up to 28 million litres a day to the Witwatersrand.

1904 – A Drilling Division was established in the old Transvaal.

1913 – Alex du Toit published a report, ***The geology of underground water supply with special reference to South Africa***.

1920 – Alex du Toit joined the Union Irrigation Department as a water geologist and, in doing so, probably became the first hydrogeologists in the country.

1924 – By this time where were 115 active drilling machines in South Africa.

1936 – The Geological Survey started using geophysical method (magnetic and electrical resistivity) for the siting of boreholes.

1945 – The Council for Scientific and Industrial Research (CSIR) was constituted by Parliament.

1946 – First geochemistry report published by

CW Bond, A geochemical survey of the underground water supplies of the Union of South Africa with particular reference to their utilisation in power production and industry.

1950s-1960s – Intensive geophysical investigations were carried out on mine dewatering, subsidence and sinkhole formation.

1956 – The Water Act of 1956 superseded the Irrigation and Conservation of Water Act of 1912. State control was introduced over the abstraction of groundwater for the first time. Subterranean Government Water Control Areas were established for local groundwater use areas.

1957 – The first Subterranean Government Water Control Area (SGWCA), the Uitenhage SGWCA, was proclaimed.

1958 – Schonland Research Institute was founded as the Nuclear Physics Research Unit to focus on isotope research.

1960s – Mr Johannes Roelf Vegter becomes the first formal groundwater lecturer at the University of Pretoria, in the Geology Department. He lectured under-graduates while mentoring post-graduate students. The only other groundwater training in South Africa was taking place at that stage at Rhodes University under Andrew Stone.

1969 – Minister of Water Affairs (Fanie Botha) appoints a Committee of Enquiry into the groundwater situation in South Africa. A report was produced with the following recommendations: a) That the interaction between groundwater exploitation and land use practices be researched; b) That a coordinated programme of long-term recording of water levels and groundwater be started; and c) That the hydrogeological characterisation of the country's geological formations initialised.

1970 – This year was declared National Water Year and fuelled interest and growth in the groundwater sciences, among others. Enslin produced an insightful report on groundwater recharge, stating that "approximately 2 500 million m^3 groundwater could be developed in future."

1971 – The Water Research Commission (WRC) was established following the promulgation of the Water Research Act.

1974 – The sub-department Geohydrology was set up by the WRC within the Geology Department of the University of the Free State (UFS)

1975 – The Institute for Groundwater Studies is founded at the UFS under Prof FDI Hodgson. Dr Gerrit van Tonder was one the first students to study under Hodgson at the newly-established institute

1977 – The Groundwater Division of the Geological Survey was transferred to the Department of Water and Sanitation (DWS).

1978 – An association of scientists, consisting mainly of hydrogeologists and technicians in the Geological Society was formed in November, i.e. the Groundwater Division of the Geological Society of South Africa.

1979 – The Borehole Water Association of South Africa was founded.

1985 – The Institute for Groundwater Studies combined training and research functions, and now did both at the Institute.

1993 – Hydrogeological mapping of the country starts. Vegter publishes a set of national maps and explanatory brochures for WRC and the DWS.

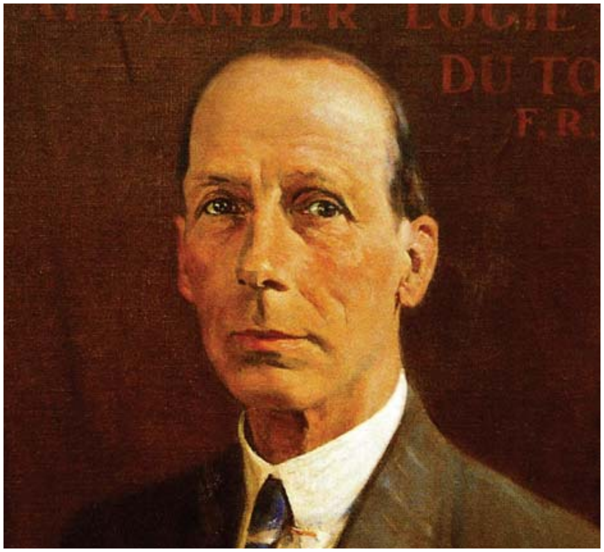
1995 – The first attempt to provide a synoptic and visual representation of groundwater resources of South Africa is made by Vegter.

1997 – A South African Chapter of the International Association of Hydrogeologists (IAH) is established.

1998 – The Drilling Contractors Association of South Africa is founded. The new National Water Act is constituted.

2003 – The DWS commissioned a project to a consortium of consultants to carry out the Groundwater Resource Assessment. The programme comprised two phases and some of the main outputs include quantification of aquifer storage in South Africa, a groundwater planning potential map, recharge quantities as well as the classification of aquifers and water use. The project was completed in 2005.

An old cable tool drill-rig in the Free State.



Alex du Toit.

Busting myths around groundwater

We cannot see groundwater except where there is a spring or a flowing artesian well. Because of its hidden nature, groundwater has historically been viewed as mysterious by many people. With our current knowledge of geology and the laws of physics it is actually possible to provide logical explanations of how much water there is, how it is stored and how it moves in the subsurface. Still, there are quite a few misconceptions and even myths around groundwater out there.

Groundwater straight from the aquifer.

> *If there is magic on this planet, it is contained in water*
>
> *- Loren Eiseley*

Misconception	Naked, wet truth
Groundwater flows in big rivers and dams underground	Water sometimes flows in cavities and solution channels in limestone areas, but most of the time it flows in tiny fractures, fissures and open pore spaces in the rock
Groundwater is dirty and you cannot drink it	Even though groundwater comes from under the ground, it is usually clean and clear! The overburden and/or alluvial deposits act as a filter and the longer the water spends underground, the cleaner it actually gets
Groundwater cannot be polluted, it is too deep under the ground	Unfortunately, groundwater can be polluted. Investigations are done continuously to determine flow paths of polluted water that enters the subsurface via infiltration/leachate and pollutes the groundwater. At a locality where a non-permeable layer, e.g. clay, is present, the pollution can be 'trapped' as it moves down from the surface
Groundwater and surface water are separate systems	Groundwater contributes to streams, especially in dry periods. When streams are flowing in the dry season, chances are good that most of that water comes from groundwater. In the wet season, the running stream will then again replenish the groundwater.
Groundwater is not sustainable	Various groundwater supply schemes in South Africa (and the rest of the world) contradict this statement. Not only is groundwater sustainable, it is a cheaper system to develop than surface water
Once pumped out, the groundwater is gone forever	Groundwater is a renewable resources, although in some places the rate of replenishment is very slow. Groundwater is part of the hydrological cycle, and therefore, water will enter the groundwater system again. We need to manage our groundwater sustainably, however, and make sure that we do not take out more groundwater than can be replenished.

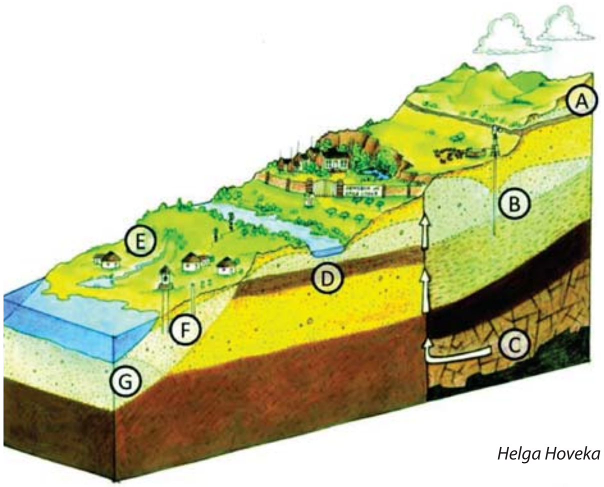
Turning bad news into good news

Compared to all water on the Earth, the available freshwater is only a very small portion. As populations continue to grow worldwide, and the demand for water increases, the only sensible option is to use all available water sources conjunctively, in the most optimal manner possible. We must never forget that we have one hydrological cycle and one Earth.

Good news	Bad news
There is a lot of freshwater in the world	The freshwater is not always located where man needs it
Water is free from nature	Infrastructure is required to treat and deliver the water and this can be expensive
In many areas, water is easily accessible at a low cost	People assume it will always be available and often take it for granted
Nature is constantly recycling and purifying water in rivers, lakes and groundwater systems	Man is polluting water faster than nature can recycle it
There is a huge amount of water underground	Man is using this water faster than nature can replenish it
Around 7 billion people have access to safe water	Around 1 billion do not
Millions of people are working their way out of poverty	Generally, wealthy people use more water
The pace of industrialisation is increasing	A growing industry will increasingly require more water
Industry is becoming more efficient in its water us	Many industries are still using water unsustainably.
Awareness of water issues is increasing	Translating awareness into action can be slow

Groundwater is a sustainable resource for many communities in South Africa.

Groundwater is available everywhere, but not always in usable quantities. However, generally, it is much cheaper to develop a groundwater resource within a 2 km radius from potential users than to lay a pipeline from the closets dam or even build a dam. Groundwater infrastructure is relatively cheap and can be put in place much faster than surface water infrastructure. In some places in the country the available groundwater is already being utilised, but in the majority of areas in South Africa the groundwater resources are still underutilised.



Helga Hoveka

This diagram shows various groundwater flow systems contributing to the value of groundwater to society:

a) Seepage from perched aquifer sustaining ecosystems
b) Abstraction from aquifer for agriculture
c) Deep circulating groundwater feeding hot spring recreation area via fault
d) Groundwater contributing to river flow and ecosystems
e) Gravity fed springs and wetlands
f) Dug wells from shallow aquifers
g) Groundwater flux to ocean sustaining ocean ecosystems and preventing salinization of the aquifer

SPRINGS – THE EYE TO THE UNDERGROUND

Several place names in South Africa reflect the presence of springs.

Springs have captured the imagination of scientists, travellers and philosophers for thousands of years. Many of the earliest ideas about the hydrological cycle were actually inspired by people trying to understand the source of spring water. Springs are the most obvious – and sometimes the only – evidence of an underground water resource. Very often these natural wonders were the place where exploring travellers would settle or at least stay over to refresh themselves and their animals.

Most of the water emerging from springs are meteoric in nature: that is, it originally fell on the surface of the Earth as rain or snow a very long time ago. At hot springs near active volcanoes, some of the water may have originated from magma, molten rock that also contains dissolved substances, such as water. As magma cools and crystallises in the Earth's crust, it releases much of this water.

A spring is actually a simple groundwater system, comprising:

- A recharge area where water enters the subsurface
- An aquifer or set of aquifers through which the water flows
- A discharge point where water emerges as a spring

Spring - The emergence of groundwater at the land surface, usually at a clearly defined point; it may flow strongly or just ooze or seep out
– Groundwater Foundation

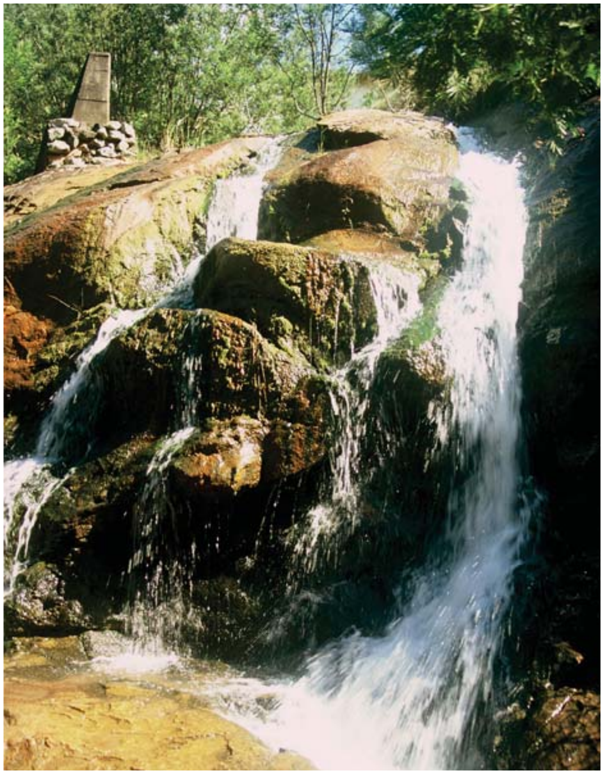
The existence of a spring can be described as follows:

- Infiltrating water reaches a low permeability zone/ barrier zone and is unable to move downward fast enough under the influence of gravity.
- The water is forced to move laterally/sideways until it intersects the land surface where erosion has lowered the topography to the water's level (e.g. on the side of a mountain slope) or the low permeability zone reached the land surface.

A range of geological structures and topographic features can direct water to the surface and form a spring. Many seeps and even wetlands are associated with topographic depressions where the water table intersects the Earth's surface.

What is a spring?

For many people, springs are the most obvious and interesting evidence of groundwater. Spring water also has practical uses. For example, springs have played a role in determining where humans have chosen to settle. Spring water is also associated in the public mind with exceptional quality, and bottled spring water is a booming business. Spring waters, particularly those from mineral and hot springs, have long been believed to possess therapeutic and medicinal value.



Haenertsburg spring.

How does a spring form?

Water infiltrates into the ground to become groundwater. It eventually drains out lower in the landscape under the influence of gravity. Such discharges are known as springs.

The existence of a spring requires that below the surface, the infiltrating water encounters a low permeability (or 'slow-flow') zone, and is unable to continue to move downward as fast as it is supplied at the surface; as a result, the water spreads laterally until it intersects the land surface.

A range of geological structures and topographic features can direct water to the surface to form a spring. Many seeps and small springs are associated with topographic depressions where the water table intersects the Earth's surface. Larger springs are usually formed where geological structures, such as faults and fractures, or layers of low-permeability material, force large amounts of water to the surface.

The volume of water that flows from springs depends on many factors, including the size of the openings within the rocks, the water pressures in the aquifer, the size of the spring's catchment area, and the amount of rainfall the catchment receives. Human activities can also influence the volume of water that discharges from a spring; groundwater abstraction in an area can reduce the pressure in an aquifer, causing water levels in the aquifer system to drop and ultimately decreasing the flow from the springs.

Thermal springs are ordinary springs except that the water is warm and, in some places, even hot. In such areas water migrates slowly to considerable depth, warming as it descends through rocks deep in the Earth. If it then reaches a large opening (e.g. a fracture) that offers a path of less resistance, it may rise more quickly than it descended. Water that does not have time to cool before it emerges forms a thermal spring.

The temperature of spring water is related to the amount, rate, circulating depth and flow path of the groundwater. The deeper the water flows, the hotter it will be due to temperate increases in the Earth's surface. If groundwater speeds are low and the springs are small, then most of the heat will be conducted through the rocks and the water will remain cold. On the other hand, if the springs are large, then the water will still be cold because the volume of water is too great to be sufficiently warmed. At warm springs the water penetrates deep enough through rock openings to be heated by the ground's natural geothermal gradient – the Earth gets warmer with depth at a rate of around 20 to 40°C per kilometre.

Springs provide us access to water that has reacted to rocks in the subsurface from far-away regions, and in some cases, distant periods of time. Spring water can, therefore, provide us with information about some subsurface geological and hydrological processes. In regions with no boreholes and no reliable borehole information, spring water may be the only source of information we have about the subsurface.

The water's age refers to the amount of time that the water spends in the subsurface before emerging at a spring or other surface point. Being able to date groundwater is important because the dates help scientists and water resource managers to determine recharge rates, and better calculate the direction and velocity of groundwater flow. It further helps to predict the contamination potential of the aquifer and the time that is needed to flush the contaminants through the groundwater system.

We can estimate water ages with chemical tracers, provided that we know what exactly the behaviour of the tracer is like in the subsurface. One example of such a useful tracer is tritium (3H), a radioactive form of hydrogen. Tritium is unstable and decays spontaneously to helium-3 through the ejection of a beta particle. The half-life of tritium is about 12 years. Tritium readily cycles through the hydrological and biological components of the environment. Tritium is heavier than ordinary hydrogen, and therefore water that contains tritium evaporates at a slightly slower rate than water containing only hydrogen-1. Tritium occurs in very small quantities naturally, being produced in the upper atmosphere by cosmic rays. Nuclear weapons testing during the 1950s and 1960s created relatively large amounts of tritium in the atmosphere that can be detected in the groundwater that was recharged during this period. Therefore, by simply measuring the relative abundance of tritium and helium produced by the decay of tritium, we can determine the age of relatively young water.

