TECHNICAL SERIES: 4

Karoo Aquifers in South Africa

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Department:
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EXECUTIVE SUMMARY

This document provides information on Karoo aquifers, designed to support and complement the information in the DWA generic guideline. Karoo rocks cover more than half of the land surface of South Africa, and although borehole yields are usually low (less than about 2 L/s) many farms, communities and towns depend on groundwater from these rocks. The geological groups making up the Karoo are generally well lithified and hard, and have little primary porosity and permeability. Groundwater storage and movement is usually via secondary features such as fractures, faults, bedding planes and dyke margins, which vary depending on the location. The success of a borehole often depends on whether such a feature is intersected during drilling. Unconsolidated aquifer material such as river alluvium overlying Karoo rocks is also a factor behind many successful Karoo boreholes.

The 1:500 000 scale hydrogeology map series published by the Department of Water Affairs provides median expected yields for boreholes in the Karoo (and elsewhere). These median yields do not include dry boreholes (many of which are not reported in any case), and the median may also mask considerable variation in expected yields. There are numerous examples of boreholes that yield considerably more that the median yields in parts of the Karoo. These boreholes have often been sited following considerable exploration work and research to understand secondary hydraulic features. Those siting boreholes for community or town supplies (“production boreholes”) need to bear in mind the possibility of yields that are higher than local medians, but also that sustainability of these higher-yielding boreholes is dependent on local conditions, which need to be well understood.

Average natural water quality in Karoo rocks is acceptable (450 – 1000 mg/L), but locally water quality can be poor due to high salt concentrations, or the presence of elements such as fluoride or nitrate, or both. Testing of water quality is essential. Karoo rocks are also vulnerable to pollution, since soil cover may be thin and fracture-dominated flow can mean pollutants move quickly, without much attenuation. Activities that disturb soil cover (e.g. burial of fuel tanks or domestic waste) are particularly likely to pollute groundwater. Groundwater pollution is difficult and expensive, or even impossible, to clean up. Vulnerability maps or assessments, and protection zones, are important tools in lowering the risk of groundwater pollution and should be considered when developing production groundwater resources.

This document is not designed to replace advice from qualified hydrogeologists. All but the smallest abstraction systems in Karoo aquifers will benefit from specialist advice at all stages of implementation - this is likely to save considerable time and money in the long-term.

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CHAPTER 1. INTRODUCTION

1.1 The Main Karoo Basin

Karoo Supergroup rocks in South Africa occur in several depositional basins. By far the largest of these is known as the Main Karoo Basin, covering an area of about 700 000 km2 (more than half of the total surface area of South Africa). This report concentrates on the Main Karoo Basin, although many of the points are relevant to the other smaller Karoo basins. The geological area known as the Main Karoo Basin covers more that just the semi-arid geographical area known as the "Karoo", but extends to the Eastern Cape coast (eastern part of the Basin) and as far north as Gauteng. See Figure 2 1 for the location of the Main Karoo Basin.

The Main Karoo Basin is defined as a "retro-arc foreland basin" (Johnson et al, 2006), which means a basin which has formed parallel to a mountain belt (in this case the Cape Fold Belt) on a geological plate that overrides another plate. The Main Karoo Basin is bounded by the Cape Fold Belt to the south, and the Karoo rocks are thickest close to that boundary (the "Karoo Trough"). The Basin generally thins out northwards against older rocks such as the Kaapvaal Craton. The main source of the sediments that filled the Karoo Basin was to the south. The Karoo sediments were deposited from the late Carboniferous (about 300 million years ago) to the early Jurassic (roughly 200 million years ago), and include glacial deposits, conglomerates, sands, silts, mudstones and igneous rocks. The Karoo rocks are famous for vertebrate fossils (especially the mammal-like reptiles known as Therapsids), extensive coal deposits, and the flood basalts that make up the Drakensberg mountains. Although most of the Karoo strata have relatively poor hydraulic properties, the sheer size of the Karoo outcrop in South Africa makes it of great interest to hydrogeologists. Many farms, communities and small towns rely on Karoo groundwater, despite generally low yields.

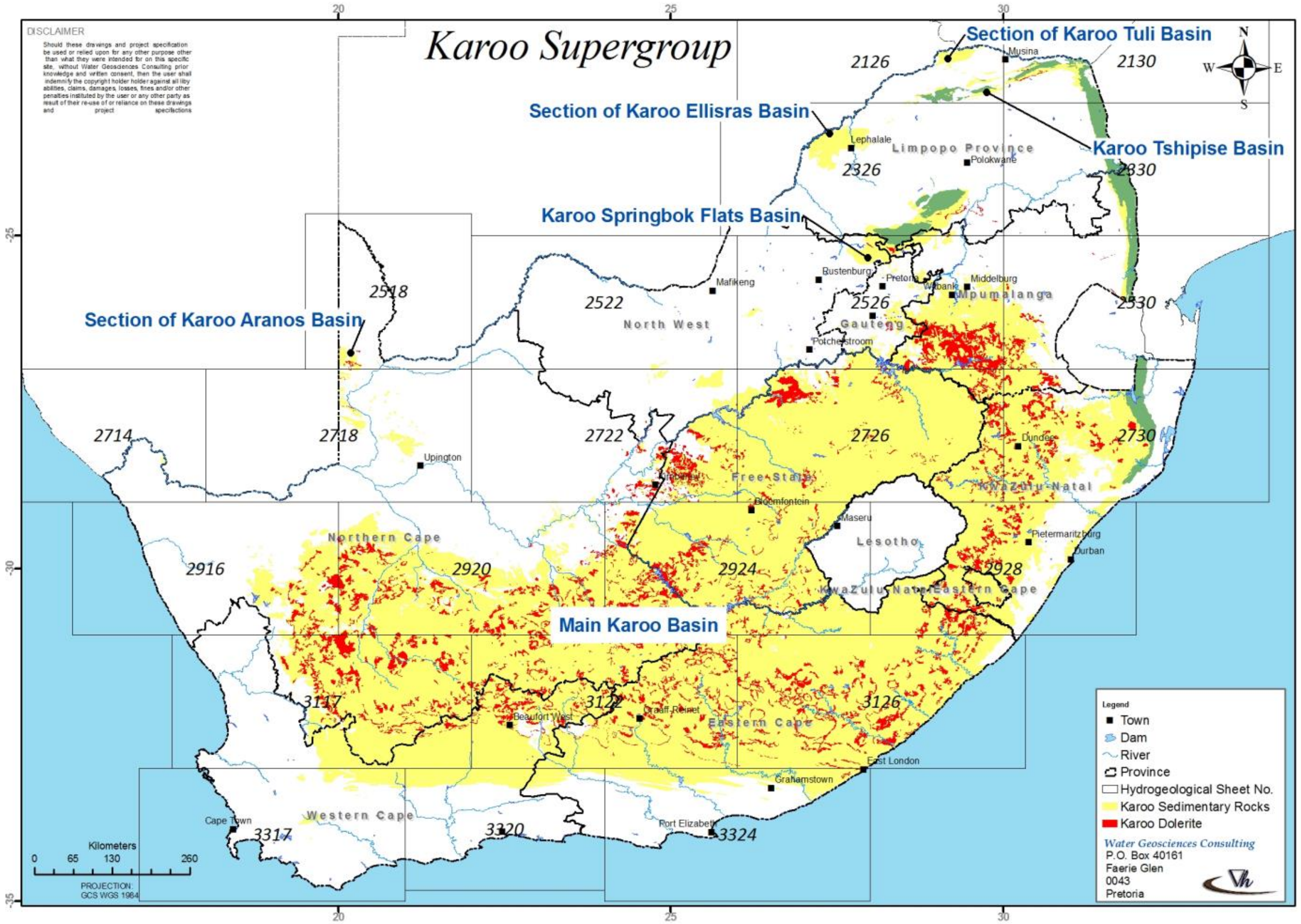


Figure 1-1: **The Main Karoo Basin**

1.2 Geology

The geological groups of the Main Karoo Basin are summarised in **Table 1-1**, and shown in **Table 2-1**. Johnson et al (2006) describe the geology and include diagrams of the groups and various formations.

Table 1-1: Simplified geology of the Main Karoo Basin

GROUP	Lithology	Sub-groups	Formations
Dwyka	Massive diamictite, with subordinate conglomerates, sandstones and mudrocks	Northern and southern facies recognised	Mbizane Fm in the north, Elandsvlei Fm in the south
Ecca	Mainly shales and sandstones	Can be divided into southern, western/northwestern and northeastern areas. Occurrence of formations depends on the geographical area – e.g. Vryheid Fm only found in northern part of basin.	Prince Albert Whitehill Collingham Vischkuil Laingsburg Ripon Fort Brown Waterford Tierberg Skoorsteenberg Kookfontein Pietermaritzburg Vryheid Volksrust
Beaufort	Mainly shales and sandstones	Adelaide (lower) Tarkastad (upper)	Koonap Middleton Balfour Abrahamskraal Teekloof Katberg Burgersdorp Molteno Elliot Clarens
Drakensburg	Flood basalt and intrusive dolerite. Interconnected network of dolerite dykes, sills and sheets. Flood basalts make up higher ground around Lesotho.		

