

**TECHNICAL SERIES: 3**

**Primary Aquifers in South Africa**



**water affairs**

Department:  
Water Affairs  
REPUBLIC OF SOUTH AFRICA

**October 2010**

# TECHNICAL SERIES 3

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## **EXECUTIVE SUMMARY**

This document provides specific information on primary aquifers designed to support and complement the generic information in the DWA generic guideline, for those planners and managers involved with the assessment, planning and management of groundwater in primary aquifers in South Africa.

Abstractions from primary aquifers are amongst the largest in South Africa, with yields in excess of 300 L/s from some specially constructed sand abstraction systems. Coastal primary aquifers (e.g. the KwaZulu Natal Coastal Aquifer) can also represent relatively large and often underexploited resources of fresh groundwater.

The 1:500 000 scale general hydrogeology map series and its accompanying booklets (available from the Department of Water Affairs) are an important introduction to the primary aquifer development potential of various parts of the country, but should not be seen as a substitute for local investigations. Many primary aquifers (e.g. river alluvium) do not appear on the national map series, and low regional median yields depicted on the maps may hide the possibility of large local abstractions from primary material.

Groundwater exploration and the construction of groundwater abstraction systems in primary aquifers is specialised work for all but the simplest systems. Primary aquifers can have very diverse shapes and depths, and special techniques (e.g. collector wells) have been developed to abstract water from them. The drilling of “conventional” boreholes in primary aquifers can require specialised drilling and construction techniques to prevent boreholes collapsing and to ensure long borehole life. Primary aquifers often interact very closely with surface water resources (or the sea, at the coast) and a good understanding of this is needed for long-term sustainability. Although the quality of water in primary aquifers is often good, specific water quality problems such as biofouling and / or iron precipitation need to be considered. Water quality may also be influenced by nearby surface water.

Although the mainly intergranular flow found in primary aquifers does retard contaminants, primary aquifers can be very vulnerable to surface pollution because of shallow water tables and proximity to surface water resources. Appropriate abstraction-point construction, vulnerability assessment and implementation of a protection zone policy are recommended to help protect against groundwater pollution. Floods can also damage abstraction systems in primary aquifers, depending on location, and some constructions take this into account.

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

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## CHAPTER 1. INTRODUCTION

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For the purposes of this report primary aquifers are defined as aquifers made of unconsolidated material, with water supply potential. Primary aquifers in South Africa occur mainly as extensive coastal deposits (e.g. the Atlantis aquifer, the Zululand coastal aquifer, or the Bredasdorp aquifer), as alluvium associated with ephemeral and perennial rivers, and as extensive deposits in the north west of the country (e.g. Kalahari sands). The first two types are of most interest for water supply purposes, since water levels in the Kalahari sands tend to be deep and water quality is often poor. Alluvium may be accompanied by additional permeable material such as scree or rockfall from adjacent higher ground (e.g. Newlands Aquifer, adjacent to the Cape Flats Aquifer), effectively enlarging the primary aquifer. Unconsolidated material produced by the in-situ weathering of crystalline and metamorphic rocks (regolith) is not considered in this report (see the Crystalline Aquifer appendix for more details on these). Groundwater flow in primary aquifers is predominantly intergranular, but there is still considerable heterogeneity in primary aquifer properties linked to changes in composition (particularly the proportion of fine material), changes in thickness, and the often very diverse shapes of many primary aquifers (e.g. long thin strips of alluvium).

### **1.1 Coastal primary aquifers in South Africa**

Coastal primary aquifers represent a large and valuable water resource in South Africa, although their development has been sporadic and data on available quantities, aquifer properties, ecosystem impacts and other important parameters is often scarce. Only a few areas are currently used for moderate to large scale water supply, such as the Atlantis aquifer.

As part of a project aimed at characterising South African coastal primary aquifers, Campbell et al (1992) identified 24 major coastal aquifers in South Africa, covering a total area of about 29 600 km<sup>2</sup>. Their studies considered only Cenozoic deposits which were hydraulically connected to the sea. These authors found that little information was available on the boundaries of these primary aquifers, and used the geological boundaries of coastal Cenozoic deposits instead. Note that Cenozoic deposits are not the only coastal aquifers in South Africa – coastal hard rock formations such as quartzites of the Table Mountain Group can also contain very large amounts of groundwater.