For very old groundwater, carbon-14 dating is often used. As water percolates through the rock and soil from precipitation, it dissolves carbon. This carbon includes small amounts of radioactive carbon-14, which originally formed in the upper atmosphere as a result of nuclear reactions between cosmic particles and terrestrial atmospheric gases. Because the half-life of carbon-14 is long (5 730 years), this method is useful for determining the age of groundwater between 1 000 and 30 000 years old.

The occurrence of most springs is controlled by the structure of the rock formations. Typical geological situations (simplified) for the occurrence of springs are as follows:

- **Saturated soils over impermeable bedrock**: A spring can occur if impermeable bedrock prevents downward flow. The size of upslope area, the soil thickness and the frequency of precipitation will determine whether the spring flows year-round.
- **Permeable and impermeable rock formations**: Where rock strata have been tilted and eroded, it is possible for precipitation falling on one side of a hill to contribute to spring or seepage flow on the other side. Finding the origin of recharge to a spring can be important if the source is to be protected.
- **Barrier of intrusive rock**: A spring may result from the occurrence of impermeable intrusive volcanic rocks. In this case, water emerges as a spring, flows as a stream where the rock is

impermeable, and then seeps below the surface when it reaches permeable rock, before seeping into a stream in the valley.

- **Joins and fractures**: In igneous rocks such as granites, water moves through weathered zones, joints and fractures. A spring can occur when an impermeable layer causes water to reach the surface.
- **Geological fault as conduit**: In situations where rocks are fractured along the line of a geological fault, it may result in a spring supplied from an aquifer in contact with the fault. Depending on the topography of the land surface, there could be a line of springs related to the same fault.

Kuruman fountain in the Northern Cape.

Maloney's Eye, the sources of the Magalies River, which empties a million litres of water an hour through the dolomitic hills.

A REPORT TO THE *COMMIMSSION DES EAUX SOUTERRAINS* IN 1938 BY THE SOUTH AFRICAN ACTING SECRETARY OF MINES, MR MULLER, LISTED THE LARGEST SPRINGS IN THE COUNTRY:

- Gerhardminnebron, near Potchefstroom, 100 000 m³/day
- Steenkopjes, near Krugersdorp, 50 000 m³/day
- Pretoria springs (the Fountains), 27 000 m³/day and Rietvlei, 13 500 m³/day
- Eye of the Mooi River, 50 000 m³/day
- Bank spring, 50 000 m³/day
- Eye of Schoonspruit, 45 000 m³/day
- Bothelheletsa, Kuruman, 45 000 m³/day
- Kuruman spring, 12 000 m³/day
- Manyeding, Kuruman, 12 000 m³/day
- Uitenhage, 5 000 m³/day

It was also reported that some of the major towns in the country obtained their water from groundwater. These were Amanzi Estates near Uitenhage, where boreholes yielded about 1 000 m³/day and Bon Accord, north of Pretoria, where pumping from 3 to 4 boreholes yielded around 1 000 m³/day. Some boreholes in the gravels of the Hex and Berg rivers also yielded around 1 000 m³/day for irrigation of fruit trees.

FAMOUS SOUTH AFRICANS SPRINGS

In the semi-desert region near Murraysburg, a perennial fountain on the farm ***Toorfontein*** (meaning ***magic fountain***) bubbles out of the ground and runs over the rocks even in the severest of droughts. For this reason the early settlers in the area considered it to be magic, and it became known as the ***toorfontein***. In time, the farm developed around it and took the same name. To this day, the magic fountain still delivers its cool, freshwater.

Kuruman is the main town in the Kalahari region, and is known as the Oasis of the Kalahari. The town is blessed with a permanent source of water. Gasegonyane (meaning ***little water calabash***), or ***Die Oog*** (meaning ***the eye***) delivers 20 million litres of crystal clear water daily to the town's approximately 10 000 inhabitants. The Eye is also the source of the Kuruman River, which flows through the hot, dry Northern Cape and provides water for irrigation of about 250 ha for agriculture.

Another view of the Eye of Kuruman.

The **Dinokana Lower-Eye** in North West Province is a cultural and religious gathering place for local communities. Groundwater abstraction in the Upper-Dinokana is impacting on this spring, and it is already flowing at a much lower rate than in the past, with people fearing that this sacred place will soon die away.

The South African landscape also features a number of hot spring. Perhaps the best known hot springs in South Africa are those of Bela-Bela (formerly Warmbaths), in Limpopo. Here you find strong mineral springs that flow out of the Earth at a rate of 22 000 L/hour with a temperature of 52°C. This water gave rise to the establishment of the town of Warmbaths. The water from these springs is rich in sodium chloride, calcium carbonate and other salts that are highly beneficial to those suffering from rheumatic ailments.

A well-known holiday resort has developed around the Bela-Bela hot springs.

Die Oog (meaning the eye), in Limpopo, is historically one of the first hot spring resorts developed at a natural hot spring in the Waterberg, and offers a relaxing Bushveld holiday experience. The spring water, originating from the natural spring on the premises, has a temperature of 42°C while the temperature in the pools is 32°C, after surface cooling has taken place.

The discovery of **Avalon hot springs** near Montagu, in the Western Cape, dates back to the early history of the Cape Colony, when the first European trekkers spread out to locate the easiest gradients for their lumbering wagons over the mountains to the first plateau beyond. Naturally, they sought the river routes, and the most accessible of these passes found favour. Cogmanskloof, as it is now known, is about the easiest route of them all in the west, until midway in the pass a most formidable barrier is encountered, in the shape of a tall rock that juts out from the regular formation on the right bank. It stands among local tradition that one of the earliest trekkers injured his hand while extricating his wagon that had become jammed in between rocks in the bed of the river while negotiating the natural barrier. When the hand started to fester, the party camped on the first expanse of veld they reached – now the Montagu Commonage. The water there had a most unusual taste, and all who drank it found it strangely invigorating. Dipping his wounded hand into the water repeatedly, the trekker rejoiced in having his would quickly healed, and the fame of the fountain was established. It appears to have been known, and visited, by earlier nomadic communities of the Khoi and San long before the appearance of European settlers.

In 1828, Pieter de Wet built a house near Buffelsvlei. One morning, he was surprised to find that some of his cattle had gone missing during the night. He set out looking for them, and to his amazement came upon a place where he saw steam rising from a concealed marsh. Thus he discovered the eye of the Aliwal North spring was discovered. He was not the first person to come across the springs – generations of Khoisan and Xhosa had already been using it for hundreds and perhaps thousands of years.

The spa was opened at the springs in 1962. The therapeutic qualities of the water enticed people from afar, and they visited the spa with ailments such as rheumatism and various skin diseases. The concentrate of gas in the spring water is so high that the first restaurant on site was able to maintain its cooking fore from gas funnelled from the springs.

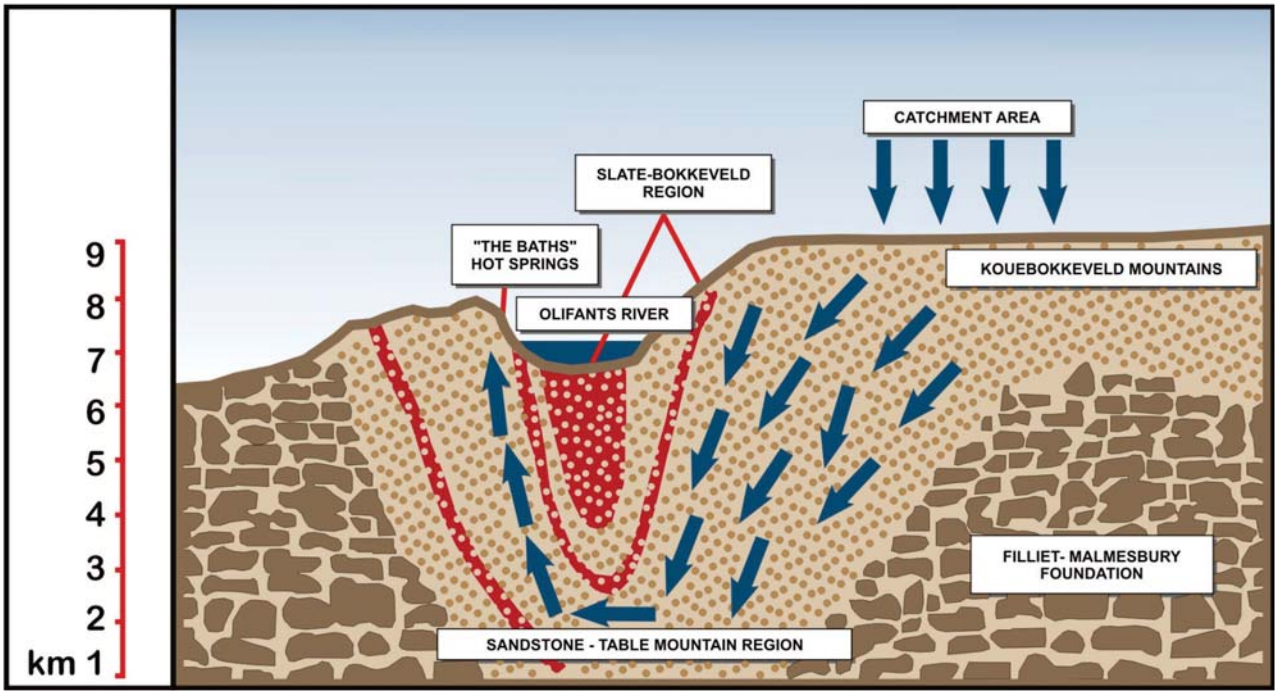
Amidst giant baobabs, acacias and striking red bougainvilleas lies yet another hot water gem. The word ***tshipise*** means ***something warm***, and rightly so, since this spring yields around 230 000 L/day of water around 56°C. Like most of the other hot springs, this spring has been developed as a holiday resort.

The water looked so tempting that none of us could resist, so our horses were turned to graze, our packs were opened, and we had each of us a glorious dip and a clean shirt.

Diary of William Mann, 1840.

The early adventurers venturing into the Overberg found no less than six springs gushing hot water and one cold from a hill at the foot of the Swartberg range. The springs had been used by Khoi pastoralists who lived and grazed their cattle there. In 1709, Ferdinand Appel, was granted 18 ha of land around these fountains on condition that he built baths for guests and lay out a garden. Soon after even important officials from the Dutch East India Company (who ruled the Cape at the time) visited the baths with their ailments. They declared these waters so beneficial that the reputation of the springs soon spread even beyond the Cape. Early in the twentieth century a three-storey spa, with accommodation for 200 guests, was built to exploit this natural phenomenon to the full. In 1946, the complex was destroyed by fire, but the municipality bought the site in 1961 and developed it into a caravan park. A grand hotel, De Overberger, was opened at the springs in 1990. Today, the springs still run as strongly as ever, producing some million litres of warm (50°C) water a day.

The Baths are located 16 km south of Citrusdal, in the Western Cape. The springs are said to have been known to the authorities at the Cape as early as 1739 when accommodation was erected for visitors at the site. Following several changes in ownership, often neglectful, the Baths were bought by James McGregor in 1903. Inscribed on the rocks near the springs are many unsolicited testimonials to their healing powers, some dating from the eighteenth century. Water still flows strongly at this spring at a soothing 43°C.



The Baths near Citrusdal is an artesian well. Water gathers in the Koue Bokkeveld mountains and sinks down through the sandstone until it reaches a depth where the surrounding earth is extremely hot. Pressure builds up, forcing the water under the Olifants River and up the other side, where it emerges in the Kloof at 43°C. The main eye, with several other eyes, deliver 105 000 L/hour of water. The main eye is now encased in a spring vault. The water is crystal clear and of sufficient drinking quality.

BOTTLED WATER – H_20 ON THE ROCKS!

In the general public's mind, spring water is associated with exceptional quality. No surprise then that bottled spring water is a booming business. Market researcher, Shawn Henning, of BMI Foodpack, reports that the South African bottled water market grew by an estimated 33% during 2005, following on a consistent annual growth trend in excess of 20% since 2001.

Spring waters, particularly those from mineral and hot springs, have long been believed to possess therapeutic and medicinal value. But it is the colder waters that end up on the shop shelves. South Africa's first bottled water was produced at the Van Riebeeck plant in Cape Town in the early years of the last century. The plant, whose water is still sourced from one of the purest aquifers in the country, was later owned by SA Breweries but has since reverted into a municipal facility. For a long time there was no competition for Van Riebeeck water as the general good quality of municipal water in South Africa left no desire to buy bottled water.

Then, about a decade ago, South Africans started to become more health conscious and resistant to the idea of chemically-treated drinking water. Accordingly, a commercially viable natural bottled water industry was born, growing at about 50% per annum in its early years to cater for the sudden new thirst for pure water among more affluent South Africans. It had begun to sink in that municipal water comes from large sources such as rivers and dams that are open to pollutants and contamination. Also, this water is distributed, sometimes for very long distances, through ageing pipelines. Therefore, it is essential to use chemicals, such as chlorine, to sanitise such water.

By contrast, natural bottled water (as distinct from manufactured bottled water, which is tap water from which the chemicals have been removed) is sourced from deep underground – in clean catchment areas where access to the public, animals and insects has been sealed off. Natural bottled water is a product of planet Earth's eternal water cycle – which ensures that all of us will eventually drink water that has been through the bodies of enormous dinosaurs. That is because water is neither lost nor made. The water that originally covered the planet billions of years ago is continuously recycled through the processes of evaporation, condensation into clouds and then precipitation back down to Earth. Back on Earth, it either runs off the surface of the ground into rivers and dams, or it seeps, over decades, through the underlying rock and sand into underground cavers or aquifers.

The rock forms a natural filter that removes any manmade or harmful chemicals from the water. Also, microbes that could be harmful to mankind simply cannot survive the length of time it takes the water to filter through the rock. As a result, the water in underground aquifers is generally clean and safe. It does contain some natural minerals such as calcium, magnesium, sodium, potassium, chloride, sulphate, nitrate and fluoride – absorbed from the rock strata through which it has passed. But these are essential trace elements needed by the body and therefore beneficial to humans in the tiny amounts found in natural or 'mineral' water. Excessive quantities of fluoride in water are detrimental to human health, so it is advisable to have groundwater intended for drinking purposes tested. Natural water also contains a few microbes, none of which are necessarily harmful to people. Some of this underground water rises to the surface in the form of natural springs – which is sealed off when used for bottling purposes. Otherwise, natural water is collected by boreholes from deep underground. In both cases, the water is piped over the shortest possible distance – usually no more than a few metres – straight into the bottles. It is not treated in any way, except for filtration to remove insoluble particles such as bits of clay. That is in an ideal world, with bottlers of integrity maintaining spotlessly clean bottling plants and putting the health of consumers ahead of profit (Source: SANBWA newsletter).

Groundwater being bottled at a large scale.

DEFINITION IN A BOTTLE

Bottled water – Water that is packed in sealed containers of various forms and capacities, and which is offered for sale as a foodstuff for human consumption, but does not contain sugars, sweeteners, flavourings or any other foodstuffs.

Carbonated bottled water – Bottled water which, after possible treatment and packaging, has been made effervescent through the addition of carbon dioxide.

Natural mineral water – Natural water that has a substantially constant temperature and mineral and trace element composition acquired from the rock strata through which it has moved.

Natural water – Bottled water derived from an underground formation which has not been modified and has not undergone treatment other than separation from unstable constituents by decantation or flirtation, removal of carbon dioxide, and/or addition of carbon dioxide.

Prepared water – Bottled water that has undergone any treatment acceptable for bottled waters and may originate from any type of water supply.

Spring water – Bottled water sourced from an underground formation from which water flows naturally to the surface of the Earth, and which is collected from the spring or a borehole tapping the underground formation, and which may be classified as a 'natural water' or 'water defined by origin', depending on the treatments undergone.

CAVES – ANOTHER MAGICAL GROUNDWATER LINK

Rainwater infiltrates the soil and slowly dissolves the carbonate rocks until a cave develops.

Several areas in South Africa are underlain by carbonate rocks and are well known for its caves. As a shelter from storms and a safe refuge in times of flight, they have played an important role in humankind's history.

So how do these caves form? Close to the surface but beneath the water table, slightly acidic rainwater that infiltrates the soil slowly dissolves and removes carbonate rock (limestone or dolomite) from pre-existing cracks and fractures in the rocks. This process of cave formation in soluble rock is very slow. Terrains that have dissolution features such as caves or sinkholes are called karst.