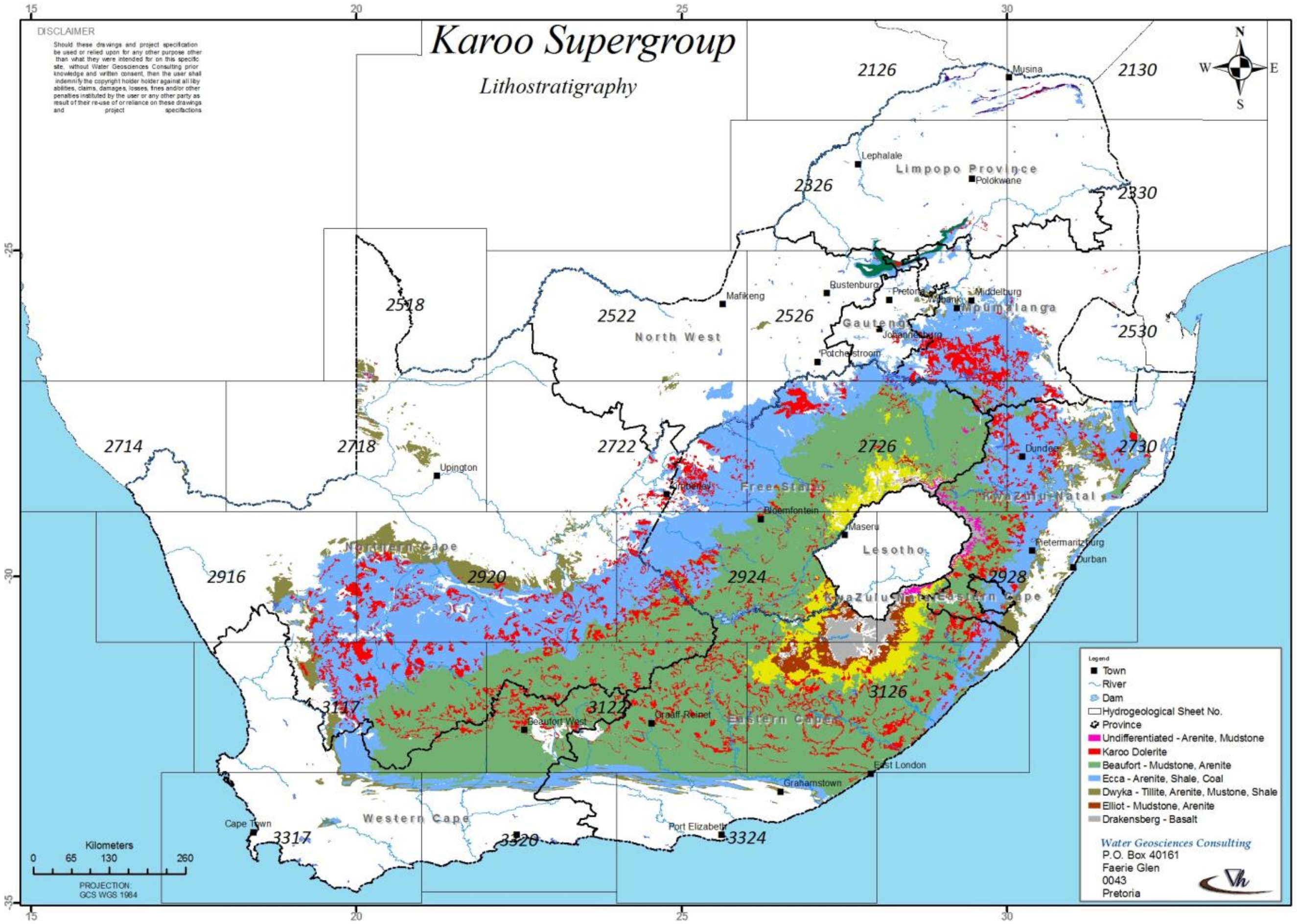


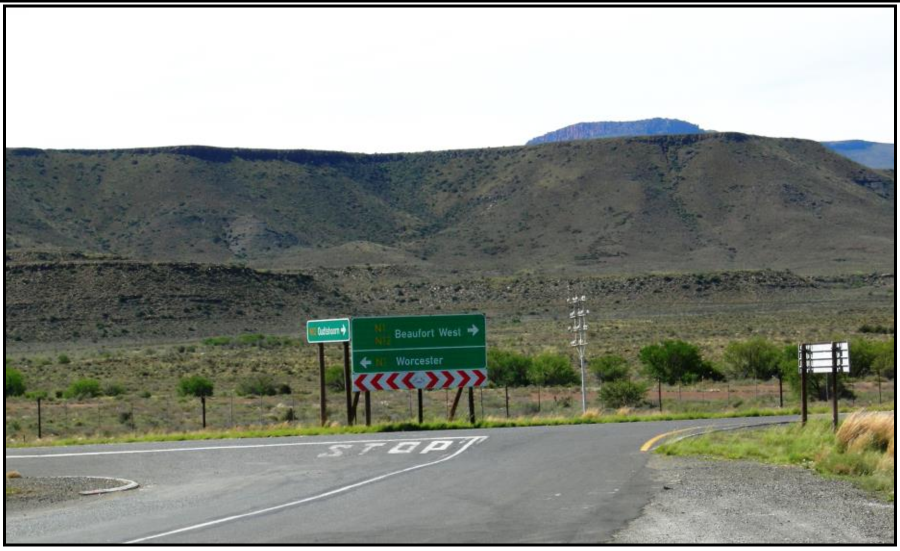
Figure 1-2: **Simplified geology of the Main Karoo Basin**

1.3 Hydrogeology

In general, Karoo rocks are well lithified and have low primary porosities and permeabilities. Groundwater storage and flow occurs in secondary openings such as fractures, faults, margins of intrusive bodies, and bedding planes. The success of a borehole in the Karoo rocks often depends on encountering one or more of these water-bearing secondary features. The sustainability of a groundwater supply depends partly on a sufficient network of interconnected fractures or other openings to continue to supply water to the borehole. Initial blow yields are therefore not always an indication of long-term sustainability.

There has been considerable research into groundwater in the Main Karoo Basin over the years, although relatively little has been done in the eastern part of the basin, where most people live and where there is high demand for water and sanitation. The coastal strip in particular, with its large rural population, is poorly understood (Murray et al, 2006). Good quality groundwater data is not always available, and data collected by the private sector is difficult to access. A lot of work has been aimed at understanding structures in the Karoo which might host high-yielding boreholes, such as dolerite ring-structures and tectonic lineaments, but anomalously high yields associated with these structures are still not perfectly understood. Most boreholes in the Karoo are drilled to depths of less than 100 m, although the occurrence of deeper groundwater is thought to be a possibility in some areas, particularly associated with certain types of dolerite intrusions.

The Main Karoo Basin is extensively intruded by dolerite dykes, sills and sheets, associated with the early Jurassic magmatism (Drakensberg flood basalts). The intrusions are interconnected, but have a range of compositional facies (Johnson et al, 2006). Fracturing, brecciation and alteration of the Karoo sediments by dolerite can increase storage and permeability. Dolerite intrusions (particularly dykes) are often targets for groundwater development. The margins of dolerite dykes are a common target for water borehole drilling, and dykes are often found using the magnetic geophysical method. A considerable amount of research has been carried out into how groundwater occurs in association with dolerite intrusions in different parts of the Main Karoo Basin, and it is recommended that further information specific to the area of interest is obtained before serious groundwater exploration begins. In some areas, borehole yields may be better away from dolerite intrusions. The southernmost part of the Main Karoo Basin (roughly south of Beaufort West) has little or no dolerite as it is underlain by rocks of the Cape Supergroup.



Sedimentary rocks of the Beaufort Group, dolerite intrusions and alluvium underlie the Karoo town of Beaufort West, which had 37 000 inhabitants in 2001. The small Gamka Dam supplies about a quarter of the town's water supply, but most domestic water comes from boreholes and springs. Boreholes of the town's wellfield supply about 1 600 000 m^3/a, or the equivalent of about 50 L/s pumping continuously (GEOSS 2005 and 2007). Transmissivities in the wellfield range from less than 10 m^2/day to more than 400 m^2/day and no direct correlation is seen between transmissivity and mapped geological unit (GEOSS, 2007). Borehole yields are generally less than 5 L/s, although higher yields have been recorded. Yields are generally higher when the contact zones with dolerite intrusions are targeted. Borehole rest water levels correlate closely with topographic elevation. A deep and a shallow aquifer have been identified, and the groundwater is thought to be divided into compartments by dolerite dykes – although some leakage is expected between compartments. Additional water supplies are needed by Beaufort West. Recent research into available groundwater supply options (GEOSS, 2007) has led to the definition of three main "groundwater response units", based on groundwater chemistry and piezometric response, and progress towards more efficient and sustainable management of the full groundwater resources available to the town.