As part of the study Campbell et al (1992) carried out a comprehensive literature review, and sent a questionnaire to all 136 coastal municipalities and regional services councils (as they then were). Of the 106 respondents, 45 indicated that groundwater formed all or part of their water supply. The authors estimated the total abstraction of groundwater by these 45 respondents at approximately 5 million m<sup>3</sup> per year, or about 159 L/s if pumping continuously. It is likely that far more groundwater is available than this from coastal aquifers – for example in a study of groundwater in the Alexandra (Eastern Cape) dune fields, Campbell and Bate (1991) estimate that groundwater in that area enters the surf zone at a rate of about 1 m<sup>3</sup> per running metre of beach per day.

At the time of the study, Campbell et al (1992) estimated that little was known about the water supply potential of South Africa's coastal aquifers. Water quality data was only

available for 13 of the 24 identified coastal aquifers. In particular, estimates of safe yields and other data important for aquifer management is very limited. Campbell et al (1992) identified the characterisation and the establishment of water balances for South Africa's coastal aquifers as the highest research priority at the time. Whilst considerable work has been done since the publication of this report in 1992, there are still large gaps in our knowledge of the properties and water supply potential of these aquifers.

### **1.1.1 Ecological impacts and aquifer-dependent ecosystems**

Coastal aquifers may be especially sensitive to the ecological effects of groundwater abstraction. Habitats such as estuaries, coastal lakes, coastal marshes and the surf zone can all depend to some extent on groundwater flows for their ecological functioning. These ecosystems can be particularly sensitive to changes in the water table elevation. The volume and quality of groundwater discharging to coastal ecosystems are both important, however, since groundwater carries nutrients (such as nitrate) which are vital for ecosystems. Large-scale development of coastal groundwater resources will need careful consideration of ecological impacts.

A classification system for aquifer-dependent ecosystems (ADEs) in South Africa has been proposed by Colvin et al (2007) based on the aquifer type (e.g. carbonate, alluvial) and on habitat type (e.g. riverine aquatic, spring). Identifying ADEs and assessing the impact on them of groundwater abstraction is a complex task. Colvin et al (2007) provide information and protocols on how to do this. In some cases ADEs may be the limiting factor on groundwater development potential, and this may be especially true in primary aquifer systems with their shallow water tables and close proximity to surface water resources. The complexity of many ADE / groundwater systems and the relative lack of data means that an adaptive approach is recommended for groundwater development, which has the flexibility to change as resource conditions change and as new data becomes available. Monitoring is a vital part of achieving an acceptable balance between ADEs and groundwater development.

## **1.2 Examples of extensive coastal primary aquifers**

### **1.2.1 Zululand Coastal Aquifer**

The northeast coastal plain of South Africa is underlain by an extensive primary aquifer system known as the Zululand Coastal Aquifer. The coastal plain extends for about 250 km south of the border with Mozambique, and for at least another 1 000 km northwards into Mozambique, and is underlain by a primary aquifer (Meyer et al, 2001). In South Africa the aquifer has a surface area of around 7 000 km<sup>2</sup>, making it one of the largest primary aquifers in South Africa (Meyer et al, 2001). The wedge-shaped primary aquifer consists of Quaternary sands underlain by Miocene sandstone and calcarenite, and is about 110 m thick at the coast. It is estimated that recharge as a percentage of mean annual precipitation varies from about 18% at the coast to 5% 50 km inland, and groundwater quality is generally good. Shallow groundwater levels support several freshwater lakes in the area, which at present are used for water supply by the majority of the population of the area. Borehole yields of up to 25 L/s can be achieved in the calcarenite (Meyer et al, 2001). At present the aquifer is underutilised, with considerable discharge of fresh groundwater to the sea, and further work is necessary before the

effects of greater groundwater development and the potential for further commercial forestry can be better understood. A preliminary figure for groundwater discharge to the sea of  $3.28 \times 10^5$  m<sup>3</sup> per year per km of coastline was calculated, based on an average recharge of 11 % and average rainfall of 900 mm (Meyer et al, 2001). This equates to an average of about 0.9 m<sup>3</sup> per metre of coastline, although the volume at any particular point depends greatly on local hydrogeological characteristics. It is considered that there is a fine balance between the ecology of the region, and the groundwater regime.