The chemical reactions leading to limestone dissolution are provided below:

Water + carbon dioxide ------> carbonic acid

$H_20 \quad + \ CO_2$ --------------------> H_2CO_3

Carbonic acid + limestone -------> calcium + bicarbonate

$H_2CO_3 + CaCO_3$ ----------------------> $Ca + 2HCO_3$

The Cango Caves, one of South Africa's great geological wonders, is located about 30 km from Oudtshorn in the foothills of the Swartberg Mountains. The caves, which extend over 16 km, were formed about 20 million years ago when water seeped through cracks into the limestone, dissolving the rocks and creating a remarkable series of chambers and passageways.

Inside the Sterkfontein caves in Gauteng.

Lani van Vuuren

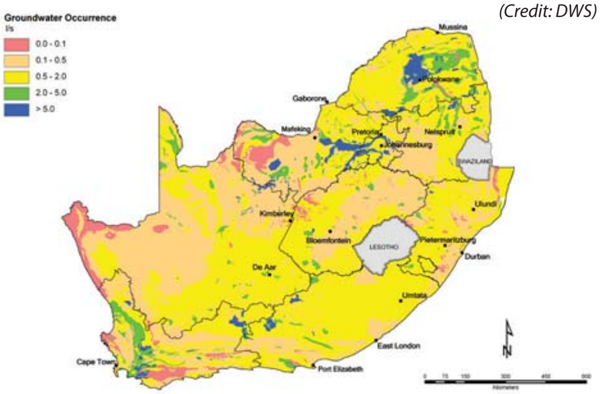
CHAPTER 4: GROUNDWATER USE IN SOUTH AFRICA

In many countries throughout the world the potential of groundwater as a sustainable water supply is underestimated. As a result, this resource is often neglected. This is largely because of its hidden nature, and because of water planners' historic focus on bulk surface water supply.

South Africa is the predominant hard rock groundwater systems only contribute about 15% of the total bulk water supply. Until the promulgation of the National Water Act in 1998 groundwater was largely considered 'private water' i.e. belonging to the person on whose land it was found. Today, however, groundwater is acknowledged as a national asset and an integral part of South Africa's water resources.

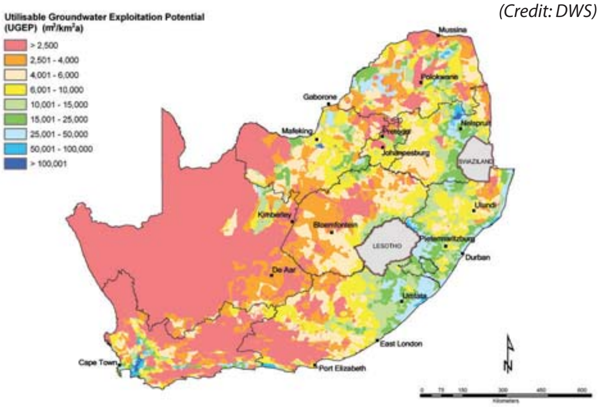
Groundwater has played a major role in reducing the backlog for domestic water supply by half, and it currently contributes between 45% and 60% to domestic water supply. Contribution to rural areas, where the largest part of the basic water services backlog remains, could be as high as 90%.

(Credit: DWS)

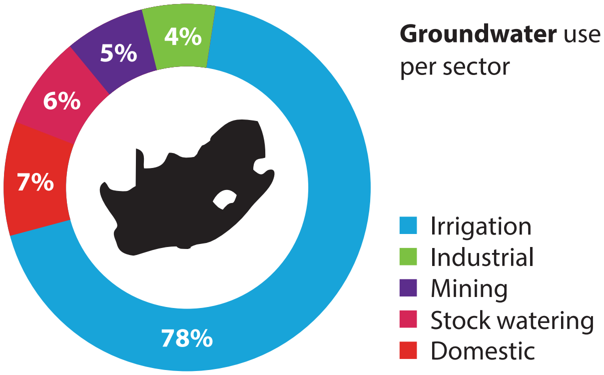


Groundwater occurrence in South Africa.

(Credit: DWS)



The utilisable groundwater exploitation potential in South Africa.



Groundwater use in South Africa per sector.

WET FACT

According to UNEP, agriculture accounts for over 80% of the world's water consumption.

How much groundwater do we have?

Groundwater abstraction is hardly a new practice. Many of South Africa's indigenous communities relied on groundwater for their survival, while the names of many modern-day towns reflect the dependence on early settlers on groundwater. Even big cities such as Johannesburg owe their early survival to the availability of groundwater.

Ten years ago the first attempt was made at a synoptic and visual representation of the country's groundwater resources. In 2003, DWS initiated the Groundwater Resource Assessment Phase 2 (GRA2) project, aimed at quantifying the groundwater resources of South Africa on a national scale.

Some people still believe that groundwater is unfit to drink. However, this is not necessarily true. In many cases, groundwater can be to drink. soil and sand act as a filter, which means that the same water falling onto the surface, infiltrates the ground, and is pumped out the borehole is probably than if the water had remained on the surface. There are some natural conditions that can make groundwater unfit for drinking, however.

The chemical composition of natural groundwater is affected the most by the host rock in which it is found. Therefore, groundwater chemistry will differ from one place to another. For example, groundwater from the shales of the Malmesbury Formation in the southern parts of South Africa is unsuitable for most uses due to naturally high total dissolved salts. Groundwater from granite aquifers often contains fluoride in high concentrations, whereas water from the dolomites is usually good drinking water, but quite hard. Groundwater from springs is used widely to deliver bottled water to consumers. These waters are usually of excellent quality, and rarely needs any treatment. Unfortunately, just like any source, groundwater can be contaminated as a result of human activities.

GROUNDWATER CONTAMINATION

Groundwater contamination is a real, but sad reality. It is serious as most of the time the contamination is irreversible or very difficult to remedy. However, by taking a few precautionary steps contamination can be avoided.

Causes of contamination

We often think of water quality as a matter of taste, clarity and odour. The higher the quality of the water, the more uses it will have. Both groundwater and surface water main contain different constituents, including microorganisms, gases, inorganic and organic materials. The chemical nature of water keeps on evolving as it moves through the hydrological cycle.

How much groundwater do we have?

Total volume of groundwater	235,5 billion m^3
Groundwater resource potential	49 billion m^3
Average groundwater exploitation potential	19 billion m^3
Potable groundwater exploitation potential	14,8 billion m^3
Utilisable groundwater exploitation potential	10,3 billion m^3

Source: GRAII project, DWS 2005

GROUNDWATER POTENTIAL IN SOUTH AFRICA

According to a study by the Department of Water and Sanitation, South Africa has a total of around 50 billion m^3/a potential available groundwater. Now consider that the holding capacity of the Gariep Dam is 5 000 million m^3 (5 billion m^3). That means the resource potential of groundwater in South Africa is worth TEN full Gariep dams.

In total, some 235,5 billion m^3 of groundwater may be stored in aquifers in South Africa. Of course, not all of it is usable and can be abstracted. There are many limitations to the possible abstraction of groundwater for use, for example, restrictions to ensure enough water for the environment (in legislation known as the Ecological Reserve), and restrictions on the maximum level drawdown in dolomitic aquifers due to the hazard of sinkhole formation or avoiding intrusion of saline water.

The groundwater resource potential is the maximum volume of groundwater that can be abstracted per unit per annum without causing any long-term 'mining' of the aquifer system (i.e. without continued long-term declining water levels). It is not equivalent to the sustainable or optimal yield of the system, which normally takes into account issues such as intrusion of poor quality water, practical and cost issues relating to extracting the water, and so forth. The average groundwater resource potential of aquifers in South Africa is estimated, under normal rainfall conditions, at 49 billion m^3/a, which decreases to 42 billion m^3/a during a drought.

When taking into account limitations such as groundwater quality; the potable groundwater exploitation of aquifers in South Africa is estimated at 14,8 billion m^3/a, which declines to 12.6 billion m^3/a during a drought. Nationally, this represents almost a 30% reduction in the annual volumes of available groundwater for domestic supply due to water quality constraints.

Source: The Water Wheel, November/December 2005

Click to view the video.

The quality of groundwater is influenced by various activities by mankind.

The kind of chemical constituents found in groundwater depend, in part, on the chemistry of the precipitation and any other water recharged to the groundwater system. Near the coast, precipitation contains higher concentrations of sodium chloride, and downwind of industrial areas, airborne sulphur and nitrogen compounds can make precipitation acidic.

One of the most important changes in groundwater chemistry occurs in the soil. Soils contain high concentrations of carbon dioxide, which dissolves in the groundwater, creating a weak acid capable of dissolving many silicate minerals. As the groundwater then moves through the rock from the recharge area to the discharge area, it may dissolve substances it encounters or it may even deposit some of its constituents along the way. We can therefore say that the eventual quality of groundwater depends on the composition of the precipitation, the kinds of rock and soil formations through which it flows, the temperature and pressure conditions and possible on the amount of time the water spends in the rock (residence time).

Scientists assess water quality by measuring the amounts of the various constituents contained in the water. These amounts are usually expressed as milligrams per litre (mg/L). Any addition of undesirable substances to groundwater caused by human activities is considered to be contamination. It has often been assumed that contaminants left on or under the ground will stay there ('out of sight, out of mind'). This is simply wishful thinking. Groundwater often spreads the effects of dumps and spills far beyond the site of the original contamination. For example, one litre of petrol can contaminate a million litres of groundwater. Groundwater contamination is extremely difficult to resolve, and at most times impossible to clean up.

WET FACT

Groundwater can become contaminated with substances which occur as a liquid (e.g. oil), or can be dissolved in water (e.g. nitrate) or by contaminants small enough to pass through the pores in soil (e.g. bacteria. These contaminants enter the groundwater system through infiltration from some land use activities and other potential contaminant sources.

But what exactly are those things that contaminate groundwater? Is it really possible that anything we do on the Earth's surface can have an impact on groundwater quality? The answer is a definite 'yes'; most land use activities have an impact on groundwater. Let us investigate a few of them.

There are two main groups of contamination sources, namely human and natural. Human-induced contamination sources include:

- landfill/waste site leachate (metals, total dissolved solids, organics)
- industrial waste (metals, synthetic organics)
- leaky petroleum tanks, pipelines
- vehicles (metals, organics)
- agriculture (fertilizers, pesticides, nitrogen, phosphates)
- sewage (nitrogen, organics, microbes).

Groundwater can also be contaminated due to natural causes. Mineral dissolution, brine seepage and seawater intrusion may make groundwater unfit for human consumption. This natural impact is, of course, linked to the geology and the composition of the rocks that constitute the flow regime of the groundwater at a specific locality.

Filthy water cannot be washed

– African proverb

SALTWATER INTRUSION

Freshwater is less dense than saline water, and tends to flow on top of the surrounding or underlying saline groundwater. Under natural conditions, the boundary between freshwater and saltwater maintains a stable equilibrium. The boundary is typically not sharp and distinct, but rather is a graduation from fresh to saline water known as the zone of dispersion, or the transition zone. When water is pumped from an aquifer that contains or is near saline groundwater, the saltwater/freshwater boundary will move in response to this pumping. That is, any pumping will cause some movement in the boundary between the freshwater and the surrounding saltwater. If the boundary moves far enough, some wells become saline, thus contaminating the water supply. The location and magnitude of the groundwater withdrawals with respect to the location of the saltwater determines how quickly and by how much the saltwater moves. One of the major concerns most commonly found in coastal aquifers is the induced flow of saltwater into freshwater aquifers caused by groundwater development. This is known as saltwater intrusion. When groundwater is pumped from aquifers that are in hydraulic connection with the sea, the induced gradients may cause the movement of saltwater from the sea toward the well. The key to controlling this problem is to maintain the proper balance between water pumped from the aquifer and the amount of water recharging it. Constant monitoring of the saltwater interface is necessary in determining proper control measures.

How do we know when groundwater is contaminated?

It is very easy to see when a river is contaminated; plastic bags and other rubbish may float on the top; water might turn green from algae blooms or fish kills and plant die offs may occur. But how do we know when groundwater is contaminated; it is not possible to see the water underneath our feet?

A nasty odour, bad taste or strange colour could be the first indicators that groundwater quality is not up to standard. Other indicators are:

- Concentrations of certain constituents are above background values
- Anthropogenic (human produced) substance detected
- Concentrations of parameter(s) exceeds water quality standards:
- Primarily concerned with human drinking water quality and also ecological standards

Unfortunately, sometimes the first indication we get that groundwater is contaminated is when it starts to adversely affect people's health. Cholera is one example of an illness that can be contracted from contaminated water.

This is a harsh reality throughout Africa where most people are reliant on groundwater as their sole source of supply, but not protection measures are in place to ensure a good groundwater quality. Problems may be caused by siting on-site sanitation too close to groundwater resources, or by siting boreholes close to contamination sources.

WET FACT

According to UNICEF, one gram of human faeces can contain 10 million viruses, a million bacteria, a 1 000 parasite cysts and 100 parasite eggs.

Can we measure contamination?

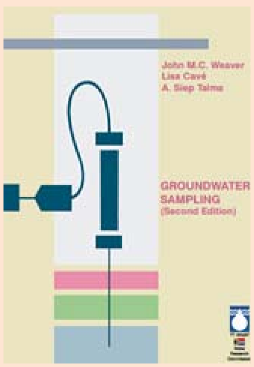
Contamination can be measured in groundwater resources. Water samples are taken at boreholes or springs and then analysed. For reliable results, this analysis should be undertaken by an accredited laboratory. If contamination is expected, then specific constituents could be analysed for in more detail, based on the nature of the potential source of contamination.

Various electronic equipment can be used to take field measurements. These include hand-held, pH, electrical conductivity, dissolved oxygen, redox potential, and temperature meters as well as specialised electronic borehole logging equipment. Once a sample has been analysed and specific contaminants identified, a plan of action should be implemented immediately to aim and rectify the problem.

Unfortunately, in many instances, we detect contamination only after the groundwater becomes unsuitable for it's intended purpose (eg. drinking). Because groundwater generally moves slowly, one activity/person can contaminate groundwater at one point and the contaminated groundwater will follow the flow path in the aquifer towards the point of discharge.

A plastic sampling bottle and handheld pH and electrical conductivity metres for field measurements.

A small 12V pump is used to pump out water to measure pH and electrical conductivity at the wellpoint and to fill a sample bottle.



The document, *Groundwater sampling: A comprehensive guide for sampling methods: Second edition*, by Weaver, Cave and Talma (**WRC Report No. TT 303/07**) provides consistent groundwater sampling techniques that will ensure that all groundwater quality data collected is representative of in situ groundwater quality. Using these techniques will reduce sampling error to a minimum. Groundwater quality data collected according to these described techniques can then reliably be used to evaluate hydrogeochemical conditions. Also consider the national standards from the South African Bureau of Standards (1993), *SABS ISO 5567-11 South Africa Standard: Water Quality – Sampling. Part 11: Guidance on sampling of groundwaters*.

How can we prevent groundwater contamination?

If we are able to prove that many land-based activities have an impact on groundwater quality, does it mean we have to stop all of our activities? Of course not. However, we can go about things differently and prevent or at least minimise some of these impacts.

The availability of groundwater and the suitability of its quality for different uses are intertwined. For example, saline water, which have high solids concentrations, occur adjacent to fresh groundwater almost everywhere. Although water with high salt loads represents huge volumes of groundwater in storage, they are not included in most inventories of available groundwater because of their unsuitability for almost all uses. Groundwater with slightly lower dissolved solids concentrations may be suitable for some uses but not for others. For example, some cattle can tolerate a higher dissolved solids concentration in their drinking water than humans. The classification of water based on total salts is illustrated below.

Classification of water based on total salts

Classification	Total dissolved salts (TDS) mg/L
Freshwater	0 to 1 000
Brackish water	1 000 to 10 000
Saline water	10 000 to 100 000
Brine	Greater than 100 000

A key consideration in managing a groundwater resource is its vulnerability to sources of contamination that are located primarily at and near the land surface. Because of generally low groundwater flow rates, once contaminants have reached the water table, their movement to nearby surface-water discharge areas or to deeper parts of the groundwater-flow system is slow. For the same reason, once parts of an aquifer are contaminated, the time required for a return to better water quality conditions because of natural processes is long, even after the original sources of contamination are no longer active. Groundwater quality remediation projects are generally expensive and usually only partly successful. Groundwater management is actually inexpensive to implement, but still, many a user or water supplier is learning the hard and expensive way. Over-utilisation and contamination of a groundwater resource are irreversible. The simplest management principles are protection and water demand management.