Figure 1-3: Box on the groundwater supply at Beaufort West

The Karoo towns of Victoria West and De Aar are both dependent on groundwater for municipal suppyl. De Aar, in the Pixley ka Sema District Municipality, has a population of about 46 000 people. It is situated at about 1 300 m above sea level, and has a mean annual rainfall of only about 300 mm. The name "De Aar" means "The Artery", and is a reference to the strong perennial spring (thought to originate in underground "arteries") around which the town was founded. Reputedly South Africa's second largest rail junction, today the town of De Aar still obtains its water supply from groundwater via a network of 68 boreholes. The town struggled to meet demand for water (despite the spring) until the mid 1930s when the municipality purchased the entire subterranean water supply of the village of Burgerville (about 34 km away) for use by De Aar. It is estimated that about 1 620 000 m^3/a (about 52 L/s if pumping continously) is supplied to De Aar, partly by boreholes and springs in and around Burgerville. Little remains of Burgerville today apart from ghostly traces of the former grid of streets – see satellite image below:

The small Karoo town of Victoria West was founded in 1855 on the banks of the ephemeral Brakrivier, and today has a population of about 11 000 people. It is located on the N12 highway about half way between Cape Town and Johannesburg. Victoria West derives its water supply entirely from groundwater sources – 20 to 30 % from boreholes to the east and west of the town, and the rest from more distant boreholes around the small town of Hutchinson about 13 km SE of Victoria West. In 2001 the total water demand for Victoria West was estimated at between 220 400 m^3/a and 334 000 m^3/a (between about 7 and 11 L/s, if pumping continuously) (Chevallier et al, 2001). A small dam on the Brakrivier to the immediate west of the town was built in 1918 following flooding in the early 20th century, but this is used mainly for irrigation purposes and not for potable water supply.

Figure 1-4: Box on groundwater supplies to De Aar and Victoria West

CHAPTER 2. Groundwater Development and Conceptual Understanding of Primary Aquifers

2.1 Existing classifications of Karoo aquifers

There have been a number of studies over the years aimed at broadly classifying and quantifying the groundwater resources of South Africa, including the Karoo. These studies are useful in gaining an overview of regional potential, but are not a substitute for site investigations. They are briefly described below:

2.1.1 The Groundwater Resources of South Africa

In 1995 a report and accompanying set of groundwater maps known as the "Groundwater Resources of South Africa" was published by the Water Research Commission (Vegter, 1995). The maps were based on analysis of data from approximately 120 000 boreholes held by the Department of Water Affairs. The seven national scale maps on two A0 size sheets were a first attempt at a visual representation of South Africa's groundwater resources, and are as follows:

- Borehole prospects
- Saturated interstices
- Depth of groundwater level
- Mean annual groundwater recharge
- Groundwater component of river flow
- Groundwater quality
- Hydrochemical types

These groundwater maps did not directly address the problem of "sustainability". In 1998 a Groundwater Harvest Potential map was compiled (Baron et al, 1998), which estimated the total sustainable volume of groundwater that could be extracted annually in South Africa for different areas. Regional estimates of storage and recharge were used to calculate this sustainable yield (Woodford et al, 2006).

2.1.2 The National Hydrogeology Maps

At the same time as the above national scale maps were being compiled, the Department of Water Affairs (DWA) began to develop a series of twenty-one 1:500 000 scale hydrogeological maps covering South Africa. The series was completed in 2003. The maps in this report have a grid showing the area covered by each hydrogeological map. Each hydrogeological map will also be accompanied by an explanatory brochure, and to date nine of the brochures have been finished. These maps and brochures currently provide the best general overview of groundwater prospects in the Karoo. They should be consulted at the feasibility / planning stage of any proposed groundwater development. However, siting of boreholes and detailed planning of groundwater schemes require more information, including site investigations.

The groundwater classification on the Hydrogeological Map Series includes four classes of aquifer overlying a simplified geological background represented by a letter as follows:

- Intergranular (type a)

- Fractured (type b)
- Karstic (type c)
- Fractured and Intergranular (type d)

The land area is furthermore divided into five productivity or "borehole yield" classes, ranging from 0-0.1 L/s to >5 L/s, and numbered from 1 (lowest yield class) to 5 (highest yield class). Thus an alphanumeric code is assigned to any area providing information on both the mode of occurrence and the yield class.

The Hydrogeological Map Series includes schematic cross sections showing typical groundwater occurrence, as well as a series of four inset maps as follows:

- Distribution of borehole data (1:2 000 000 scale)
- Elevation above sea level (1:2 000 000 scale)
- Mean annual precipitation (1:2 000 000 scale)
- Groundwater quality (1:1 500 000 scale)

Note that borehole yields are based on a median of available data, and that data in parts of the Karoo is scarce. The maps in this report are based on the same national hydrogeological dataset underpinning the maps, although they do not go into the same detail as the maps and booklets.

2.1.3 South Africa's Groundwater Regions

A long-term project recognising the subdivision of the country into 65 "Groundwater Regions" has been underway since the early 1990s (Vegter, 2001). These regions are based on the occurrence of groundwater (mainly type of porosity – i.e. primary or secondary) as well as on lithostratigraphical, physiographical and climatic considerations (Vegter, 2001). It is intended that each region will ultimately have a separate groundwater report and map or maps, explaining and depicting groundwater occurrence and conditions in the region in detail. Groundwater issues including methods for geophysical exploration, recharge, hydrochemistry and the siting of boreholes are discussed in the reports. Sixty-four Groundwater Regions have been defined, and to date four of the reports have been completed (Vegter, 2006). The completed reports are available from the Water Research Commission (WRC). The Groundwater Regions work is continuing as resources and skills allow, with at least one further region currently in the pipeline.

Unfortunately none of the regions which have been completed so far cover the Main Karoo Basin, but the report outlining the project (Vegter, 2001) does include information on the history of groundwater development in the Karoo and a scheme for processing borehole data on the Karoo strata and dolerite. The report includes a map of the Groundwater Regions, and approximately 20 Regions cover the main Karoo basin.

2.1.4 ISPs and other planning documents

South Africa is divided into 19 Water Management Areas (WMAs). An overview of water resources in each WMA and suggestions for improving management of water is currently provided by documents called Internal Strategic Perspectives (ISPs). Each WMA has at least one ISP (some have two or more). The ISPs usually have a short groundwater section, which can provide useful and relevant information for groundwater exploration and management. It is recommended that they be consulted prior to serious groundwater development.

District and Local Municipalities in South Africa are also required to draw up Integrated Development Plans, aimed at coordinating all development in each municipality, as well as Water Services Development Plans, aimed specifically at water services. These documents in general do not carry much technical information about groundwater, but it may be useful to consult them prior to any groundwater development plans, and also to ensure that groundwater development forms part of any revisions to these documents. Groundwater development can have important economic spin-offs (e.g. improved irrigation) and these need to be acknowledged. Groundwater development aimed at basic public water supplies should form part of municipal spatial planning, and consultation with relevant municipal officials is necessary.

2.1.5 The NORAD documents

The NORAD Toolkit for Water Services is a collection of documents, software and maps aimed at improving the management of groundwater at municipal level in South Africa. The work was divided into seven separate projects ranging from an audit of water supply schemes to the writing of guidelines and standards and was completed in 2003. The work was a collaborative venture carried out with the support of the Norwegian Agency for Development Cooperation (NORAD). Deliverables are aimed at municipalities, water services authorities and providers, national water authorities, NGOs and consumers.

The outputs (documents, maps, etc) of the NORAD programme include the following:

- Thematic groundwater maps for each province (excluding Gauteng) giving basic information on administrative boundaries, water quality and depth to water level.
- Groundwater software, including
    i. Software for auditing and comparing water services (SUSIT)
    ii. Software for organising and interpreting groundwater data
    iii. GDAS software for providing easy access to groundwater data held at DWA and CGS
- Documents providing information and guidelines on the following:
    i. Overview of rural groundwater monitoring and management
    ii. Standard descriptors for geosites
    iii. Groundwater protection
    iv. Groundwater monitoring for pump operators

All of the NORAD outputs are available on the DWA website at http://www.DWA.gov.za/Groundwater/NORADtoolkit.asp

2.2 Research in the Main Karoo Basin

The following table summarises some recent groundwater studies in the Main Karoo Basin (after Murray et al, 2006):