The term 'groundwater mining' or overdraft refers to the situation where groundwater is pumped at a given rate from an aquifer that is not replenished at the same rate through recharge (output >input in water budget). This means that boreholes will eventually dry up, even if only temporarily.

There are endless steps listed in recommendation reports to ensure that proper groundwater management takes place. These steps include data gathering, monitoring equipment, and databases as well as data evaluation. Monitoring and management are easily portrayed as long, difficult processes, but with a simple monitoring system and basic data evaluation all it takes is one logical water manager to diagnose problems and act pro-actively. These seemingly complex issues might be the reason why groundwater monitoring and management have not been as effective as it should be in most parts of the world.

There are a few decision-makers and political role players on different levels of management that start to realise the benefits and necessity of good monitoring and management practices. This combined effort to implement proper monitoring and management have proved over and over again to not only be successful, but also showed decision-makers, and especially political roleplayers, that the long-term economic benefits far outweigh the financial input.

Another roleplayer is elemental to successful groundwater management: the groundwater user. Worldwide trends indicate that the groundwater user will need to play an increasing role to ensure that groundwater is managed properly at a local scale. Awareness and a basic knowledge of groundwater, together with the buy-in of local water managers as well as the community of users are crucial to ensure the sustainable use of the resource.

The challenge is to meet the growing needs from finite water resources, allow for development of industry and settlements, while maintaining the planet's life support system.

THE NEED FOR GROUNDWATER MANAGEMENT

Most people will agree that we need to manage our groundwater resources; just like we regulate dam levels by means of outflow and adapt our water usage when we realise our water source is under stress. The publication, *A framework for groundwater* *management of community water supply*, published by DWS in 2004 offers various information on groundwater management, some of which is highlighted below.

For rural water-supply purposes, there are four reasons why groundwater should be managed (we can also argue these same reasons for domestic and bulk water-supply in urban areas):

- **To prevent the aquifer from being over-pumped**: If an aquifer is over-pumped, a long-term depletion of the groundwater results throughout the entire aquifer. This over-abstraction can negatively affect all users of the aquifer, including aquifer dependant ecosystems.
- **To optimise individual borehole pumping rates**: if individual borehole pumping rates are too high, a localised depletion of groundwater results. Energy is also wasted, since the pumping head is unnecessarily high; and if the water level in the borehole is drawn down to the pump intake, a combination of air and water will be pumped. Pumps can be damaged in this way.
- **To prevent poor quality groundwater from entering the aquifer**: If abstraction from the aquifer is too high, poor quality groundwater can be drawn into the aquifer.
- **To minimise groundwater contamination from surface sources such as pit latrines, animal kraals, fertilizers and dipping tanks**: These surface activities occur widely throughout rural areas and are real threats to groundwater contamination.

Groundwater should be managed in terms of its quantity and quality. This would ensure that the resource is used efficiently, and it would minimise the risk of deteriorating quality or availability. Besides the basic borehole information, such as location, depth, diameter etc., the following data should be recorded on a regular basis:

- **Borehole water levels**: This is to establish whether the aquifer is being over-pumped, and to establish an efficient pumping rate for individual boreholes. In certain areas it may be necessary to monitor water levels of non-utilised boreholes as well as production boreholes. The units of measurement are in metres below ground level, measured to the nearest centimetre. A dip meter, which consists of an electrical cable and a multimeter or a light, is used for measuring borehole water levels. Water levels should be obtained on a monthly basis. In order to establish a routine, however, it may be advisable to collect the data on a daily or weekly basis. The data only needs to be interpreted once or twice a year, depending on the vulnerability of the aquifer to over-utilisation.
- **Groundwater abstraction rate**: This is to relate abstraction to water levels. Abstraction is measured in m^3/day with a flow meter, or by recording the discharge rate and the number of hours pumped per day. In the absence of a flow meter, daily abstraction needs to be monitored. Regular manual flow readings with a stopwatch and container are needed to verify the flow-meter's accuracy.
- **Groundwater quality**: This is to assess whether the aquifer is being over-pumped, and to assess whether any contaminants have entered the aquifer. It may be necessary to analyse for specific determinands or microorganisms on a regular basis (such as electrical conductivity, fluoride, nitrate and faecal coliforms). However, it is important to obtain at last one comprehensive 'background' analysis. The frequency of analyses should largely be based on the ambient groundwater quality.
- **Potential pollutants**: While it is not necessary to collect data on potential sources of groundwater pollution, it is necessary for staff in all institutions involved in groundwater management to look out

for, and report on, potential contamination sources.

- **Rainfall:** it is not necessary to monitor rainfall at every production borehole. Accurate correlation of water level with rainfall is required, depending on the specific monitoring purpose. For Type 2 monitoring, monthly data from the nearest rain gauge station should be used if water levels, or water quality and rainfall, need to be compared.

Groundwater protection

The City of Tshwane takes the protection of its groundwater sources seriously.

Government has invested a lot of money into water treatment, distribution systems and sometimes even monitoring. Today, more and more organisations and individuals are also starting to invest in a vital component of water-supply systems: source protection. All kinds of things can contaminate groundwater. Cattle grazing at a water point can lead to faecal contamination; pesticides used in agriculture can runoff into streams or percolate into groundwater, and waste sites can cause contaminated leachate to reach the groundwater level.

It definitely makes sense to keep sources safe from contamination – sense from an economic perspective and from a health perspective. Let's look at the economic perspective first.

Many contaminants cannot be removed by standard treatment techniques. For example, it takes expensive ion exchange processes to remove excess nitrates, a common contaminant in agricultural areas. It is cheaper – and generally easier – to prevent nitrates from getting into the water sources in the first place.

From a health perspective, source protection is an important component of an integrated approach to ensure safe drinking water. The truth is, treatment plants are not always effective 100% of the time, so we need to have additional defences in place. This barrier of defences starts with the protection of the source to prevent costly clean-up exercises and prevent health risks.

There are precautionary measures to protect groundwater abstraction points. Some of the measures that should be taken to protect groundwater abstraction points to minimise the risk of pollution include:

- Groundwater abstraction points should be sited away from all activities that pose a pollution threat.
- Groundwater abstraction points should preferably be sited upslope of and outside the villages and should be properly fenced off.
- Groundwater abstraction points should be built with adequate protection ensuring that surface water does not reach the groundwater. Failed or abandoned boreholes or wells must be properly backfilled and sealed.
- Pump houses should be kept in a neat and dry state. For diesel pumps, oil and diesel spillages should be mopped up and all oil and diesel

- leakages should be sealed as soon as possible. The pump house floor should be properly constructed without cracks or open joints.
- Springs should be adequately protected and developed to prevent water contamination.

Geological conditions

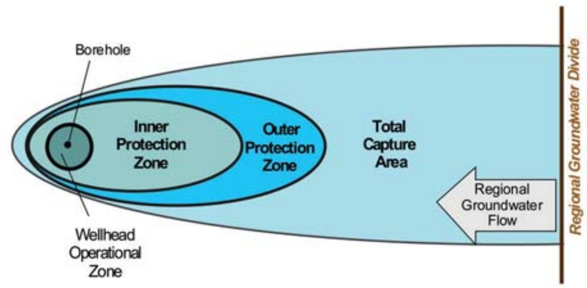
Geological conditions have a significant impact on the groundwater flow and the amount of water that can be abstracted from a borehole or a well. The geology also governs the change in water quality as the water moves through the unsaturated and saturated zones. Coarse-grained rocks and soils tend to have higher permeability and porosity, which in turn allows for each and rapid flow of water. These types of rocks make good aquifers provided the quality of the water is also of a good standard. Fractured rocks may also allow rapid movements of water through them. This is in contrast to the fine-grained rocks with a low porosity. In these rocks water flows very slowly. Some rock layers are almost completely impervious (i.e. no water flows through at all).

The rock types and the thickness of the geological layers will determine the rate and the amount of reduction of contaminants that can take place, as well as the level of impact that surface drainage will have on the underlying aquifers. Generally, in fractured and shallow coarse-grained rocks there is limited reduction or removal of contaminants, while in deep fine-grained rocks significant reduction of contaminants can be expected. However, in many cases fractures and faults have a far greater influence on the flow rates and reduction of contaminants than the flow through the geological layers themselves.

Some of the processes that change the quality of the water are influenced by the chemical nature of the rock, and the existing physical conditions. As a result, groundwater derives its chemical character from the rocks or the soil through which it is flowing, however, this is also determined by the rate of the reactions and the amount of time available.

A useful reference is this regard is the DWS 2003 publication, ***A protocol to manage the potential of groundwater contamination from on-site sanitation***.

Protection zoning – a potential approach



A simplified presentation of proposed protection zones, which could support proper groundwater resource management.

Groundwater (or wellhead) protection zoning still has to be implemented in South Africa although the DWS has acknowledged the use for and importance of implementation of this management approach.

Groundwater protection zoning is a supplemental methodology for groundwater management that incorporates land use planning. The land is managed to minimise the potential of groundwater contamination by human activities that occur on or below the land surface.

The core of the protection zoning approach is the wellhead or borehole protection zoning adopted in many developed countries. In this simple concept, the wellhead protection area is the surface expression of the region contributing water to the borehole/well. The delineation of a protection zone is the process of determining what land or geographic area should be included in a protection zone programme. This area of land is then managed to minimise the potential of groundwater contamination by human activities that occur on the land surface or in the subsurface.

In general, it has been shown that contamination of drinking water occurs where three main components exist:

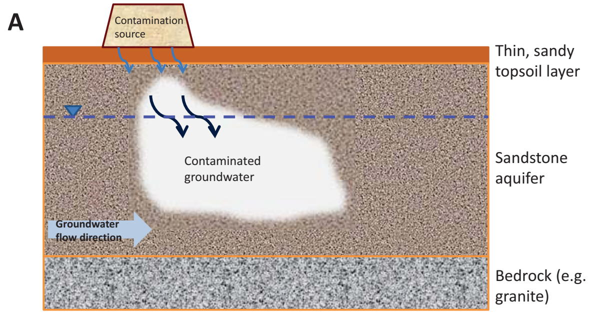
- A potential source of contamination
- An underlying aquifer
- A pathway for transfer between the two.

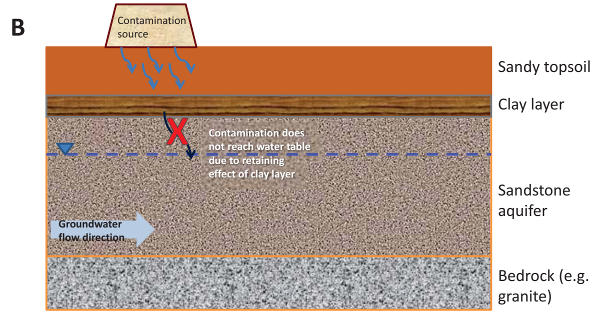
This pathway can either be indirectly through the soil, or directly through man-made structures which intersect the water table such as boreholes, trenches and quarries. The size and shape of the protection zone depends upon the hydrogeological characteristics of the aquifer system and the design and operational characteristics of the borehole used to pump water from the aquifer system.

Fractured rock aquifers underlie most of South Africa, and provide water supplies to millions of people. Protection of fractured rock aquifers requires recognition of the hydraulic and geological characteristics that make these settings so vulnerable to contamination. Such characteristics can include flow through interconnected preferential pathways, high flow velocities, rapid recharge and potentially little attenuation of contaminants. Groundwater movement through fractured aquifers can be very rapid – tens to hundreds of meters per day compared to only a few centimetres a day in many granular aquifers. Therefore, many fractured aquifers can transport contaminants rapidly for long distances with little attenuation of contaminants.

The key to aquifer protection is a basic understanding of local hydrogeology. Even in complex geological environments, the basic principles of groundwater flow still hold. Water moves from higher to lower hydraulic head through the most permeable parts. All protection methods, from simple calculations to sophisticated models, must begin with a basic conceptual model of understanding.

AQUIFER VULNERABILITY





A. Contamination reaches the water table from the contamination source. Only a thin layer of topsoil exists at the site, and no clay layer is present. B. A relatively thick, sandy topsoil acts as filter for the contaminated leachate from the contamination source. Contamination is further retained by a clay layer in the aquifer and no or very little contaminants will reach the water table.

Aquifer vulnerability is the likelihood of an aquifer being affected by a contaminant load imposed by human activities at the ground surface. The assessment of the vulnerability is mainly based on the estimated travel time for water to move from the ground surface to the water table. As the water moves through the ground, natural processes reduce the concentration of many contaminants.

The vulnerability of aquifers to contamination from sanitation systems and other pollution sources is high in areas of high rainfall and shallow water tables. The vulnerability is also high for fractured aquifers and other permeable environments such as sandy or gravel soils. This is mainly because of high flow rates and less time and distances available for filtration, die-off and adsorption processes to take place. Proper management of groundwater and control of hazardous activities on vulnerable aquifers is essential for the protection and the sustainability of the groundwater resource. A proactive approach to protect the groundwater resources from pollution is encouraged, as it may be very difficult and costly to treat the groundwater once it has been contaminated, particularly in terms of inorganic contaminants.

Realising the importance of protecting our groundwater, resources, it is now a good time to take a look at the things we can do to achieve this.

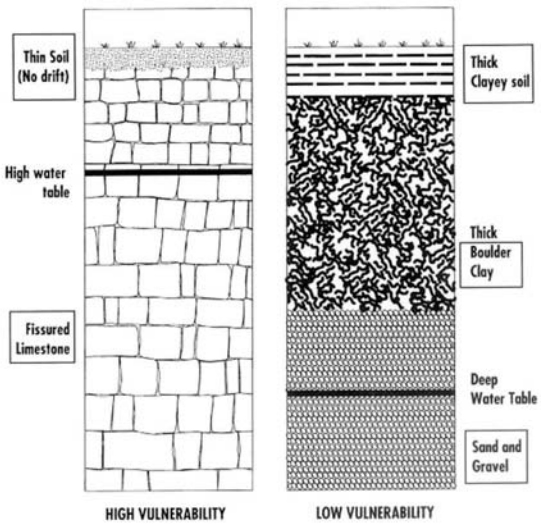
Groundwater monitoring

The objective of a monitoring network is to acquire and interpret data that would reflect changes or trends in the groundwater quantity and quality, so that we can adopt or modify strategies for water utilisation, conservation and protection. But how can we 'see' what changes occur within the groundwater? How do we measure the 'invisible'?

Generally, but not always, the flow of groundwater follows the surface topography. Therefore, where possible, boreholes should be sited upgradient and some distance from any potential contamination sources.

Once the correct position of a supply borehole is established, the next question usually is 'where do we put the monitoring boreholes?' Again, apply a dose of logic and refer back to the diagram used to determine the position for a supply borehole. It is easy to see where potential contamination will flow, as it simply follows the groundwater flow path. It is therefore suggested that groundwater quality monitoring boreholes be positioned between the contamination source and the supply borehole. To ensure an even better management strategy, it is recommended that additional monitoring points be put in place upslope of the contamination source as well as down-slope of the supply borehole.

Now we have a good handle on the changing picture of the groundwater quality at that specific location, but how do we monitor the amount of water that is available (i.e. the quantity)?



Two different geological settings illustrating the concept of aquifer vulnerability.

Watch that level!

As discussed at the start of this chapter, we have a good idea of how much groundwater is available for exploitation in South Africa. Groundwater is increasingly acknowledged as a reliable and even strategic water resource in the country.

So how can we ensure that this happens? The answer lies in groundwater quantity monitoring. This includes groundwater levels, abstraction rates and rainfall figures. All these are necessary for current management, but also for future management and groundwater allocation.

Groundwater levels

We measure groundwater levels in meter below collar or sometimes meters above mean sea level. It is important that we know if the water level (or water table) stays constant, rises or deepens below the surface. This gives us an indication whether the aquifer system is under stress or not.

Monitoring of water levels depends on the borehole construction and pumping equipment installed in the borehole. The target accuracy for water level recordings are 10 mm. Reasonably costed measuring tapes equipped with an electric contact mechanism activated when in contact with water are commonly available in South Africa.

A water level recorder is lowered in a freshly drilled borehole.