Table 2-1: Summary of some previous groundwater research in the Karoo

Name / Author / Date	Available from	Summary
Geological and hydro-morpho-structural analysis for groundwater potential in rural water-stressed areas in the Mzimvubu to Keiskamma Mater Management Area (WMA No 12) Chevallier L et al, 2005	Council for Geoscience, Bellville, Cape Town.	Study of the hydrogeological properties of fractures, lineaments and intrusions in the study area. The study concluded that lithostratigraphy and morphology most important factors re borehole yield. Lineaments of certain orientations produced higher yields. However, the study highlighted some important gaps in our understanding of the hydrogeology of the area. For example, boreholes close to dolerite intrusions such as dykes and rings had *lower* yields than those further away from these features. The same applied to satellite lineaments. Yields of boreholes drilled on fracture systems were lower than other boreholes. These conclusions contradict many conceptual models of Karoo hydrogeology and emphasise the need for further work in this area. Data is also lacking, and spatial accuracy poor.
Hydrogeology of the Main Karoo Basin: Current Knowledge and Future Research Needs Woodford AC and Chevallier L (eds.) 2002	Water Research Commission (WRC Report No. TT 179/02)	This comprehensive report summarises work in the Karoo Basin, discusses various techniques, and sets out recommendations for future work. Includes details of methods used to investigate Karoo aquifers (e.g. geophysics), discusses past studies, and makes recommendations re the siting, drilling and construction of boreholes.
The Influences of Dolerite Sill and Ring Complexes on the Occurrence of Groundwater in Karoo Fractured Aquifers: A Morpho-Tectonic Approach. Chevallier L et al, 2001	Water Research Commission (WRC Report No. 937/1/01)	Dolerite ring and sill complexes in the Karoo basin are classified into three basic “morpho-tectonic models”. Borehole information indicated that groundwater is partly dependent on terrain slope. “Open” fracturing was shown to be developed at certain structurally controlled positions. A detailed local field investigation was carried out in the Victoria West area (assessment of existing data, mapping, and drilling of 67 test boreholes). Many of the boreholes were high yielding (13 to 70 l/s), and an increase in yield with depth was recorded. The authors make recommendations for further research.
Exploitation Potential of Karoo Aquifers Kirchner et al, 1991	Water Research Commission	This report aimed to develop a method for assessing the exploitation potential of

Name / Author / Date	Available from	Summary
	(WRC Report No. 170/1/91)	Karoo aquifers, and hence considered recharge in some detail. Mean recharge in the Karoo basin was calculated at around 2-4% of rainfall, although this was shown to change considerably depending on the nature of surface material (e.g. alluvium increases recharge). Recharge was found to be mainly via preferred pathways, occurring chiefly following “extreme” rainfall events every few years or so. Field research included the drilling of 96 boreholes, a series of pumping, step and packer tests, the installation of neutron probes, and the monitoring of precipitation. Groundwater chemistry is presented but not discussed in detail.
Karoo Aquifers: Their Geology, Geometry and Physical Properties Botha JF et al, 1998	Water Research Commission (WRC Report No. 487/1/98)	Karoo aquifers found to have complex geometry, which determines their hydraulic behaviour. Modelling was carried out based on data from a single test site, although it proved impossible to develop a new numerical model for the analysis of Karoo aquifers. Recommendations include the “proper management of aquifers”, based on the concept of safe yields. The collection of better data, including detailed geological logs, discharge rates and piezometric levels, is recommended.
Karoo Aquifers. Deformations, Hydraulic and Mechanical Properties Botha JF and Cloot AHJ, 2004	Water Research Commission (WRC Report No. 936/1/04)	Stressing of Karoo aquifers by pumping can cause aquifer deformation and irreversible damage. A numerical model of a hypothetical fractured aquifer was developed, and tested using pumping test data from a single test site. Aquifer deformation was not observed in the field. Not enough is known about the properties of Karoo aquifers to determine “safe” pumping rates that will not damage the aquifer.
Groundwater Research Needs in the Eastern Karoo Basin of South Africa Murray R, Cobbing, J, Woodford A, Ravenscroft	Water Research Commission (WRC Report TT 286/06)	Provides a synopsis of groundwater research needs in the Eastern Cape Province (eastern part of the Main Karoo Basin), aimed at improving water supplies and sanitation. Includes summaries of past research, and an overview of

Name / Author / Date	Available from	Summary
P and Chevallier, L. 2006		planning and institutional issues related to groundwater development in South Africa. This part of the Basin has received relatively little attention in the past.

2.3 Groundwater exploration in the Karoo

Relatively low yielding boreholes (e.g. supplying farms and for stock watering) are the norm in the Karoo, with windmills often used to pump the water. These boreholes may be sited using basic geophysics (magnetic traverses to locate dykes) or even by assessing the local topography and geology in the field. Many boreholes have been sited by water diviners, and this still continues today. A “step-up” from farm boreholes are those boreholes intended to supply communities or towns, where higher yields and better reliability are required. These boreholes (“production boreholes”) should be sited with care by a hydrogeologist to get the best results. Extra investment in borehole siting, drilling and borehole construction will repay itself in the form of a more reliable groundwater supply. Careful data collection during drilling (exact location, logging of chip samples, penetration rate, logging of water strikes, full construction details, etc) is needed to ensure the best borehole construction and to help solve hydrogeological problems which may arise. Properly sited production boreholes may have yields several times that of the regional median.

A groundwater exploration programme aimed at drilling production boreholes should begin with an assessment of available groundwater data, leading to an understanding of the structures and environments most suitable for groundwater exploitation (DWA, 2008). Often this will be associated with dolerite dykes or tectonic lineaments, but local features such as river alluvium can be very important. In some areas, particular structures (e.g. dolerite ring structures in the Queenstown area of the Eastern Cape Province) have an important bearing on groundwater occurrence. The national hydrogeological maps (and booklets) together with research reports and borehole data from the Department of Water Affairs and elsewhere give an idea of the most likely yields, water quality, depth to groundwater and other important factors.

Aerial photographs and satellite images are used to give an overview of the area (e.g. drainage patterns, topography) and to identify lineaments such as dykes and faults. Remote sensing is usually followed by field investigations, which often include geophysical traverses done on foot in the field. Common geophysical techniques in the Karoo rocks include magnetics, electro-magnetics and resistivity, or a combination of these. Airborne geophysics can be used to map larger areas, but is expensive. Interpretation of geophysical results should be done by an experienced geophysicist.

There are many examples of boreholes in the Karoo that yield considerably more water than the median yields in the area suggest. In many cases these boreholes have been carefully sited using scientific techniques. On the Queenstown hydrogeological map there is an area of large-scale groundwater abstraction around the town of Queenstown, in which several boreholes with yields in the range 0.1 – 1 Mm3/a (3 – 30 L/s) are marked, all falling on Beaufort Group sediments marked “d3” (i.e. median yields of 0.5 – 2 L/s). The towns of Sterkstroom, Burgersdorp, Tarkastad, Komga, Jamestown, Bedford, Adelaide and Thornhill all marked as having “domestic” abstractions of the same magnitude (i.e. 3 – 30 L/s) on the same map, also in “d3” Beaufort Group rocks. A study in the Victoria West area by Chevallier et al (2001) sited several boreholes with yields in the range 13 – 70 L/s in Karoo rocks associated with dolerite intrusions. Median yields in the area are considerably lower than this. However, exploration for high yielding boreholes in the Karoo can be problematic in some areas – for example, Murray et al (in press) carried out considerable fieldwork in the Butterworth area in the eastern Karoo Basin (Adelaide Subgroup of the Beaufort Group) aimed at groundwater associated with the margins of dolerite sills and associated feeder dykes. Despite remote sensing, geological models and field geophysics, no high-yielding boreholes were found (15 boreholes were drilled, 2 boreholes were dry, the median yield of the rest was 1.2 L/s, and the highest blow yield was 4 L/s). However, the area is notorious for low yields and dry boreholes, and even the small supplies of groundwater found are important in the area given the steep topography and difficulty in establishing safe and sustainable surface water supplies.

2.4 Borehole construction in Karoo rocks

Karoo boreholes are typically less than 100 m deep, and many are less than 50 m deep. There is some evidence for deeper groundwater in parts of the Karoo, but shallower horizons appear to yield most groundwater. Many boreholes in fractured Karoo rocks are constructed by placing a short length of casing to just below the weathered or unconsolidated zone, and then leaving the hole open (i.e. no casing) below (**Figure 2-1**). This is the simplest and cheapest method, but there is a risk that rocks will detach from the borehole walls and block the hole, trap the pump, or cause other damage. If there is no casing, a gravel or filter pack cannot be used or developed, risking fine material entering the borehole (Woodford and Chevallier, 2002). For production boreholes, it is recommended that screen and casing is used for the full depth of the borehole, with the screen positioned adjacent to fracture zones or zones of water inflow. Most Karoo boreholes have diameters in the range 100 mm to 250 mm (roughly 4 to 10 inches), but specialist installations such as wells with adits in alluvial material overlying Karoo rocks can have much larger diameters. Drilling in the Karoo rocks is usually by means of air-flush rotary percussion.

Boreholes in unconsolidated material (e.g. alluvium overlying the Karoo rocks) should be screened throughout the water bearing horizons, and cased elsewhere (Figure 2-2). A suitable gravel pack should be used to stabilise the borehole and prevent the ingress of fine material. Exploiting groundwater in river beds may require specialist technologies (e.g. large diameter shallow wells with adits, or a wellpoint system), and these need to be protected against irregular flooding. See the Primary Aquifers Appendix for more information.

All boreholes should be completed with a suitable surface sanitary seal (the top of the casing sealed with concrete) to prevent surface water entering the borehole down the outside of the casing. Steel casing and screen can corrode in Karoo groundwater, depending on the water chemistry, and PVC screen and casing should be used if necessary (Woodford and Chevallier, 2002).

A common problem with production boreholes in Karoo aquifers is the over-estimation of borehole sustainable yield, and the use of a pump of an unsuitably high capacity. Pumping at too high a rate can lead to the water level in the borehole (not necessarily in the adjacent aquifer) being drawn down to the pump intake. This can damage the pump and allow air into the deeper levels of the aquifer, causing fouling by iron bacteria and screen blockage by chemical precipitation. Allowing the water level in the borehole to drop too far also raises pumping costs. A pump and pumping rate should be chosen which gives only a moderate drawdown. Pumping at a higher rate does not necessarily yield more water in the long term and can cause expensive damage.

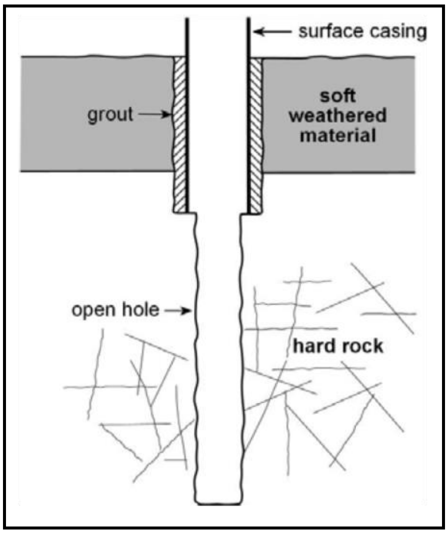


Figure 2-1: Schematic borehole design for hard formations (after MacDonald et al, 2005)

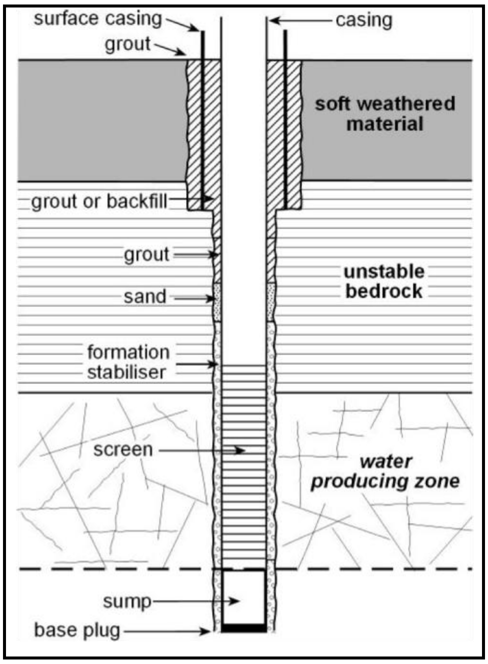


Figure 2-2: Schematic borehole design for unstable formations (after MacDonald et al, 2005)

2.5 Pumping tests in Karoo aquifers

The interpretation of pumping tests in Karoo aquifers must take into account the existence of discrete, water-bearing features such as fractures and bedding planes. Once dewatered, these features can lead to a sudden increase in drawdown with time. Many Karoo pumping tests are interpreted using the “FC Method” spreadsheet, developed by the University of the Free State, which applies a range of mathematical solutions to the pumping test data. As with any pumping test solutions, these should be treated with caution, particularly where pumping tests are of only short duration. In particular, assumptions about borehole sustainability which are based on only short pumping tests need to be resisted – this is because low storage and poor recharge (**Figure 2-3**) in parts of the Karoo can lead to declines in borehole performance as local storage is exhausted. See Woodford and Chevallier (2002) for more information on pumping test interpretation in Karoo aquifers.

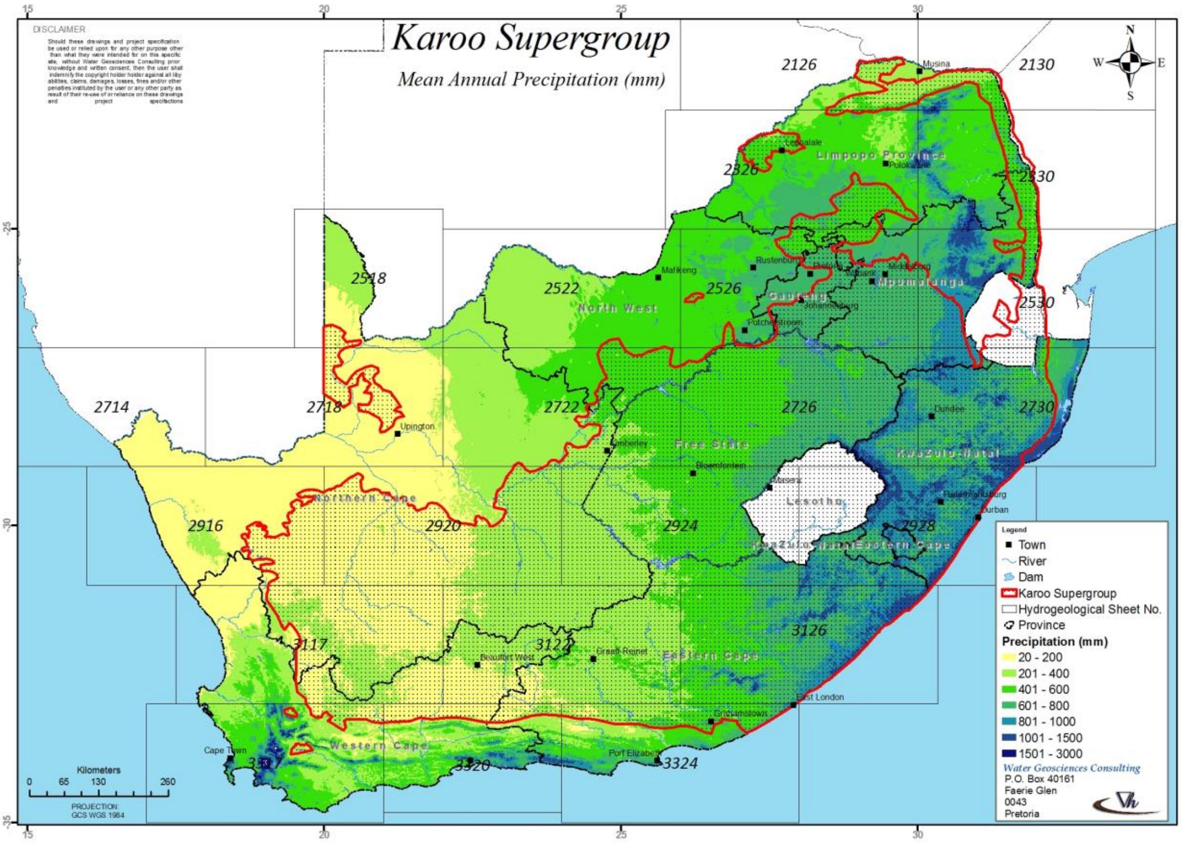


Figure 2-3: Mean Annual Precipitation across South Africa

2.6 Groundwater quality

Most of the Main Karoo Basin has total dissolved solids (TDS) concentrations in groundwater in the range 450 – 1000 mg/L, which is within generally accepted drinking water limits (Woodford and Chevallier, 2002). However, low recharge, an arid climate and long residence times can mean that some Karoo groundwater is mineralised beyond acceptable standards. Changes in climate patterns are thought to be the main factor controlling the concentrations of major dissolved elements (Woodford and Chevallier, 2002), although other factors such as aquifer lithology and hydraulic properties, groundwater depth, vegetation and soil cover, and topography all have an impact on natural groundwater quality. The total dissolved solids content of groundwater in general increases from east to west across the basin, in line with declining precipitation. Groundwater in the Dwyka Group is often brackish or saline, due to long residence times and the presence of connate water. Naturally-occurring minor dissolved elements such as fluoride, nitrate and iron can occasionally be above drinking water limits in Karoo rocks. This is often found in parallel with high concentrations of salts in general, but is sometimes associated with specific rock types (e.g. volcanic pipes) in which groundwater is otherwise of reasonable quality.

Groundwater quality can vary over quite short distances, and poor quality water can be found in generally good quality areas, and vice versa. Groundwater intended for drinking water supply should be tested by an accredited laboratory to establish whether it is safe to drink. This can normally be done cheaply and quickly. National-scale water quality maps (e.g. the insets on the national hydrogeological map series) are only intended to give a regional overview of water quality and not to guide individual water supply schemes.