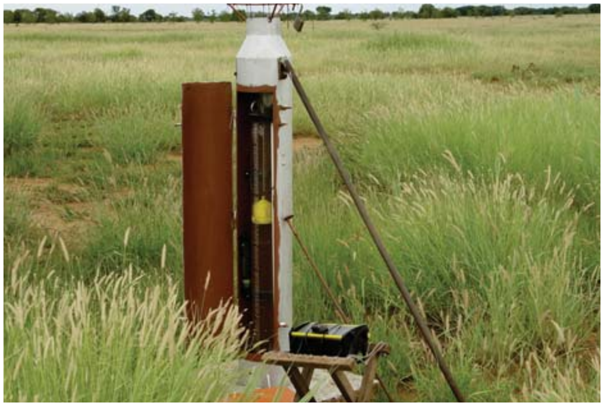
SAFE YIELD
The annual amount of water that can be taken from a source of supply over a period of years without depleting that source beyond its ability to be replenished naturally during years of normal rainfall.

Abstraction rates
Groundwater abstraction is one of the outputs of a groundwater system. It is necessary to know how much is going out of the system to help us balance the 'budget'. The installation of in-line water flow meters is not common practice on most water-supply boreholes. This would be the preferred and recommended way of recording the volumes of water pumped on a daily basis. Where such a flow meter is not available, at least monthly tests should be undertaken to determine the pumping volume at an abstraction borehole. This should be done by using a container of fixed volume and the time measured to fill this container of known volume.

Rainfall data
Rainfall is the main 'input' into the (ground)water systems; it is what makes us think of this valuable resource possible. Local, daily rainfall figures, combined with other hydrogeological data and information enable us to calculate the available groundwater for sustainable use. So how can we use this information to help manage the resource better?

It is quite difficult to make sense of sheets and sheets of data, without adding knowledge to it. With the help of a simple spreadsheet program (for example, Excel) it is easy to get a good picture or understanding of the resource behaviour. By drawing up graphs of water level versus time, combined rainfall and water levels versus time and finally incorporating abstraction rates management now suddenly seems much more feasible. Compiling these graphs are useful and practical, easy to evaluate and then to recommend adaptive measures to ensure good use – for now and the future – of the resource.

Examples of some of the types of electronic water level recording devices. Data is transferred directly to your laptop where evaluation of the data will take place.



Rainfall gauges, developed by the DWS, used as part of the groundwater monitoring network in the country. The data can be stored electronically and then downloaded with a specific instrument.

SOUTH AFRICAN WATER LAW

Traditionally, South African water law gave the owner of the land the right to use the groundwater occurring on his land (section 5(1) of the 1956 Water Act). The system worked relatively well for some time, since access to and abstraction of large quantities of groundwater were limited due to the lack of appropriate technology.

The National Water Act (promulgated in 1998) changed the whole situation radically. Groundwater is no longer regarded as 'private water'. The Minister of Water and Sanitation is now the custodian of all water resources. The Act further states that there will be no ownership of water (surface or groundwater). There are only two uses of water protected by right under South Africa's water legislation, namely the right to water for basic human use and the right to water of the environment. Water of a certain volume, quality and sustainability is required to sustain human life, as well as the ecological functions of which human life depends. This water needs to be reserved in such a manner that the long-term sustainability of the resource is not jeopardised. To effectively try to manage the water quantities utilised, the Act provides the directive for the registration of water use. All water users, who do not receive their water from a service provider, local authority, water board, irrigation board, government water scheme or other bulk supplier and who are using water for: irrigation, mining, industrial use, feedlots or in terms of a General Authorisation, should register.

This registration process allows a person to take water for small gardening (not for commercial purposes) and the watering of animals (excluding feedlots) on land owned or occupied by that person, from any water resource which is situated on or forms a boundary of that land. This only applies if the use is not excessive relative to the capacity of the water resource and the needs of other users. This means that most users using groundwater in towns and cities as well as those users with windmills on their own properties need not register.

Monitoring, conservation and allocation for the Reserve of groundwater are all address in the new Act. Licensing of water use also forms part of the National Water Act.

Groundwater licensing at a glance

The use of groundwater for small applications, such as the watering of livestock, is permissible without a license.

Authorisation to use groundwater is legislated under the National Water Act, the Environmental Conservation

Act, and the National Environmental Management Act. There are basically three types of water use authorisation:

- **Schedule 1 uses**: Relatively small quantities of water, mainly for domestic and stock watering purposes, but also for emergency situations and certain recreational purposes.
- **General Authorisations**: Under which limited water use is conditionally allowed without a license. Current Government Notice 399 of 26 March 2004" and not Government Notice 1191 of 8 October 1991.
- **Water use licenses**: Licences are used to control water that exceeds the limits imposed by Schedule 1 and General Authorisations. Water use licenses give existing or prospective water users formal authorisation to use water for productive or beneficial purposes.

General Authorisation allows for conditional water use without a licence. The country's aquifers have been divided into different zones, which allow for differing quantities of water that may be abstracted. Water use that exceeds the limits posed by Schedule 1 and Generation Authorisations requires licensing.

With the democratisation of the country in 1994 there was a strong policy shift towards providing basic services, including water and sanitation services, to the whole population as soon as possible. The indication in 1994 was that 14 million people did not have access to the most basic form of water supply. By 2006 the backlog was reduced to 4 million, and groundwater has played a major role in this regard. Already, the rural domestic use from groundwater in South Africa has increased from 120 million m^3/a in 1986 to 310 million m^3/a in 2000. Overall, more than 60% of the country's population is supplied with water through groundwater, and in some provinces this figure is as high as 90%.

Groundwater is used in many parts of South Africa, especially rural areas.

Groundwater and climate change

Groundwater resources and their long-term replenishment are controlled by long-term climate conditions. Climate change will therefore have a significant impact on groundwater resources.

Groundwater has to be used and managed in a sustainable way in order to maintain its buffer and contingency supply capabilities as well as adequate water quality for human consumption, even with climate change impacts.

Land use planning has to consider groundwater resources as a precious and finite resource, and take all possible measures to protect groundwater resources and their recharge mechanisms in the long run.

How will groundwater be affected by climate change? Despite the lack of detailed knowledge, there is consensus on qualitative changes of climate. Higher variability in precipitation is very likely to occur along with more frequent extreme events, such as storms, floods and droughts. Groundwater will be less directly and more slowly impacted by climate change as compared to, for example, rivers. This is because rivers are replenished on a shorter time scale, and drought and floods are quickly reflected in river levels. Groundwater, on the other hand, will be affected much slower. Only after prolonged droughts will groundwater levels show declining trends.

This is also why increased groundwater pumping can, for a limited time span, serve as a contingency supply scenario in order to mitigate water shortages during droughts when watercourses have run dry. Groundwater levels of many aquifers around the world show a decreasing trend, but this is generally due to groundwater pumping exceeding groundwater recharge and inflow rates, and not to a climate-related decrease in groundwater recharge.

Increased variability in rainfall may decrease groundwater recharge in humid areas because more frequent, heavy rain will result in the infiltration capacity of the soil being exceeded, thereby increasing surface runoff. In semi-arid and arid areas, however, increased rainfall variability may increase groundwater recharge, because only high-intensity rainfalls are able to infiltrate fast enough before evaporating, and alluvial aquifers are recharged mainly by inundations during floods.

Can we do something to minimise the impacts? Groundwater needs to be protected, and its use and maintenance adapted to climate change. Preventing groundwater degradation and unwise exploitation will prove more cost-effective than trying to clean up and restore mismanaged aquifers. Monitoring and research must happen to achieve a better understanding of groundwater systems and their dynamics. Wise land use, the protection and maintenance of groundwater systems and technical installations for the simple access to groundwater resources are key to prevent groundwater contamination, ensure sustainability of economic investments, and groundwater availability during extreme (flood or drought) conditions.

Groundwater is likely to play an even greater role for human development under changing climatic conditions

- Groundwater and climate change: Challenges and possibilities, 2008. BGR

So how do we go about this management challenge?

Most groundwater experts are optimistic about successful management of groundwater resources. They believe that if a comprehensive and prudent groundwater management plan is implemented, something can be done to solve and/or contain current problems and prevent others from occurring in the future. It is possible to identify possible sources of contamination and clean aquifers can be Maintained and protected, and polluted sites can be contained and cleaned.

Groundwater management cannot focus on groundwater sources alone; the mere existence of the hydrological cycle must force us to manage any water source hand in hand with the rest of the environment. These waters and their environments are interdependent. To focus on one and exclude the other inevitably leads to unnecessary new problems, perhaps more threatening and difficult to solve than the original problem.

Groundwater management is the most efficient on a local level because the hydrogeology is very site specific. A wellfield (or a single supply borehole) in the Karoo basin and boreholes in the Table Mountain Group aquifer will have to be managed differently. Geological setting, vulnerability, different user requirements and possible contamination threats will vary from one location to another.

According to the DWS, groundwater management can be grouped into the following five areas:

- Fulfilling legal obligations (i.e. ensuring use and protection of groundwater according to national and international laws)
- Monitoring and analysing data (e.g. groundwater levels and abstraction)
- Optimising groundwater usage
- Protecting groundwater from contamination
- Creating awareness and educating people about sustainable groundwater use.

Successful management will therefore not only address monitoring and data evaluation, but has to incorporate all the other areas of management as well.

In South Africa, fractured-rock aquifers underlie the largest part of the land area. This adds yet another dimension to a groundwater management plan. In a fractured rock system a major fracture usually provides most of the water to a borehole. It is important to locate the exact position of that fracture (in terms of depth) with the main water strike and ensure sustainable management. If the water level drops below that position of the main fracture, the borehole will 'dry up'. The very same fracture providing water for use on the surface is also a preferential flow path that will transport pollution at high rates.

Operation and maintenance of groundwater supply infrastructure

Like any water-supply system, proper operation and maintenance of groundwater systems are essential.

In general, it is people's perceptions or lack of awareness of groundwater that represent an important cause of emerging management problems. Some of the main reasons why groundwater resources in these systems are perceived to be unreliable are poor operation and maintenance, rapid pollution; sudden failure of schemes; and a general lack of capacity at the local level of manage and protect groundwater resources.

Proper operation and maintenance of the water-supply infrastructure is an important part of successful groundwater management. This includes the correct operation and maintenance of the pump, maintenance of the borehole site as well as any piping system and reservoir that forms part of the supply infrastructure.

Groundwater is one of the most valuable natural resources possessed by many developing nations. Without proactive management and protection, there is a serious risk of irreversible deterioration on an increasingly widespread basis. Under the pressure of the need to rapidly develop water supplies, there is rarely adequate attention to, and investment in, the maintenance, protection and longer-term sustainability of groundwater.

What can the groundwater user contribute to groundwater management? Awareness of groundwater and its related issues is a huge stepping stone towards contributing to our national water resources. It is necessary that groundwater users be aware of at least the very basic concepts on aquifers, flow paths and potential threats to the resource. Self-regulation of groundwater users holds the key to ensuring clean water for a future generation.

Groundwater users should ask their local municipality the following questions:

- Are the water levels and groundwater quality being monitored on a regular base?
- How did the water levels (and the quality fluctuate in the past few months?)
- What potential contamination threats are currently in our community?
- Are there any measurements that I can take (e.g. rainfall, abstraction rate)?
- Am I helping to keep the infrastructure secure and in good working order.

It is critical that the water users get involved in the management of the groundwater resource. By contributing with information, being alert to damaging land-use activities and by being a responsible water user the overall task of groundwater management on a national- and regional level suddenly becomes much more feasible.

A national perspective on groundwater development is captured in the publication, ***Water for Growth and Development***, published by DWS in 2009.

Groundwater offers a significant volume of additional water to agriculture, the mining sector, towns and rural communities. For many towns and rural communities, it is often the only available and affordable supply of water capable of supporting future growth and development. Although groundwater is widely accessible and often close to the point of use, planners and consumers frequently either do not recognise it as a resource, or shun it as inferior to surface water.

Groundwater is a major water-supply source for many Karoo and coastal towns. Dolomitic aquifers are a major freshwater source in the North West Province (e.g. Tosca). Agricultural developments ranging from potatoes in the Sandveld, to tomatoes in Dendron, also depend on groundwater. Cape Town, Oudtshoorn and others have explored the Table Mountain Group Aquifer as a major source of water to use in conjunction with surface supplies.


WRC archives

The Table Mountain Group Aquifer is already supplying water to a large number of water users in the Western and Eastern Cape.

A HIDDEN RESOURCE TO BE RECKONED WITH – THE TABLE MOUNTAIN GROUP AQUIFER

The formations of the Table Mountain Group were formed some 400 million years ago when sediments were washed down prehistoric rivers and deposited in a shallow marine environment. Over time the layers became buried, eventually forming rocks such as quarts sandstones, shales and siltstones under the increasing pressures and temperatures. Continental movement caused the layers to be squeezed into folds. The Table Mountain Group is the lowest component of the Cape Supergroup and constitutes the largest parts of the Cape Fold Belt Mountains. The Table Mountain Group of rocks comprise a major sedimentary unit that stretches from Vanrhynsdorp in the north to Port Elizabeth in the east, forming an arc of mountain ranges running south parallel to the west coast and then curving sharply east parallel to the south coast. The depth extensions of the aquifer are confirmed by the numerous hot springs that occur exclusively within the Table Mountain Group. A large number of users access water from the aquifer, some exclusively so.

There are more than 30 major users of groundwater, among them numerous towns that are completely dependent on the aquifer as their sole source of water. These are places like Steytlerville, Jeffreys Bay, St Francis Bay and Humansdorp in the east, Bredasdorp, Struisbaai and Botrivier in the south and Lamberts Bay, Leopoldville and Graafwater in the west. Research and testing is ongoing and expectations are high for this potential large-scale water resource.

Groundwater supplies rural communities from the Eastern Cape (former Transkei areas) to Limpopo and in time may supply up to 20% of the country's water. Most importantly, as an under-exploited resource, groundwater offers a relatively conflict-free way of providing water to rural communities across the country.

The department has highlighted the importance of groundwater in integrated water resource management. To exploit groundwater effectively, DWS will invest accordingly to quantify as accurately as possible resource volumes at a scale useful to planners and users at local level. At present, the country lacks the depth in skills and leadership in hydrogeology to drive the understanding and acceptance of groundwater from national down to local management level. Steps must be taken to strengthen hydrogeological skills and build technical training capacity at institutions across the country.

The sustainable use of groundwater requires the careful initial siting of boreholes and subsequent monitoring and management to ensure that water use does not exceed supply. As with all water resources, successful use depends entirely on sound management, and this is particularly important where the supply is 'invisible' to the user. The department has developed a National Groundwater Strategy that will address these issues and provide a way forward.

For marginalised communities to improve their quality of life issues such as supplying enough water for productive use rather than just subsistence use should be considered. Communities should be involved and take ownership of their water resources. At the same time, the role of groundwater in maintaining the natural and economic resource base in the community; and the sensitivity of these systems to overexploitation should not be overlooked

– Dr Kevin Pietersen

A long-term national view of the potential combination use of water source

Water source	2008	Mid-term 2025	Long-term 2040
Surface water	77%	72%	65%
Groundwater	8%	9%	10%
Return flows (e.g. irrigation, treated effluent, mining)	15%	17%	22%
Desalination	<1%	2%	3%

CHAPTER 5: TRAVELLING THROUGH OUR GROUNDWATER PROVINCES

The total volume of available, renewable groundwater in South Africa is estimated to be around 19 km³ per year. This can be compared with the 32 km³ capacity of South Africa's dams. South Africa's surface water resource are almost fully allocated, however, while only a small proportion of the total volume groundwater available is used.

Whatever the exact figures, it is apparent that groundwater is in the same league, volumetrically, as our stored surface water resources, and groundwater in this country requires better planning and greater funding due to this fact alone. Groundwater has been used in southern Africa for millennia, from springs and indirectly via baseflow to rivers and lakes. Johannesburg's earliest safe water supply was groundwater, first from springs and then from boreholes in the dolomite aquifers to the southwest of the city. Today, both Tshwane and Johannesburg still use groundwater for part of their water requirements. Although most large-volume water users now rely on surface water, the majority of small water supplies, which are critical to livelihoods, health and dignity, depend on groundwater.

WESTERN CAPE

Numerous vineyards in the Western Cape make use of groundwater for irrigation purposes.

The landscape

The Western Cape is known for a variety of attractions; winelands, fruit farms, beaches and mountains. The rugged upright topography has a profound effect on water supply in the Western Cape. The high winter rainfall, together with these mountains, produces large volumes of runoff, which is captured in numerous dams for municipal and irrigation water supply. Despite the high rainfall in the mountains, the Western Cape is a semi-arid region, and only a few major rivers traverse the landscapes. Both the Table Mountain sandstones and the quaternary sand deposits contain important groundwater resources that are widely utilised.

The water situation

Although the intended use for water differs through parts of the Western Cape, the commonality is just that: the need for water. From irrigating vineyards or potato fields; or stock watering to supplying water for domestic use; water forms the lifeline of various activities. Most irrigation schemes in the province utilise surface water to try and keep up with the demand. Groundwater supplies many of the towns, such as Atlantis, Prince Albert and Lamberts Bay, while some towns use groundwater and surface water conjunctively, e.g. Somerset West.

Quartzites and bedding planes near Citrusdal.

The baseflow in most Western Cape rivers originates from seepage from groundwater. Therefore, where boreholes extract water from the same groundwater source, the surface water runoff is reduced by the quantity of water abstracted from the boreholes.

Sand dune areas occur along parts of the western and southern coasts, and the rolling hills of the central area consist mainly of Malmesbury shales. Surface water originating from runoff from the Table Mountain Sandstone areas is of low natural salinity, while that from area where Malmesbury shales occur is moderately saline. The geological strata similarly affect the groundwater chemistry.

Controversial as it may be, the Berg River Dam, outside Franschhoek will temporarily alleviate Cape Town's critical water shortage within a few years. However, if the city's water demand continues to grow at current rates, the additional volume of water that this new dam will provide will be fully utilised within just five years, leaving us back where we started.

The major problem is that the easiest and biggest alternative options to boost the city's water supply have either unacceptably high environmental and social costs or very high monetary costs – notably, the desalination of seawater.

Other possible future water-supply schemes that the City of Cape Town are:

- Tapping the Cape Flats Aquifer. This is a primary aquifer – an underground water source formed naturally in sediments, such as sand – which is more easily tapped than a secondary aquifer formed in fissured rock. However, water from this aquifer will need to be treated as some of it is highly contaminated
- Reusing sewage effluent, both indirectly through exchanging this effluent for clean water allocations currently used by farmers for irrigation, and directly by purifying it to potable standards, as is done in cities such as Windhoek.
- The Eerste River diversion, a scheme to channel some winter water from this river into the water treatment plant in Stellenbosch.
- The Voël Vley augmentation scheme, to increase that dam's current capacity.
- A water diversion scheme to capture excess winter water from the Lourens River near Somerset West.
- Desalination of seawater.
- Another major city water initiative underway is an investigation into the feasibility of tapping into the Table Mountain Group Aquifer found in the Cape Fold Mountains of the Western Cape.

GROUNDWATER USE IN SPECIFIC AREAS

Robben Island

The dock at Robben Island.

Robben Island is probably best known as the jail used to intern political prisoners during the apartheid era. However, the island has been used for many purposes since it was first stocked with a small flock of sheep by Sir Thomas Herbert in 1614. The supply of water has been a key factor in developing the island. Initially, freshwater springs were utilised, but as water demand increased boreholes were added.

The geohydrology of Robben Island is considered typical of many small islands around the world where a relatively thin lens of freshwater overlies denser saline groundwater. A total of 11 production boreholes are used to abstract groundwater on the island. Historically, typical yields ranged between 0.5 L/s and 1.5 L/s but a yield of 14.4 L/s was reported for one of the boreholes. This production borehole is fitted with a flow gauge and is pumped at a rate of 1.9 L/s, which is not the recommended yield.

Unfortunately these boreholes have not been managed properly over the years, and serious problems have been encountered with the water supply. The quality of the groundwater has deteriorated on the island and pumping at a too high rate has led to the intrusion of seawater into the underlying aquifer system. Initially, a reverse osmosis plant was used to overcome the gradually deteriorating groundwater quality problem. However, a seawater desalination plant was installed in 1998 to replace the dysfunctional groundwater treatment plant. Because of technical and management problems, groundwater continues to be used.

The evaluation of existing information indicates that the long-term safe yield of the aquifer to be 460 Kl/day. This is sufficient to supply some 2 000 day visitors, 450 overnight visitors and the infrastructure required to run the island (information in this section taken from the 1998 Parsons and Associates study on 'Assessment of the Groundwater Resources of Robben Island').

Sandveld, West Coast

A panoramic view of the Sandveld region.

Many of the boreholes that currently supply water for four municipalities in the Sandveld – Lambert's Bay, Elands Bay, Graafwater and Leipoldtville – are producing less water or water of a deteriorating quality. Several other boreholes in the Wadrif-saltpan area, which also supplies Lambert's Bay, are now four metres below sea level, prompting fears that there could be an inflow of seawater into the aquifers feeding the boreholes. Because of the extremely low rainfall in the Sandveld – the area receives less than 200 mm rain a year – and the extremely low nutritional value of the sandy soil, all potato crops are irrigated and heavily fertilised.

Potato production uses, on average, 7 000 m^3 of water per hectare per year. There are some 1 727 irrigated production circles, mostly used on a four-year rotational basis.

The clearing for potato production is of huge concern to environmentalists, because of water use and the unique natural fynbos and renosterveld vegetation that is destroyed.

Atlantis aquifer

The town of Atlantis, located 50 km north of Cape Town, has been fully dependent on groundwater from its inception in 1976. However, groundwater supplies are limited, and artificial recharge through infiltration basins has been introduced to augment local groundwater supplies. A successful recharge operation was started by means of the diversion of stormwater and wastewater flows of inferior quality from the industrial area. On average, approximately 7 500 m^3/day of water is recharged upgradient of the well field while some 4 000 m^3/day higher salinity is treated and discharged into basins downgradient of the well field close to the ocean without further use for recharge. Hydrochemical monitoring of the various water sources has protected the overall quality of the system.

In 1999, the scheme was augmented with a limited supply from surface water sources to meet peak demands, but the town is still dependent on groundwater. Infiltration ponds are used to infiltrate water into formations of good permeability, which are not overlain by an impervious layer. Ponds are either excavated, or are enclosed by dikes or levees that retain recharge water until it has infiltrated through the floor of the basin. In the Atlantis area, minimal runoff is generated under natural conditions due to the high infiltration capacity of the soil. It was realised that large volumes of stormwater runoff would be generated after urbanisation and the associated hardening of surfaces. This was seen as a valuable water source for augmenting freshwater supplies in this region, and prompted the construction of a stormwater collection system. As an added water source, treated domestic wastewater is recharged to the aquifer along with the stormwater.

The Atlantis scheme is a successful groundwater supply scheme through proper planning and management.

The accepted abstraction capacity for the Wtitzand wellfield is 5 million m^3/year, and for the Silwerstroom wellfield 1,8 million m^3/year. This means that about 40% of the abstracted water from the Witzand wellfield derives from artificial recharge.

Managing water quality and, in particular, salinity has been one of the greatest challenges for the Atlantis water scheme. Management actions to control salinity in the Atlantis water supply have included the launching of a detailed chemical investigation of the salinity sources. Regular monitoring takes place around the recharge and abstraction areas and at potential pollution sources. This also provides an early warning system against any potential uncontrolled spills and illegal discharges of harmful contaminants. Improved environmental practices have been initiated by some of the industries. These have resulted in the commissioning of site assessments and, in some cases, the initiation of groundwater monitoring programmes. Increased understanding of their contamination threats allows these industries to improve their operating procedures to protect their water resource.

Iron-related clogging of abstraction boreholes due to overpumping of the boreholes has proven to be an extensive and serious problem. From 1999 to 2002, boreholes were examined and rehabilitated using special treatment techniques.

The Table Mountain Aquifer

The development possibilities of the Table Mountain Group aquifer in the Western (and Eastern) Cape have led to many discussions and even some disagreements. The proposal to investigate groundwater in the aquifer as a potential source for bulk water supply for agricultural and urban use has been discussed since the early 1970s. The possibility of large-scale groundwater supply to the Cape metropolitan area from the Cape Flats and West Coast aquifers was evaluated during the Western Cape Systems Analysis in the early 1990s.

Jaco Nel

Water seeping out between rock layers in the Franschhoek area approximately one month after good rains

The fractured rock groundwater systems of the Table Mountain Group Aquifer constitute a vast aquifer system, extending from just north of Nieuwoudtvile southwards to Cape Agulhas and eastwards to Port Elizabeth. The full volume of the aquifer rocks in this whole region covers a staggering 100 000 km^2.

The groundwater intersections or pathways in the aquifer are commonly at depths of greater than 100 m below ground. The recharge to the TMG aquifer is believed to be in the range of 7% to 23% of mean annual precipitation (i.e. snow, rainfall and mist).

Groundwater from this aquifer is said to be among the purest in the country. However, the pH is as low as 5, which means that the very is acidic and, therefore, corrosive, in places. This means that, should bulk water supply form the Table Mountain Group aquifer ever be considered, some form of treatment will have to be included to ensure that the water is of potable standard and to minimise the damage to water distribution infrastructure.

In the mid-1990s, consulting firm Umvoto Africa's detailed study of the Table Mountain Group Aquifer in the catchment of the Olifants River or the DWS showed that there would also be opportunity for developing the aquifer to supply the Western Cape supply system, which serves the municipalities of Cape Town, Stellenbosch, Paarl and Wellington, as well as towns on the West Coast and in the Swartland area. Irrigators along the Berg and Eerste rivers, and irrigators and urban users in the Riviersonderend catchment also receive water from the system. However, groundwater extraction from this system is still only a fraction of overall water supply.

A 2001 study, which investigated various water supply and demand management options at reconnaissance level, again highlighted the potential of the Table Mountain Group aquifer to augment water supplies in the area. Among others, this study concluded that the aquifer has the potential of yielding high volumes of good quality water; the overall cost of developing and operating wellfields in the aquifer compares favourably with other water-supply schemes; and that it is important to study this potential to full feasibility level. Following this study, the Western Cape's environmental authorities gave the go-ahead for exploratory drilling at 27 sites within the study area, which extends from Cape Hangklip in the south to Tulbagh in the north.

Matjiesfontein

Matjiesfontein, fondly known as the Grand Duchess of the Karoo, was established in 1884 by an entrepreneurial Scotsman, James D Logan. When Logan arrived at Matjiesfontein, it was a bleak and deserted place. Looking past the barren landscape, Logan saw a way of making a fortune from the Karoo's scarcest commodity – water. As an experienced railway man Logan knew that every locomotive needed 250 000 L of water to cross the Karoo, and that there was no reliable source of water between Touws River and De Aar. Logan found a groundwater source capable of delivering 50 000 L/hour and piped it into Matjiesfontein. With more water than he needed, he developed an elaborate 'water world', which opened in November 1889.

The historic town of Matjiesfontein.

Matjiesfontein, South Africa's first health resort, has a proud record of 'firsts' to its credit. Always ready to try something new, Logan built a large wind-powered mill to crush wheat and to generate electricity for Tweedside Lodge. This was the first private dwelling in South Africa to have electric lighting. Logan also pioneered waterborne sewerage, and South Africa's first flushing toilets were located at his home. Logan further opened the first artesian well in South Africa on Tweedside, and sank several boreholes. Each time he found a good supply of water he planted fruit trees. No one had ever dared such a project in the Karoo before, but the cherry, pear and peach orchards flourished. The fruit was sold as far away as the Kimberley diamond diggings and Cape Town. Logan also laid a 20 km telephone line, then the longest in South Africa, from his house on Tweedside farm to his residence at Matjiesfontein. (Information in this section taken from Laingsburg Tourism Bureau.)

Oudtshoorn

In common with most Karoo towns, Oudtshoorn faces frequent water shortages. Following the initiative of Alderman Isidore Baron, the Oudtshoorn Municipality has for the past few years undertaken a groundwater exploration project aimed at assessing the potential of using groundwater from very deep aquifers to augment the town's water supply.

The so-called DAGEOS (Deep Artesian Groundwater Exploration for Oudtshoorn Supply) project is targeting the huge Peninsula Aquifer, which is thought to occur at depths of over 800 m beneath the primary exploration site in the Blossoms area, about 25 km south of Oudtshoorn. Secondary exploration areas are located further east, towards the Kamanassie mountains, and further south in the Waboomskraal area.

Three exploratory boreholes have been drilled in the Blossoms area, and it was the second hole where a significant water strike was encountered. The exploratory borehole yielded an impressive water blow yield of about 30 litres a second. The water in the Peninsula Aquifer is under pressure, and successful penetration of this aquifer will probably result in artesian flow from the aquifer (the water will flow to the surface as a result of the pressure in the aquifer). The boreholes into the Peninsula Aquifer will be specifically designed and well sealed throughout their upper sections to prevent any uncontrolled leakage of water into our out of the overlying Skurweberg Aquifer.

Deep artesian groundwater from the Table Mountain Group Aquifer is also being considered by the Oudtshoorn Municipality either as an alternative source of water or as a supplementary source to use in conjunction with surface water.

Other interesting groundwater places

The spring on the Gifbergpas is a welcome oasis for travellers.

Halfway up the **Gifbergpas** near Vanrhynsdorp you will find a spring with a constant flow of 0.05 L/s, a very low salt content and slightly acidic quality. The presence of the spring is due to the contact between the sandstone and the underlying shale surfacing on the side of the mountain. A very neat structure has been built where the groundwater flows out of the sandstone rock (from the Table Mountain Group) to capture the water. Tired and even curious travellers can drink from the water and fill their bottles for the road ahead.

The **Calitzdorp Spa** and the **Toverwater** hot spring are two more interesting groundwater places to visit in the Western Cape. Both are situated in a Table Mountain Group Sandstone – Bokkeveld Group shale environment. The water from the Calitzdorp Spa (temperature 50°C) circulates from a depth of approximately 3 300 m beneath the surface, and the water from the Toverwater spring (temperature 44°C) circulates from a depth of approximately 2 700 m.

Majestic landscape of the Karoo.

Groundwater feeds many rivers in the Western Cape. This perfect swimming spot is on the River on the farm Gevonden in the Rawsonville district.

A historic hand-operated waterpump at the windmill museum in Loeriesfontein.

Northern Cape

The landscape

The Northern Cape covers the largest area of all the provinces, yet it has the smallest population. This arid landscape reflects a stark natural beauty, with the Orange River forming the northern boundary of the province. Located about 1 000 m above sea level, the land is flat, and the northern part gently slopes towards the Orange River. In a good year, rainfall can be 100 mm, but this only occurs once in a decade or so. The vegetation is sparse, comprising mostly annual grasses and hardy shrus with thin lines of thorn trees.

The best known physical feature of the Great Karoo is undoubtedly its hundreds of mesas, or flat-topped hills. Here you will also find the drought-adapted succulent plants that store water in their thick leaves to tide them over until the next rains.

The water situation

The arid climate and limited potential of natural water resources in the province are a major constraint for economic development. Approximately 30% of the population depend on groundwater resources. The overexploitation of groundwater resources is a concern in some areas, and proper monitoring and management of the groundwater is essential to ensure the sustainability of supply.

The province is water poor, with rivers characterised by irregular flows and occassional episodes of flooding. The main water sources are the groundwater in the dolomites of the Ghaap Plateau and surface water from the Orange and the Vaal river systems. throughout the province, people are dependent on groundwater, except along the two main river systems.

The Ghaap plateau can be divided into three regions:

- **Tosca-Vergelee area** – Large yields of groundwater occur in this area. There are at least 21 centre pivots extracting groundwater for agricultural purposes in this region. The current rate of extraction of groundwater may lead to the exhaustion of the aquifer, as the natural recharge rate of the groundwater may not be able to balance the present rate of extraction.
- **Pomfret-Lykso area** – This area has a large groundwater potential. Currently, the groundwater in this area is used only for domestic and stock-watering purposes.
- **Lykso-Reivilo-Boetsap area** – Groundwater in this area is primarily used for irrigation and domestic uses.

Groundwater is utilised widely in the province for stock watering, and the ever present 'decorative' windpump is evidence that beneath this dry, barren landscape, lies silent life-giving veins.

Interesting groundwater sites

The Loeriesfontein windmill museum is well worth a stopover.

The late Dr Walton, a British-born Capetonian, was well known for his interest in different aspects of conservation, including the conservation of water-pumping windmills or windpumps. In order to share this collected knowledge with a wider audience, he prompted organisations and places to start a windpump museum. The Fred Turner museum at Loeriesfontein was the only respondent. Since its establishment there, the **windmill museum** has collected over 27 windmills, all assembled and on display. The culture and historical way of life of the 'trek farmers' of Namaqualand (also known as Bushmanland or Hantam) is displayed in the Fred Turner museum, which is housed in the old school adjacent to the windmill display.