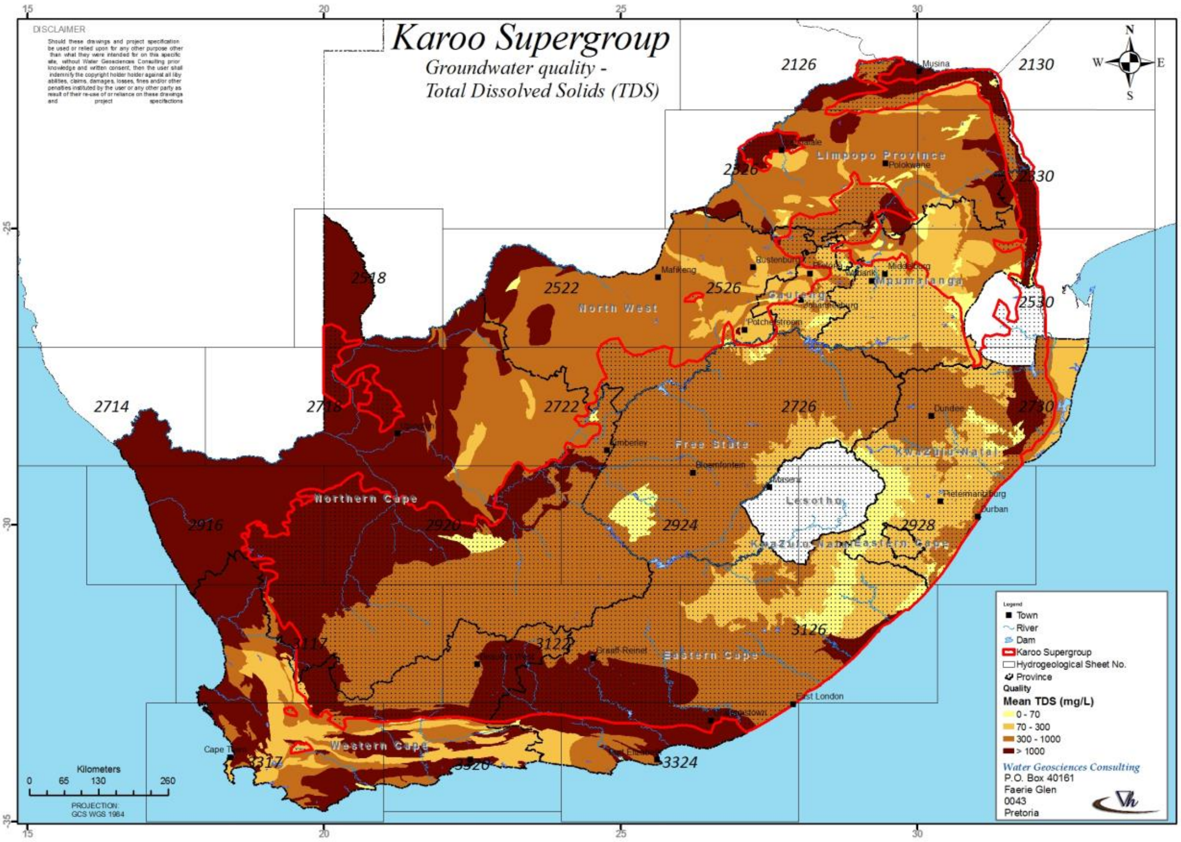


Figure 2-4: **Total Dissolved Solids (TDS) in Karoo groundwater**

Windmills have been used since the nineteenth century to pump groundwater, and thousands are in use in South Africa today. The torque provided by the large number of blades means that even quite low winds turn the wheel, which is oriented into the wind by a tail. If the wind speed is too high, a mechanism turns the wheel out of the wind, preventing damage to the windmill. The rotation of the wheel is converted by a crank and gearbox to the up and down movement of the pump rods, which steadily bring groundwater to the surface via a submersible borehole cylinder.

Apart from basic maintenance (e.g. checking gearbox oil, tightening rods, checking cylinder and seals, which can be done yearly) windmills need little attention, and can operate for years in harsh conditions. Farmers who manage large stock farms (such as those found in the Karoo) rely on their windmills to provide stock drinking water in the semi-arid environment. Many windmills also provide drinking water to farms, homesteads and small communities in the Karoo. Amongst others, the well-known "Climax" brand of windmill is still available in South Africa (via Southern Cross Industries, based in Bloemfontein). Boreholes pumped by windmills need to yield enough water to ensure that water levels do not drop below safe limits even in periods of constant wind. A small windmill can pump about 4 000 L/day (about 0.05 L/s) assuming average wind speeds of about 4 m/s (Beaufort Scale of 3, or "gentle breeze"). Large windmills can pump 20 times this amount (i.e. about 1 L/s) or higher in the same conditions. Windmills can pump water against heads of several tens of metres. These characteristics make them suited to Karoo aquifer conditions, where yields from most boreholes are relatively low, and depths to groundwater can be considerable.

Figure 2-5: Box on Karoo windmills

CHAPTER 3. GROUNDWATER PROTECTION AND VULNERABILITY

3.1 Borehole design

Once groundwater is polluted it is difficult and expensive to clean it up – and in some cases practically impossible. It is much cheaper and easier to prevent the pollution in the first place. The first step towards protecting a borehole is to ensure that it is constructed properly and securely. There should be a concrete (or bentonite clay topped with concrete) sanitary seal at the top of the casing to prevent any surface water or contaminants "short-circuiting" the soil zone and entering the groundwater down the outside of the borehole casing. Boreholes should also be securely capped and locked to prevent any contaminants being put into them. Boreholes in areas which might be flooded (e.g. flood plains, dry river beds) may need to be specially designed to prevent flood waters entering them or damaging them. Production boreholes should be securely fenced off and locked to discourage vandalism. These basic precautions can save large amounts of money.

3.2 Groundwater protection zones in the Karoo

A common method that is used world-wide to help protect groundwater quality is to establish areas or "protection zones" around groundwater abstraction points (and sometimes well fields and even whole aquifers too) within in which activities that may pollute groundwater are controlled. Protection zones can be defined in various ways, ranging from simple circles drawn around boreholes (assuming a homogeneous, isotropic aquifer and no regional groundwater gradient) to zones of complex shape derived using numerical groundwater modelling and taking into account aquifer properties, topography, groundwater flow direction and recharge. They can vary in size from a few tens of metres around a borehole to hundreds of square kilometres protecting an entire recharge area. The final protection zone or zones that is decided will depend not only on the physical properties of the aquifer and the presence of potential hazards, but also on the skills and resources available to enforce the protection zones and the existing land use in the area to be protected. The NORAD documents (DWA, 2004) suggest four source protection zones (see below). Other countries adopt slightly different categories.

While the concept of travel times is relatively easy to derive and implement for porous aquifers, it poses major challenges for aquifers with preferred flow-paths, i.e. fractured and karst aquifers. In fractured Karoo aquifers, proper delineation of protection zones requires an understanding of the fracture sizes, directions and degree of interconnectedness. Sometimes this can only be established by carrying out extensive fieldwork (e.g. fracture mapping and tracer tests). However, it is suggested that from a practical point of view, protection zones in Karoo aquifers begin with a best estimate of travel times and groundwater gradient, and also taking into account local geology (e.g. the presence of high permeability dykes). As further information is gathered, the understanding of flow in the aquifer can be refined and the protection zones better understood. Although most protection zones are defined using numerical groundwater models, analytical solutions are very useful as a first estimate in areas where groundwater data is scarce.

Whilst protection zones should ideally form part of most groundwater protection strategies, they usually need other methods (such as monitoring networks, vulnerability maps and effective enforcement of policy) to make the best use of them. In particular, aquifer vulnerability mapping at some level followed by a risk assessment would often be seen as a pre-requisite for protection zoning. Methods for protecting groundwater from pollution often involve the separate consideration of the pollution Source, its Pathway to or through the aquifer, and the Receptor (aquifer or water body as a water resource vs. wells or springs as a water source) which will be impacted. Ideally a combination of resource and source protection should be implemented to ensure the optimal protection of groundwater within a catchment. Unlike in other parts of the country, low population densities in the Karoo mean it should be relatively easy to enforce land-use restrictions in areas designated as protection zones.

The NORAD toolkit (DWA, 2004) recommends four protection zones, as follows:

1. Zone 1: Radius of influence of the water supply borehole, or area in which the water level in the aquifer is “noticeably affected” by the pumping well.
2. Zone 2: Distance outwards from the borehole, beyond the radius of influence, for which the travel time of groundwater is less than 25 days.
3. Zone 3: Distance outwards from the borehole, beyond the radius of influence, for which the travel time of groundwater is less than 50 days.
4. Zone 4: Distance outwards from the borehole, beyond the radius of influence, for which the travel time of groundwater is more than 50 days.

The NORAD documents recommend that if potentially contaminating activities fall into any of the zones, actions need to be taken. Since the fourth zone is potentially very large, this probably needs to be implemented at the discretion of the supervising hydrogeologist, using common sense. It is also sensible to fence off an area of at least ten metres radius around a public water supply borehole and prevent any unauthorised access (including animals) into this area, in addition to the implementation of protection zones.

3.3 Vulnerability mapping in the Karoo

Vulnerability mapping is a way of showing the vulnerability of an aquifer or area to groundwater contamination, and vulnerability maps are generally used as planning tools – they do not usually replace local investigations and assessments. It is also possible to map vulnerability to drought, which refers to the likelihood of boreholes drying up (Calow et al, 1997). Vulnerability of groundwater to contamination depends on various factors, such as depth to groundwater, nature of the aquifer material, recharge or soil properties. The National Research Council (NRC) has defined groundwater vulnerability to contamination as the likelihood of contaminants reaching a specified position in the groundwater system after introduction at a location above the uppermost aquifer (NRC, 1993). There are various methodologies for assessing vulnerability or constructing vulnerability maps, such as the DRASTIC method (Aller et al, 1985) - the methodology chosen depends on the characteristics of the area being considered, as well as the availability of data. Vulnerability is often depicted as a relative rather than absolute characteristic. The NORAD documents (DWA, 2004) recommend five relative vulnerability classes, from Negligible to Extreme. Vulnerability maps are also usually "intrinsic" which means they focus on the aquifer properties and do not take into account the properties of the contaminant – strictly speaking, vulnerability changes depending on the properties of the contaminant being considered. Rapid groundwater flow along preferred pathways in Karoo rocks, plus the thin soils in the western part of the Main Basin, raise the vulnerability of these aquifers. Activities that disturb the soil cover, such as landfill sites or underground tank burial, remove this protecting layer and can greatly increase groundwater vulnerability to pollution.

There is a general vulnerability map available for South Africa (Parsons and Conrad, 1998), although more information is usually needed for site-specific planning, where local characteristics take preference. The South African Groundwater Decision Tool (SAGDT) can also calculate vulnerability, but the results should be used with care since the tool cannot always take local characteristics into account (DWA, 2006b).

A study aimed at securing public water supplies from groundwater should make estimates of relative vulnerability, as well as taking careful account of potentially polluting activities. These estimates would depend on the available groundwater and aquifer properties data.

Saayman et al (2007) recommend that an aquifer vulnerability decision support framework in South Africa be divided into three stages, and integrated into the Strategic Environmental Assessment and Environmental Impact Assessment processes. The three stages are as follows (Saayman et al, 2007):

- Screening and Scoping – to determine whether an assessment of groundwater contamination risk is required for decision making;
- Assessment – to determine the risk of groundwater contamination, which depends on the characteristics of the contaminant and the vulnerability of the aquifer to pollution; and
- Decision-making – which integrates the outputs of the risk assessment into a cost benefit analysis, which the decision maker evaluates with consideration of relevant laws, regulations and guidelines and the principles and values of society.

3.4 Groundwater pollution in the Karoo

Anthropogenic (man-made) groundwater pollution in the Karoo can be a serious problem in certain specific areas, associated particularly with towns (e.g. landfills and fuel storage) and with mining activities. Groundwater can travel quickly in fractured Karoo aquifers, with little "filtering" or attenuation of contaminants. Thin or absent soils further add to the risk of surface contamination. Sources of contamination include waste disposal and landfill sites, sheep dipping facilities, fuel and chemical storage (especially underground tanks), disposal of brine (e.g. from mines), animal feeding areas, mine tailings and leaking sewers. Once polluted, it is usually difficult and expensive to clean up groundwater. Nitrate contamination of groundwater by agriculture (e.g. fertilisers, or animal waste) is also found. Although population densities in the Karoo are often low, studies have shown that landfill sites and underground fuel storage can be a serious risk to public water supply boreholes (Woodford and Chevallier, 2002). In the northern part of the Main Karoo Basin, coal mining has led to contamination of surface water and groundwater, mainly by acidity generated by sulphide minerals in waste dumps, and the associated mobilisation of metals and other pollutants. Other mining impacts on Karoo groundwater quality include the disposal of brines derived from gold mines in the Welkom area.

CHAPTER 4. SPECIAL RECOMMENDATIONS

Groundwater is an important or main part of the water supply to many towns in the Main Karoo Basin, including Adelaide, Beaufort West, Bedford, De Aar, Graaff-Reinet, Jamestown, Sterkstroom, Tarkastad and Victoria West. Greater groundwater use is also an option for many towns which are experiencing problems meeting current domestic water demand. They key success factor for groundwater supplies is that they are developed scientifically (following established guidelines) and that sustainability it taken into account. There are many examples of municipalities being disappointed by groundwater schemes due to scheme failure, yields dropping, quality problems, or falling water tables.

If the recommendations in the "Guideline for the Assessment, Planning and Management of Groundwater Resources in South Africa" (DWA, 2008) are followed then there is a good chance that groundwater schemes (and "production" boreholes) will meet expectations.

Assessment, planning and management are the three steps needed for successful, long-term operation of aquifers in South Africa. Certain characteristics of Karoo aquifers relating to assessment, planning and management will be discussed in more detail, to provide information to water resource managers using the DWA (2008) generic guideline. The following information is aimed at the municipal-level water manager or planner responsible for a local area or community, or a site-specific study. The sub-headings follow those in the Guideline.

4.1 Site-specific assessment

4.1.1 Undertake desk study and remote sensing

All of the different sources of data for the site need to be collected together. General information such as the hydrogeological maps (and booklets where available), general reports, and NGDB data first need to be collected. Site-specific reports for other parts of the Karoo (but in the same geological group) may have relevant information and also need to be collected. Privately-held "grey" data (e.g. held by mines or consultancies) is valuable, but negotiations may be needed to obtain this data.

4.1.2 Identify areas for additional work

Higher yielding Karoo boreholes often depend on secondary features such as dykes or overlying primary aquifer material. The nature and extent of these must be carefully considered. Aerial photographs and satellite images (including Google Earth images) are often used to study the area before more detailed work is undertaken.

4.1.3 Hydro census

Large distances and widely-spaced boreholes in the Karoo mean that a hydrocensus may be expensive and time-consuming. Many boreholes are on private farms, and farmers may require an overview of the project before offering their assistance. Early public consultation, as laid down in the Guideline (DWA, 2008), is highly recommended.

4.1.4 Sitting of exploration / monitoring boreholes

See Section 3.3 (above) for information on siting boreholes in the Karoo. An initial conceptual model of groundwater occurrence in the area of investigation is important – boreholes may be much more successful where they are associated with lineaments, or bodies of alluvium, for example.

4.1.5 Drilling and testing of exploratory / monitoring boreholes

See Section 3.4 above. It is very important that all data is captured during drilling, and that all boreholes are properly designed and constructed.

4.1.6 Prepare a conceptual groundwater model

This stage should be a refinement of the conceptual model developed after the remote sensing and hydrocensus. The sitting and drilling of exploration boreholes should be carried out in terms of an initial conceptual model.

4.1.7 Risk assessment

Low population densities and levels of industry in the Karoo can mean a lower risk of groundwater pollution – but potentially polluting activities (e.g. machine workshops, latrines, stock feeding areas, sewage treatment works, etc) occur in even very small Karoo communties and in some rural areas. Thin soil cover and fractured aquifers raise the risk of groundwater pollution. Any potentially polluting activity needs to be noted, and the risk incorporated into the conceptual model. Flooding in the Karoo is rare, but when it happens it can be severe – the extent of previous floods must be taken into account.

4.1.8 Surface / groundwater interaction

Perennial surface water is scarce over much of the Karoo, but like elsewhere abstraction of groundwater can affect shallow groundwater resources (e.g. feeding springs) and surface water courses. Abstraction from river alluvium (e.g. at Leeu Gamka) can have longer-term negative consequences, including soil salinisation. In the eastern Karoo, communities can be dependent on springs and small streams fed by baseflow.

4.1.9 Present to stakeholders and obtain input

This should be done clearly and honestly, in line with the recommendations in the guideline (DWA, 2004). Input from stakeholders needs to be taken seriously.

4.1.10 Numerical modelling in primary aquifers

Numerical modelling in the Karoo is likely to be difficult for anything but fairly simple models since data is scarce, recharge sporadic and the aquifers anisotropic. Yields to boreholes can depend almost entirely on discrete, anomalous features such as dykes, which are difficult to characterise. Data requirements are very high. Professional advice is strongly recommended.

4.1.11 Assessment report

The assessment report should contain all the data gathered during the assessment phase, and make a clear list of assumptions. Negative impacts such as impacts on surface water or enforcement of protection zones must be honestly stated. The uncertainty inherent in predicting groundwater availability in the context of limited storage in Karoo aquifers and low recharge should be honestly stated.

4.2 Site-specific planning

4.2.1 Summarise required data / information

Issues outside of the immediate groundwater context need to be considered, such as the impact on groundwater-dependent ecosystems or the overall availability of groundwater to existing users.

4.2.2 Prepare feasibility level design and costs

Water managers in the Karoo (especially the semi-arid parts) should be aware of the issue of sustainability. Initial yields obtained from boreholes may decline as storage is exhausted. Planning should take into account the likely long-term response of local and regional groundwater to the planned abstractions. Sporadic high rainfall events can provide an ideal opportunity for artificial recharge of aquifers via infiltration basins or similar. The DWA Artificial Recharge Strategy (DWA, 2007) provides further information (see www.artificialrecharge.co.za for more information). Technical options considered should be broadened to include large diameter wells in alluvium, or wells with adits. Storage of water in sand dams may also be possible.

4.2.3 Confirm extent of monitoring programme

Following the summary of data and the feasibility design, a monitoring programme must be prepared. In the Karoo, groundwater flow is often via discrete features such as dyke margins or bedding planes. Monitoring systems aimed at “early warning” of contaminants need to take this into account. Karoo groundwater can also have anomalously high natural levels of certain constituents (e.g. nitrate and fluoride) – sampling must take this into account. Interaction of fractured Karoo aquifers with overlying alluvium also needs to be considered. Water level monitoring must take into account that recharge to Karoo aquifers can be episodic – i.e. only happen every few years. Access to long-term water level records is valuable. Monitoring may require relatively time-consuming visits to remote farms.