The town of **Kuruman** has been a centre of focus for Christian missionaries, and explorers for almost 200 years. It is a pleasant surprise to find the lush oasis among arid places such as Pofadder and Hotazel. Today, Kuruman is the main town in the Kalahari region, and is known as the 'oasis of the Kalahari'. The town is blessed with a permanent source of groundwater – Gasegonyane (meaning 'little water calabash') delivers 20 million litres of crystal clear water daily to the town's 10 000 inhabitants.

The town of **De Aar** has relied solely on groundwater sources for its water supply since its establishment in 1902. Four wellfields in the vicinity of the town ensure that all the inhabitants' water needs are met. The sedimentary rocks and dolerite dyke sand intrusions owe their water-bearing properties to joining and fracturing, which is generally limited to the top 20 to 30 m below surface.

Weathering processes play an important role in opening up joints and fractures and in covering the rocks into more porous media.

Eastern Cape

The small town of Nieu Bethesda.

The landscape

The Eastern Cape is marked by the variety and beauty of its natural landscape, which extends from the mountainous slopes of the Drakensberg to the flat and dry Karoo. The eastern part of the Eastern Cape is renowned for its long and unspoilt coastline, which varies from natural beaches to tranquil bays.

The water situation

Somewhat sporadic occurrence of springs are seen in the province. The springs cannot be directly correlated with structural geological controls, but rather with topographic controls and lithological changes. Springs in the Fort Beaufort and Seymour areas are associated with dolerite dykes and those in the Bedford area with dolerite sill intrustions.

There are dense localised concentrations of boreholes around the larger population centres (Graaff-Reinet and

Middelburg), which demonstrates the dominance of groundwater usage in the eastern Great Karoo. Usable amounts of groundwater are abstracted from the shallow primary aquifers and the secondary fractured-dolerite aquifers. Similar borehole concentrations are centred about the smaller agricultural centres of Somerset East, Cookhouse, Bedford, Adelaide, Fort Beaufort and Seymour. At the Albany Coast and south and east of Grahamstown, a large number of boreholes are in use.

Within the Fish River basin, land use is predominantly grazing for livestock (94%), particularly sheep. Cattle ranching is the main land use in the lower Fish River catchment. As a result of the transfer of Orange River water, there is intensive cultivation and irrigation of land in the valleys of the Teebus and Groot Brak tributary rivers and along the main stem of the Great Fish River.

As there are not many large urban centres, pollution and other impacts due to urbanisation tend to be fairly limited in the province. The towns of Nieu Bethesda, Aberdeen, Jansenville, Riebeeck East, Alexandria, Boknes, Cannon Rocks, Paterson, Kenton-on-Sea, Tarkastad, Hofmeyr, Steynsburg and Middelburg all rely solely on groundwater supplies. Borehole development is prominent not only in these towns but also around them. Groundwater is often the only source of water for rural domestic use and stock watering. Groundwater is also used for urban supply in coastal towns, but cannot always support the growing demand, particularly during the peak holiday season.

There are four main aquifer systems in the province:

- The Katberg Sandstones – a fractured rock aquifer
- The Witteberg Quartzites – a fractured rock aquifer
- The Intergranular Coastal Aquifers – primary aquifers of marine, fluvial and Aeolian origin
- The Dolerite Dyke system – a fractured rock aquifer.

Groundwater can be considered as a strategic resource since it delivers reliable yields and acceptable water quality. The Katberg and Witteberg aquifers are relatively unexploited, and yield good quality groundwater, being fractured sandstone aquifers. Borehole yields from these aquifers are expected to be in the moderate to good rate (5 to 20 L/s) and, being in the highest rainfall areas and receiving good recharge. These aquifers would be best exploited if they were explored and developed on a regional scale, and if production boreholes were drilled to depths of no less than 300 m. The coastal aquifers are currently exploited for use in coastal towns, but are not necessarily well managed.

The groundwater quality varies from good to very poor, depending on the position and recharge patterns. Boreholes are generally shallow (less than 100 m) or the groundwater is extracted using well points. The dolerite dyke and sill system extends throughout the Fish and Sundays sub-areas. Small and large Karoo towns use groundwater from this aquifer system.

Groundwater use in specific areas

Uitenhage

The Uitenhage Arterial Basin lies in the Eastern Cape, and is South Africa's most important artesian groundwater basin, supplying approximately 1 400 Ml/year (44 L/s) of water from springs for domestic use in Uitenhage, as well as supporting large citrus irrigation schemes. Groundwater from this basin has been extensively utilised from the early part of the 20th century, including periods of over-exploitation results in the declaration of a groundwater control area to limit abstraction to sustainable rates.

WET FACT

The Uitenhage Nature Reserve was established around the Uitenhage springs. There are guided tours to the springs, a lookout tower and animal and bird enclosures.

The aquifer comprises fractured Table Mountain Group sandstones. Borehole yields commonly range from 5 to 10 L/s, and the groundwater quality is excellent, with low salinities. Water hardening, however, is required due to the acidic and corrosive nature of the groundwater, typical of other Table Mountain Group aquifer water in South Africa.

Groundwater at the Uitenhage springs flows from fracture Table Mountain Group sandstone at the foot of the Grootwinterhoekberge, approximately 8 km north-northeast of Uitenhage. The cumulative artesian flow rate from nine eyes is 45 L/s. The spring flow-rate has varied over time, especially in the period from the early 1900s to the 1960s.

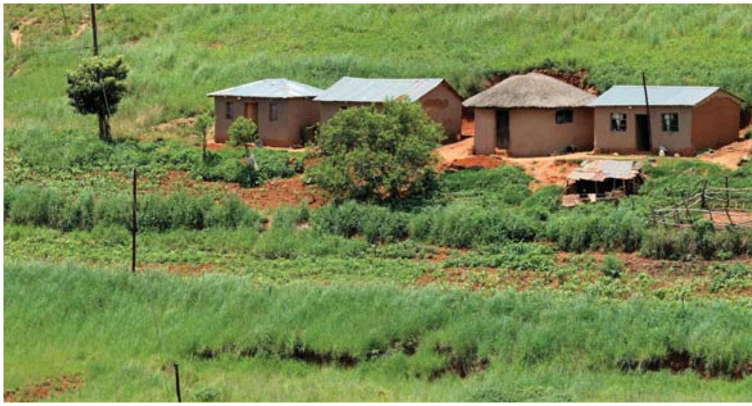
Port Elizabeth

In 1829, an enterprising businessman, Fortuin Weys, built a pump to pipe water from a well on the western edge of Market Square, in Port Elizabeth, to the beach, making it easier for sale and transport to ships. This well was unable to supply enough water for the town, however.

The first mention in the records of the municipality of Port Elizabeth dealing with water supply for the town was the receipt of a letter from Mr Coleman, dated 5 July 1848, submitting certain views on the subject. On 12 July 1848, the commissioners of the town decided to meet with him. At the same meeting it was decided to advertise for tenders for the sinking of a borehole, 5 feet in diameter, to hold no less than 6 feet of water. Only one tender was received from Mr Joseph Morton, and it was decided to sink the borehole near the property of a Mr Diesel.

KwaZulu-Natal

The majestic Drakensberg mountains in KwaZulu-Natal.



Rural huts dot the KwaZulu-Natal landscape. Many of these households depend on groundwater as their only water supply.

The landscape

This hilly province is home to the headwaters of our biggest rivers. Hence, high in the Drakensberg mountains, is where drops of rain gather, until a water mass meanders through the countryside. All the large rivers in the province, such as the Bushmans, the Mkomazi, the Mzimkulu and the Mzimvubu, have their source in the Drakensberg escarpment. The northern coastline is well known for the beautiful St Lucia estuary and Kosi Bay lakes.

The water situation

Historically, very little attention was given to groundwater in this province. It was considered a 'well-watered' province with adequate supplies of surface water. The severe droughts of 1982-1983 and 1991-1993 as well as in 1995-1996 changed this perspective, when water use restrictions were imposed, and attention was diverted to groundwater as a possible alternative source of water. Public as well as private organisations undertook major groundwater drilling and spring protection programmes in an attempt to alleviate the shortages of potable water, particularly in rural areas.

Groundwater utilisation is visible throughout the province, and uses range from domestic to stock watering, and even contribute to bulk water supply and industrial use. Most of the groundwater used in the rural areas is abstracted by means of handpumps, and only about 30% of all boreholes used on formal rural farms are equipped with motorised pumping units.

Aquifer types in the province are either intergranular, fractured or integranular and fractured.

Springs occur throughout the province. Although the average yield of the springs is about 0.05 L/s, there are small towns, such as Mount Ayliff and Kokstad, that are wholly or partially dependent on spring water for their water supply. A vast number of springs are used as a source for domestic and stock water in the southern rural areas. In the southern interior parts of the province, the slopes immediately below the bases of major Karoo dolerite sheets are usually characterised by spring lines. The average yield of springs in the northern parts of the province is 0.05 L/s. Next to the Swaziland border post at Mahamba is an exceptional spring with a yield of 7.5 L/s. Spring yields are strongly influenced by seasonal rainfall variations, with the yield of a spring of about 2 L/s in the wet summer months, which falls to about 1 L/s in the dry winter months.

WET FACT

Mont-Aux-Sources, the highest peak of the Drakensberg mountains, literally means 'mountain of fountains'. More than one important river has its origin here.

A number of true thermal springs – which have year-round groundwater temperatures in excess of 25°C – are found in the province. The Shushu thermal spring in the bed of the Thukela River, northeast of Kransklop, is the third-warmest spring in the country, with a water temperature of 53°C.

The use of groundwater in the region is constrained by the generally low yield of boreholes drilled into the secondary 'hard rock' aquifers. Despite this, groundwater is used as the sole source of water supply for some smaller urban communities, such as Blythedale Beach and Zinkwazi Beach. Some larger towns, such as Greytown, Richmond and Harding, use groundwater to supplement surface water supplies to ensure that the water demand can be met. In the major urban areas, few industries exploit groundwater, especially in the Pinetown area. Groundwater is also abstracted in the coastal areas, which include mining operations in the Richards Bay area.

Groundwater use in specific areas

Mnywaneni water scheme (Kokstad area) – The rural community of Mnywaneni, comprising some 96 households, are provided with a practical and sustainable source of water from two natural springs.

The municipality and the community have taken precautionary measures to protect the springs; they fenced off the area around the springs to keep animals away and put of a wall to stop polluted stormwater from entering the area close to the springs. The two springs are connected via a series of cleaning devices and isolation valves to a 30 kl reservoir, which ends in 22 communal stand-pipe units.

Groundwater at St Lucia – Research has revealed the following regarding the role of groundwater at the St Lucia estuary: The ecology of the St Lucia estuary is of unique international importance. During droughts, the estuary experiences high salinities, with values above that of seawater. Ion-poor groundwater flowing into the estuary from prominent sand aquifers along its eastern shoreline forms low-salinity habitats for salt-sensitive biota. During droughts, plants and animals can take refuge in the groundwater discharge zone until conditions in the estuary regains tolerable salinity. Simulations of the groundwater discharge indicate the flow can persist during droughts over at least a decade, and be of great importance of the resilience of the estuary. Human activities have reduced the river inflow and made St Lucia estuary more sensitive to droughts. The groundwater has thereby become increasingly important for the estuary's ecology. Protection of the groundwater discharge along the shoreline itself, and actions to increase the groundwater recharge are therefore important management tasks.

Groundwater plays an important role in the ecology of St Lucia.

Free State

Landscape

The Free State lies in the heart of the country, with the Vaal River forming the northern boundary and the Orange River the southern boundary. Most of the countryside is flat and this 'food pantry' of South Africa produces substantial quantities of maize, wheat, sunflower seed and sorghum. Towards Lesotho are the beautiful Eastern Highlands, with spectacular mountain scenery, character-filled towns and sandstone buildings. Gold mining, centred around Welkom, takes place on the safe reef that is also mined further north on the Witwatersrand.

The water situation

Various large dams in the province provide water to its inhabitants and associated activities. These include the Vaal, Sterkfontein, Welbedacht, Gariep, Vanderkloof and Bloemhof dams.

Throughout history, groundwater has been an important source of rural water supply in the province. It has been provided water for domestic needs, small vegetable gardens and stock watering. Even while larger towns generally had the finances to build their own dams and purification works, groundwater was used to supplement dam reserves in drought periods.

One of the largest groundwater abstraction points in the Free State takes place in the Welkom area, where mines of the Free State Goldfields are pumping approximately 33 million m^3 to the surface per year. Groundwater abstraction in excess of a million m^3 for irrigation occurs in the Petrusburg surroundings, north-west of Bloemfontein.

The following towns are dependent on groundwater as a sole source of water supply: Petrusburg, Phillipstown, Trompsburg, Fauresmith and Jagersfontein. There are also some towns that use groundwater as a supplementary and/or emergency source of water, including Jacobsdal, Hopetown, Koffiefontein, Petrusville, Phillipolis, Springfontein, Edenburg, Reddersburg, De Wetsdorp, Ladybrand and Smithfield.

Interesting groundwater places

The warm water spring at Florisbad (Brandfort district) has been used for recreational purposes for decades until it was closed in 1980. The water temperature of 29°C indicates a relatively deep circulation of this water down to the pre-Karoo bedrock of over 550 m below surface. The spring is associated with a dolerite dyke intruded into rock of the Karoo Supergroup. The decline in the spring flow rate over time could be linked to its artesian pressure drop caused by dewatering of the mines in the Free State Goldfields, located 100 km to the northeast of Florisbad.

Gauteng

Water from the Sterkfontein Dam, in KwaZulu-Natal, is pumped all the way to Gauteng in a sophisticated water transfer scheme.

The landscape

Geographically, Gauteng is not a distinctive region, but in many ways it is the heartland of South Africa. Gauteng is South Africa's smallest province, covering only 17 000 km^3, yet accounts for about 33% of the country's gross domestic product. The province is about 94% urbanised, with agriculture account for only 1% of total employment in the province.

The water situation

If Gauteng is the economic engine of South Africa, water is the fuel that keeps the engine running. But this powerhouse faces significant challenges around water and sanitation which, if not addressed adequately, could cause economic growth to grind to a halt.

With the Witwatersrand forming the watershed between the Vaal, Olifants, and Crocodile rivers, Gauteng has little of its own bulk water resources. This has made the province reliant on a series of complex transfer schemes, important water from the Thukela, Usutu, Komati, and Orange Rivers (the Lesotho Highlands Development Scheme). About 88% of the water-supply to the province is imported.

But this intricate web of bulk water infrastructure comes at a price. Water prices in the province have increased exponentially over the last few years. Customers of Rand Water, the main water supplier in Gauteng, now pay around 315.45 cents a kilolitre for purified water, with raw water costs accounting for 53% of the water utility's input costs. Unlike the rest of the country, irrigation is not the main user in the province. In fact, irrigation is only responsible for 6% of the annual bulk water consumption. Almost 80% of Gauteng's bulk water supply goes to the urban sector, with mining and industry being the second-largest water users (9%).

Gauteng's pollution concerns are worsened by the large population, mining and industrial developments and the short river sections. Although discharge standards for wastewater are high, the condition of the available streams and rivers is generally not healthy, and most are in a fair to poor state, especially those located close to the central watershed in Johannesburg and Ekurhuleni. At the same time, most of the major dams in Gauteng have unacceptably high levels of eutrophication, leading to algal production.

The high-density population, large-scale activities impacting on the environment in conjunction with the growing need for potable water in the province make water management a huge challenge. The role of groundwater is probably limited, and only innovative ideas will keep this economic engine running.

Interesting groundwater places

Cradle of Humankind – The Cradle of Humankind is a World Heritage Site which comprises a strip of a dozen dolomitic limestone caves containing the fossilised remains of ancient forms of animals, plants and hominids.

The dolomite in which the caves formed, started out as coral reefs growing in a warm, shallow sea about 2.3 billion years ago. As the reefs died off they were transformed into limestone, which some time later was converted into dolomite. Millions of years later, after the sea had receded, slightly acidic groundwater began to dissolve out calcium carbonate from the dolomite to form underground caverns. Over the time the water table dropped, and the underground caverns were exposed to the air. The percolation of acidic water through the dolomite also dissolved calcium carbonates out of the rock into the caverns, which formed stalactites, stalagmites, and other crystalline structures. Continued erosion on the Earth's surface and dissolution of the dolomite eventually resulted in shafts or caverns forming between the surface of the Earth and the caverns below.