The design and construction of monitoring boreholes depends on a range of factors (e.g. what is being monitored, ambient groundwater quality, size of monitoring equipment, etc). There is a guidance manual published by the United States Environmental Protection Agency (USEPA) called “Monitoring Well Design and Construction for Hydrogeologic Characterisation” which provides very useful information. It is available free of charge at the following web address:
http://www.dtsc.ca.gov/SiteCleanup/upload/SMP_Monitoring_Well_Design.pdf

4.2.4 Arrange interaction meetings

The DWA guideline has extensive details on stakeholder interaction (DWA, 2008), which should be consulted. Stakeholders may be prepared to assist with regular monitoring.

4.2.5 Prepare tender drawings and specifications

It is recommended that this be done with professional hydrogeological advice, since clear and unambiguous specifications will help in the tender evaluation process and may even prevent time-consuming and expensive re-advertisement.

4.2.6 Prepare planning report

The preferred option or options needs to be clearly stated and backed up by cost and technical estimates.

4.3 Site-specific management

Good long-term management of Karoo wellfields (as elsewhere) is possibly the most important factor for a reliable water supply system. A management system needs to be both predictive (i.e. anticipating future problems) and reactive (able to adapt to unforeseen problems). The public participation and "institutional" processes are just as important as technical considerations – no amount of technical understanding can compensate for the lack of a budget to replace worn-out pumps, or the lack of a training programme to ensure staff continuity! Partners in local scale management (e.g. industries or mines, other municipal departments, farmers, communities, etc) are an essential part of good long-term management. Meetings or updates on the groundwater conditions are recommended, especially in the semi-arid Karoo where current groundwater levels are of interest to many.

4.3.1 Set up WSDP, IDP, EMP

It is essential that plans for water services take into account, and ultimately update, existing planning documents including Water Services Development Plans (WSDPs), Integrated Development Plans (IDPs), and Environmental Management Plans (EMPs).

4.3.2 Implement water use scheme or remedial actions

Adaptive Management (Seward et al, 2006) is a useful concept where complex aquifers and data scarcity make it difficult to settle on issues such as sustainable abstraction rates or "safe yield". Adaptive management of groundwater means a reactive approach to groundwater management in which feedback from a monitoring or evaluation system informs and guides management policy, which changes or adapts accordingly. Adaptive management focuses on desirable outcomes (such as a certain minimum water level) and adjusts policy interventions in response.

4.3.3 Install/update and maintain monitoring network

Shallow aquifer depths and limited extents of some primary aquifers mean that monitoring functions as a very important early warning system. It is easy to neglect routine monitoring, but it is a vital early indicator of problems, which can be corrected without too much disruption if identified early. As mentioned above, monitoring systems may include nearby surface water resources and ecosystems.

4.3.4 Operation and maintenance of the system

Once the desirable parameters (water levels, water quality, pumping regimes, etc) have been set, it is vital that a system for operation and maintenance is put in place. This includes the monitoring of water levels and water quality. Low-technology options are often recommended, but the hidden costs of these (personnel management and retention) need to be set against the drawbacks of automated systems. Each scheme is likely to have its own characteristics – focus should be kept on the desired end result of the management tools. If one approach does not work, another should be tried. Lack of O&M (especially groundwater monitoring) is the precursor to scheme failure. Although this document is aimed at technical aspects of groundwater development in the Karoo, it is often budgetary, institutional, human capacity and other less obvious issues that control the final success of failure of a groundwater supply scheme. Signals from the groundwater monitoring and other control systems (e.g. records of borehole yield) need to be translated into actions. Schemes have been known to fail when all the warning signs were apparent months or even years before. In some cases outside technical assistance may be necessary (e.g. to clear blocked boreholes, or advise on growing water quality problems).

Some of the typical routine O&M tasks are listed below – although this is not a comprehensive list. Additional tasks will be needed depending on the scheme that is installed. A groundwater supply scheme might be as simple as a single borehole with a hand pump, although schemes usually involve more than one borehole, pipe-work, electrical control systems, treatment systems, etc. O&M tasks include maintaining infrastructure (cleaning and descaling pipes, replacing worn out components, cleaning of boreholes, checking the operation of switchgear, etc) as well as the monitoring of groundwater levels, groundwater quality, demand, etc. Monitoring tasks are sometimes collectively seen as part of resource or aquifer management, rather than O&M (DWAF, 2004) but they have been included here since they are repetitive and can be carried out at the same time as other O&M tasks.

- Monitoring of water levels, either manually using a hand held dipper or electronically with pressure-sensitive “divers”
- Monitoring of water quality – at least basic electrical conductivity, although public water supplies need more parameters checked regularly.
- Monitoring of pumping rates from each borehole
- Monitoring of borehole pump electricity consumption – can give early warning of pump problems or falling water levels
- Monitoring of water demand. Predictions can be made for future demand as the data set grows. A picture of seasonal demand needs to be built up.
- Cleaning and maintenance of all equipment (surface and sub-surface) according to manufacturer’s recommendations, and taking into account local factors such as aggressive water.
- Security of installations and protection from vandalism
- Reporting – should be regular and allow for the easy comparison of data

Failure of groundwater supply schemes is often blamed on the resource (i.e. the aquifer or the groundwater) rather than on the infrastructure (borehole, pump, pipes, valves etc) used to abstract the groundwater. It is common to hear that “the borehole dried up”, or “the groundwater ran out”. In fact, failure of groundwater supply schemes is almost always either due to failure of infrastructure (e.g. blocked borehole screen) or unsuitable pumping regimes (e.g. pumping at very high rates for short periods of time) that are related to a lack of monitoring. Unsuitable pumping regimes can cause infrastructure failure in various ways such as biofouling of borehole screens or the precipitation of iron or manganese on screens due to air being introduced into the aquifer. High flow rates can mobilize silt or sand, leading to rapid pump wear, and pumps can also overheat and burn out if water levels drop below their intake shrouds. Responsibility for the various O&M tasks needs to be clearly laid down and enforced – in fact it may even be more difficult and expensive to establish systems for O&M than it is to install the boreholes and pumps in the first place. Successful O&M depends on functions and procedures such as budgeting, training and retention of staff, accountability frameworks, succession planning and other "institutional" features beyond the scope of this document.

4.3.5 Data management: Gather, store and assess the monitoring data

Collection of monitoring data is vital, but worthless if it is not recorded and interpreted. Data can be captured and stored in a proprietary database such as AQUIWORX. Regular assessment of monitoring data (e.g. a chart of water levels, or water quality, or water demand) gives early warning of problems and allows solutions to be implemented early. Copies of all data should be submitted to the Department of Water Affairs, or the Catchment Management Agency, routinely (see DWA, 2008). Water users can be kept aware of the water situation by putting charts of demand or water levels in a public place.

4.3.6 Control of water use

Decisions made on the basis of the interpretation of monitoring data need to be translated into regulatory action. In extreme cases, water restrictions may be required. Collection of outstanding payments for water is also very important for long term functioning of water supply systems.

4.3.7 Summarise monitoring data in a site-specific report

A monthly report is recommended by the DWA guideline (DWA, 2008). This should follow the same format each month, in order to make comparing the data as easy as possible.

CHAPTER 5. CONCLUSIONS

Groundwater development in the Main Karoo Basin is complicated by the relatively low yielding, fractured aquifers and often low recharge. Groundwater is often associated with secondary features such as fracture horizons or dolerite intrusions. The success of a borehole can depend on whether such a water-bearing feature is intersected. Water quality is often good, but in places it can be poor, with high salinity or high concentrations of certain elements such as nitrate. However, with scientific siting of boreholes, sufficient budget for groundwater exploration, and robust O&M procedures, groundwater has proven to be a valuable and reliable resource in the Karoo (e.g. the supply to Beaufort West). It is recommended that the DWA Generic Guideline (DWA, 2008) be followed for the development of “production” boreholes, town wellfields and similar, taking into account the issues discussed in this report. Professional hydrogeological advice for all but the smallest systems is recommended, as this is likely to save time and money in the long run.

High-yielding boreholes in the Karoo, perhaps associated with dolerite intrusions, alluvium, faults or other features, can permit boreholes yielding several times more that the median yield for the area. These boreholes need to be carefully managed, and pumping rates should depend on the conceptual model of groundwater occurrence to give a better chance of long-term sustainability. Given the sometimes complex hydrogeological conditions, and the lack of data, some degree of “adaptive management” may be necessary – in other words, pumping rates and operational procedures are adjusted as the effects of groundwater abstraction become apparent over months or even years.

Aquifer vulnerability to pollution is an important consideration in Karoo aquifers, since despite often low population densities these aquifers are nevertheless vulnerable to pollution for several reasons. Monitoring of groundwater quality as well as water levels is important in establishing baseline conditions, and providing early warning of any water quality problems.

In addition to the special recommendations in this document, Karoo aquifers in general deserve more attention in South Africa, since although yields can be low they are in many cases sole sources of potable water. More data needs to be collected, together with better monitoring systems.

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