Bones, stones and plants washed down these shafts into the caves; and animals and hominids fell into the caves; became trapped, and died. The bone and plant remains became fossilised and, along with various stones and pebbles, became cemented in a hard mixture, called breccia.

Together, these cave sites have produced over 850 hominid fossil remains, so that, to date, they represent one of the world's richest concentrations of fossil hominid bearing sites. The scientific value of this area lies in the fact that this site provides us with a window in the past; to a time when our earliest ancestors were evolving.

Pretoria fountains – The Pretoria fountains were originally the only source of water for the inhabitants of the city. The first water scheme was completed in 1890, and consisted of a 300 mm-diameter aquaduct laid from the fountains into town, and a cast iron pipe network served Pretoria Central and Trevenna. The Fountains Valley water scheme was supplemented in 1902 with a 900 mm-diameter concrete aquaduct laid by the British Army shortly after the South African War (1899-1902), and the 13.6 Ml Findlay Reservoir built on the southern side of the railway station. This system ensured that the suburbs of Arcadia, Muckleneuk, Sunnyside, Roberts Heights (the current Voortrekkerhoogte), Innesdale and other residential areas could be supplied with water. The daily water consumption was 21.48 Ml/day, which was virtually the supply capacity of the fountains in 1923.

During 1929, the Pretoria Town Council decided to purchase the water rights of the Rietvlei dolomitic fountains and Grootfontein, as well as the property on which the Rietvlei Dam would later be constructed. The farm was approximately 3 000 ha in extent.

The old pumphouse in Groenkloof from where water used to be pumped from the Pretoria Fountains to Roberts' Heights. Although all the machinery inside has been modernised, the pump house is still in use today.

Johannesburg – Mining magnate, Barney Barnato, built a grand mansion in Berea in 1897, and created a lake in front of it large enough for boating, in the surrounding five-hectare estate, now the large block surrounded by Park Lane, Beatrice Lane, Barnato Street and Tudhope Avenue. The lake was filled from the spring that is the source of the Braamfontein Spruit, and it was surrounded by landscaped gardens of conifers, some of which are still around today. One tree, a cork, still exists; its magnificent trunk rising up from the ground like a gnarled giant. Barnato never lived in his mansion – some believe he was pushed overboard from a passenger liner on his way to England in 1897, while others think he committed suicide by jumping into the sea. All that remains of his estate are three magnificent wrought-iron entrance gates (the fourth was stolen), and the original gatehouse, in Barnato Street, now used as a shelter for abused teenagers.

Limpopo

Venda, in Limpopo.

The landscape

The biggest part of the Limpopo Province consists of bushveld. The region generally has a hot, humid climate, with predominantly summer rainfall. The bushveld is cattle-ranching country, and only a few drought-resistant grains, for example, sorghum, are grown on a small scale. The province is also one of the most abundantly mineralised regions in the world. The Bushveld Igneous Complex, an unusually rich saucer-like formation, holds much of the world's reserves of metals such as platinum, chromium, nickel and vanadium. The significant mountain ranges interrupt these grassy plains: the Drakensberg escarpment on the eastern side, the Waterberg stretching from west to east and the Soutpansberg in the far north.

The water situation

Groundwater is available and widely used throughout the province, but in varying quantities depending on the hydrogeological characteristics of the underlying aquifer. Most parts of the province is populated with widespread rural communities. This is especially the case for the former Lebowa and Venda homeland areas. Groundwater is the main source of water supply to these rural communities although surface water is also used conjunctively where this is available. The quality of groundwater in these areas is generally good, particularly in the more mountainous regions.

The most intensive use of groundwater resources is from the deeply weathered and fractured granite north of Polokwane, and in the area around Dendron, where large abstractions for irrigation and domestic supply are practiced. Groundwater is also used to supply the platinum mine west of Mokopane.

Individual boreholes for stock watering and vegetable gardening are feasible virtually everywhere, with the exception of the Sand River Key Area, which appears to be over-exploited. Makapansgat, a cave of great archaeological significance, is found in this area, and the exploitation of groundwater will certainly hasten the formation of sinkholes in the area and possibly impact on the archaeological site. Applications have been made to declare this area a World Heritage Site, in which case the use of this groundwater could be problematic. Despite the high level of groundwater use in the province, the available groundwater resources are still generally under-utilised.

Substantial quantities of groundwater are abstracted for irrigation purposes in the north-eastern parts of Limpopo. In total, some 15% of all available yield from water resources in the eastern parts of the province is from groundwater.

The favourable climate and soils led to the development of the Levubu (or Albasini) Irrigation Settlement in the 1940s. Originally reliant on run-of-river diversions, this scheme soon led to the construction of Albasini Dam in 1952, and its subsequent raising in 1970/71. The dam is conveniently located to serve the irrigation scheme, but the catchment area is relatively arid, leading to low yields. Severe water shortages in the early 1990s prompted intensive development of groundwater to sustain high-yielding permanent fruit crops. The main concentration of the urban population around Thohoyandou relies on water supplies from the Vondo Regional Water Scheme in the Mutshindudi River, the most important tributary of the Luvuvhu River.

Interesting groundwater places

Bela-Bela – This hot spring, the reason behind the establishment of the town, was well known to traditional communities and to herds of game centuries before the first European settlers moved into the area. Tswana people, who lived in the region in the 19th century, called the spring *Bela Bela*, meaning 'he who boils on his own'.

The mineral springs flow at a rate of 22 000 L/hour, with a temperature of 53°C. The water from these springs is rich in sodium chloride, calcium carbonate and other salts that are highly beneficial to those suffering from rheumatic ailments. Originally, the Voortrekker, Carl van Heerden, established the first farm in this area at the mineral springs, and called it *Het Bad*. In present times, an extensive holiday resort was established.

Kruger National Park

Windmills are a regular sight in the Kruger National Park.

Stretching over the provinces of Limpopo and Mpumalanga, South Africa's largest nature reserve, the Kruger National Park, is highly dependent on groundwater, particularly in times of drought, when the rivers in the park tend to run dry. The first artificial waterhole was created on request of Colonel James Stevenson-Hamilton, the first park warden, in the early 1930s. Since then, many more boreholes have been drilled in the park to provide additional permanent water sources for game. However, in recent years it was realised that a high density of these artificial waterholes might have negative impacts on the biodiversity of the park. Areas that used to be grazed only seasonally were now being grazed year-round due to the availability of water throughout the year. As a result, a considerably number of boreholes have been closed.

North West

The landscape

This is the country of blue-green maize fields, cosmos-lined roads and dust storms. Rain increases from west to east, and the grass grows taller and greener.

The water situation

Groundwater is available in vast quantities in the North West Province, and there are different kinds of aquifers:

- **Dolomitic (karstic) aquifers** with dolomite that is porous. Groundwater may attenuate in dolomite.
- **Intergranular aquifers** – These are characterised by perched water bodies over a bed of clay.
- **Fractured** – groundwater flows through a crack in the underground rock formations.

Large quantities of water are abstracted from these aquifers, mainly for urban and irrigation use, while a significant portion of the baseflow of several tributary rivers originate as spring flow from these aquifers. Some dolomitic aquifers extend across the boundaries of water management areas while inter-connections also occur between aquifers.

Sandy aquifers occur along the lower Crocodile River, from which large quantities of water are abstracted for irrigation, and with much of the recharge from streamflow in the river. Sandy aquifers also occur in the catchment of the Molopo River. Over-exploitation of groundwater is experienced in the vicinity of Mafikeng and near the Molopo River, which may partly be attributed to reduced recharge as a result of surface water utilisation. Some aquifers in the region underlie the border with Botswana, and are shared by the two countries.

The remainder of the province is mostly underlain by fractured rock aquifers, which are well utilised for rural water supplies and with little undeveloped potential remaining. The quality of groundwater is generally of a high standard. High fluoride and iron concentrations, however, are found in the eastern parts. Apart from some bacteriological pollution in the Winterveld area, no significant pollution of groundwater has been recorded. Extensive irrigation activities occur along the major rivers, with game and livestock farming occurring in many parts of the province.

The Marico River is seasonal, and originates from groundwater at a dolomitic eye. The Marico River is one of the few perennial rivers in this part of the country. The eye is a fountain (17 m deep) with the pure, clean water. It is a favourite spot for Scuba diving and camping.

The dolomitic eyes are under pressure due to exploitation by irrigation. The Schoonspruit eye and river are similarly impacted.

Several springs occur in the area called Bo Molopo. There the dolomitic aquifer is compartmentalised by numerous impermeable dykes, with springs issuing on the dyke contacts. Some of them have been commercially used for water supply (e.g. Grootfontein). Other springs occur in the Potchefstroom area (Turffontein, Gerhardminnebron), and Ventersdorp (Schoonspruit).

WET FACT

The towns of Ventersdorp, Lichtenburg, Zeerust and Mmabatho are more than 90% dependent on dolomitic groundwater.

Mining places significant pressures on the North West Province's water resources. Mining activities require high volumes of water for production and for disposal of waste products into the used water, as effluent. Depletion of surface water resources due to mining activities is difficult to differentiate from the depletion of the groundwater, as mine-water balances are generally not measured. The deep mining operations in the Klerksdorp area are an example of the depletion of the aquifers in the vicinity of the mining activities.

There is pressure on the water supply for dryland crop production, as well as stock and game farming. Irrigation in the agricultural sector accounts for the greatest water use where the majority of water for irrigation is abstracted from groundwater.

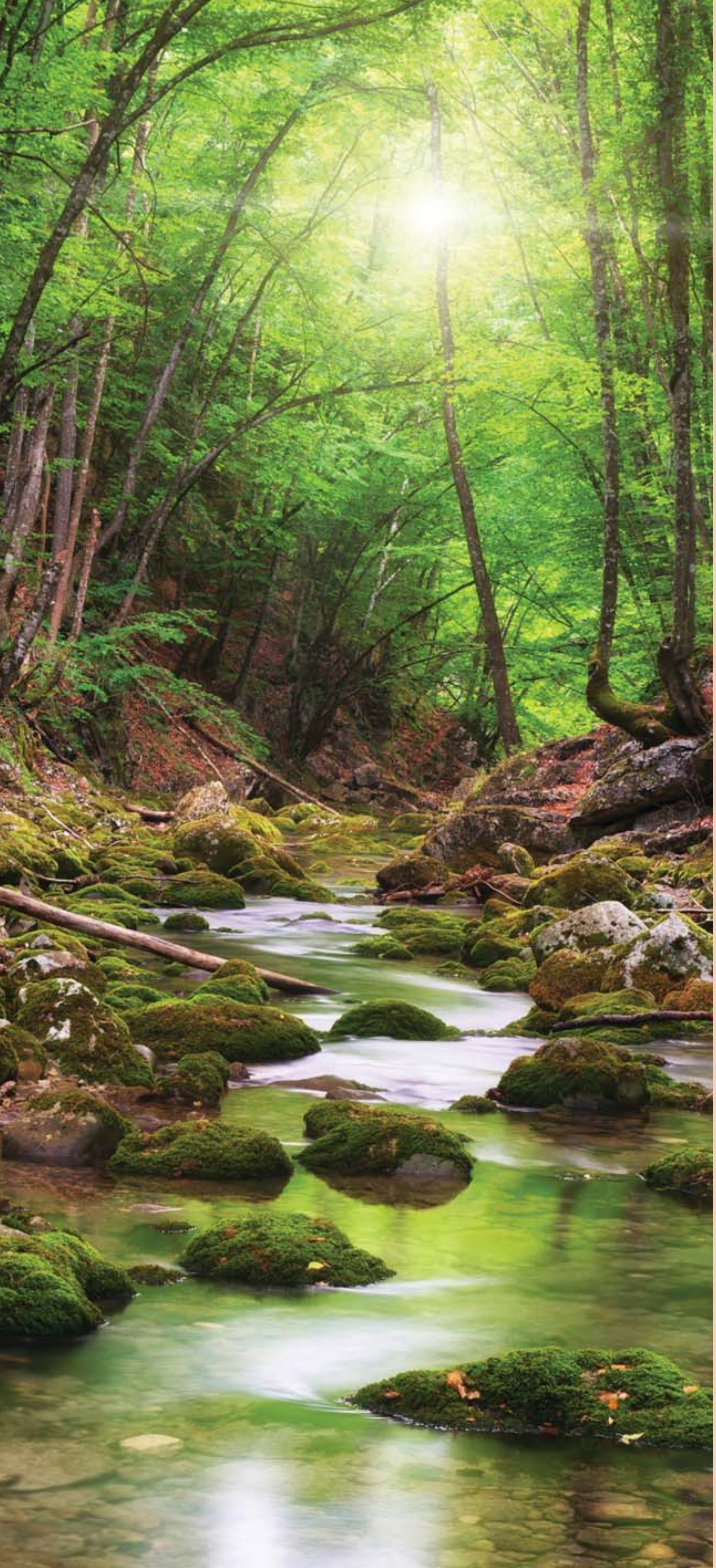
Interesting groundwater places

Dinokana – When you leave Namibia by car, you will probably travel from Zeerust to the Schilpadhek border post. On this road you will encounter the town of Dinokana.

With large pumps water is pumped from the Upper Dinokana Eye and distributed to standpipes in Dinokana and houses in Lehurutse. This groundwater source is the only source of water for inhabitants of these two towns. The Dinokana Lower-Eye is a local cultural and religious gathering place. Unfortunately, there is nothing left of the eye but a trickle, as a result of the overuse of the upper eye. The management of this linked resource is critical to preserve not only the water, but also to protect the cultural importance of this spot.

Dinokana spring, Wonderfontein.

Leaning reservoir of Itsoseng – South Africa's own tower of Pisa, the reservoir at Itsoseng is slowly 'sinking' into the ground and leaning over to one side. This is due to poor planning and construction. The subsurface cannot support a structure with the weight of a reservoir. For some reason, the exact spot for this reservoir has been identified within a depression of the landscape, where water accumulates and slowly infiltrates.



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WEBSITES

www.gwd.org.za
On this site you will get some basic information on groundwater, links to other interesting sites and news on current activities in the groundwater field.

www.dwa.gov.za/groundwater
This website tells you about groundwater research in the country by the Department of Water and Sanitation. You can obtain information in the form of maps, data sheets, reports and brochures.

http://water.usgs.gov/ogw
The United States Geological Surveys site with useful information on the basics of groundwater

www.geoscience.org.za
The Council of Geoscience can provide information, such as reports, maps and brochures on the geology of South Africa.

www.agwt.org
The American Groundwater Trust has an interesting website, especially for learners, students and teachers on groundwater topics.

www.groundwateruk.org
A British website with useful information on basics and educational information.

www.groundwater.org
Another useful groundwater website focusing on the basics of groundwater. The site provides much information for learners, students and techers.

www.wrc.org.za
The webiste of the Water Research Commission provides thousands of research reports, articles, presentations etc. on groundwater-related topics.

www.groundwater.com/groundwater_contamination.html
Sources of groundwater contamination, in graphic form.

CONCLUSION

With water demand expected to exceed water availability in South Africa in the next few decades, we will have to explore various options to reconcile demand and availability. One of these options is to increase the use of groundwater. This surely seems like a feasible option, especially since groundwater is underutilised in most parts of South Africa.

Groundwater is readily available just about everywhere, and usually requires no or minimal treatment to make it safe to drink. It is possible to supply a community with a groundwater supply in a few weeks as compared to the decades it takes to build a large dam. The total cost of groundwater infrastructure is minimal compared to the millions (or billions) of Rand required to build a dam. A borehole supply scheme can also be expanded as demand increases, provided that the aquifer can sustain increased abstraction rates. The resource also has important functions in improving food security, maintaining ecosystems, and inspiring us against drought and climate change. Improved scientific understanding and proper management of groundwater resources are therefore necessary.

Water, like religion and ideology, has the power to move millions of people. Since the very birth of human civilization, people have moved to settle close to it. People move when there is too little of it. People move when there is too much of it. People journey down it. People write, sing and dance about it. People fight over it. And all people, everywhere and every day, need it.

Mikhail Gorbachev

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Thank you for each and everyone that made a contribution to this book: from a story to a photograph and an interview. There are still loads of fascinating groundwater stories to be told; they are there waiting just beneath the surface of the minds of scientists, farmers and nature lovers. Hopefully some of these can be captured soon and so contribute to building our understanding of this blue planet of ours, so delicately and wonderfully created by our Heavenly Father.

WATER
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