### 1.2.2 Atlantis aquifer

The town of Atlantis is situated about 50 km north of Cape Town, in the Western Cape Province, and has a population of over 100 000 people. It has no major surface water sources, and annual rainfall is only about 450 mm. Atlantis is underlain by extensive unconsolidated sands, which are about 25 m thick in the vicinity of the town. Natural recharge is estimated at 15 to 30% of rainfall (Murray, 2004). Atlantis abstracts water supply from boreholes at two wellfields to the west and south-west of the town, supplying 30 – 40% of the town's water. Groundwater consumption in 2004 was 2.8 million m<sup>3</sup> (about 89 L/s if pumping continuously) (Bishop, 2006). Artificial recharge of the aquifer, first begun in the early 1980s, is carried out to improve water security during droughts, re-use waste water and storm run-off, and help to prevent the intrusion of saline water into the aquifer. Treated waste water and storm run-off is diverted to two large recharge basins about 500 m up-gradient of one of the wellfields, which are used to infiltrate the good quality water back into the aquifer for later abstraction. Poorer quality waste water (some of it from the town's industrial area) is infiltrated down-gradient of the wellfields, between the town and the sea, where it is disposed of conveniently and responsibly. This also helps to reduce seawater intrusion into the aquifer. Together with some imports of good quality surface water from the Cape Town municipal supply, Atlantis is able to meet its water supply needs using combined groundwater abstraction and artificial recharge. Adjustment of pH and ion exchange to soften the water is necessary before the water can be put into supply. Problems with clogging of boreholes have been experienced, but were resolved by the municipality using a technical specialist.

### 1.2.3 Langebaan Road Aquifer System

The Langebaan Road Aquifer System, located near Saldanha Bay on the west coast of South Africa, consists of a lower primary aquifer with a confining clay layer above. Unlike many other primary aquifers in South Africa, the groundwater resources are confined. The aquifer is known to have substantial reserves of groundwater – a study in 1997 indicated a safe yield of  $7.8 \times 10^6$  m<sup>3</sup>/a (about 247 L/s if pumping continuously), based on 8% recharge (Weaver et al, 1997, quoted in Du Plessis, 2009). A monitoring committee is currently tasked with day-to-day management of the aquifer, consisting of representatives from several interested parties and organisations. This committee may be a template for aquifer management elsewhere in South Africa (Du Plessis, 2009).

### 1.2.4 Cape Flats aquifer

The Cape Flats aquifer stretching from the Cape Peninsula to the Tygerberg / Stellenbosch mountains covers an area of about 570 km<sup>2</sup>. The aquifer is comprised mainly of Cenozoic age unconsolidated and stratified sands, with some clay lenses,

overlying bedrock of Cape granites and Malmesbury shales. The sands are up to 50 m thick and hydraulic conductivities range from 15 to 50 m/d (Adelana and Xu, 2006). Urban areas overlie part of the Cape Flats aquifer, and pollution from a range of sources (e.g. waste dumps, chemical industries, agriculture, and fuel storage) has delayed the exploitation of the groundwater resources. Overall, the natural quality of groundwater in the aquifer is suitable for public supply. The sustainable use of the Cape Flats Aquifer is estimated at 18 billion litres per annum (or about 570 L/s, pumping continuously) (Adelana and Xu, 2006). A protection zone policy and phased development with adequate quality and abstraction monitoring are likely to be necessary in order to realise the potential of this important primary aquifer. There is also potential for artificial recharge of the aquifer during times of surplus surface water (or using treated wastewater).

### **1.3 Alluvial aquifers**

Alluvial aquifers consist mainly of unconsolidated material with a large range of grain-sizes deposited by rivers. They are often of relatively recent age, and underlie present-day river courses. Rivers depositing alluvium may be perennial (flow all year round), or ephemeral. Sand rivers, found in semi-arid and arid areas, are dry on surface for most of the time. Alluvial aquifers are often of limited size and extend (some are only a few metres deep), being bounded by harder surrounding rock. They therefore often do not appear on general hydrogeology maps, and can even be overlooked when conducting local surveys.

Nevertheless, abstractions from alluvial aquifers include some of the largest groundwater abstractions in South Africa. A system on the Buffels River in KwaZulu-Natal Province yields 170 L/s, and a system on the White Mfolozi River in the same province originally yielded 313 L/s (Clanahan and Jonck, 2005). Boreholes on the banks of the Limpopo River can yield more than 15 L/s from the adjacent alluvium, whilst wellpoint systems tapping the same alluvium can yield more than 40 L/s (Hobbs and Esterhuysen, 1983).

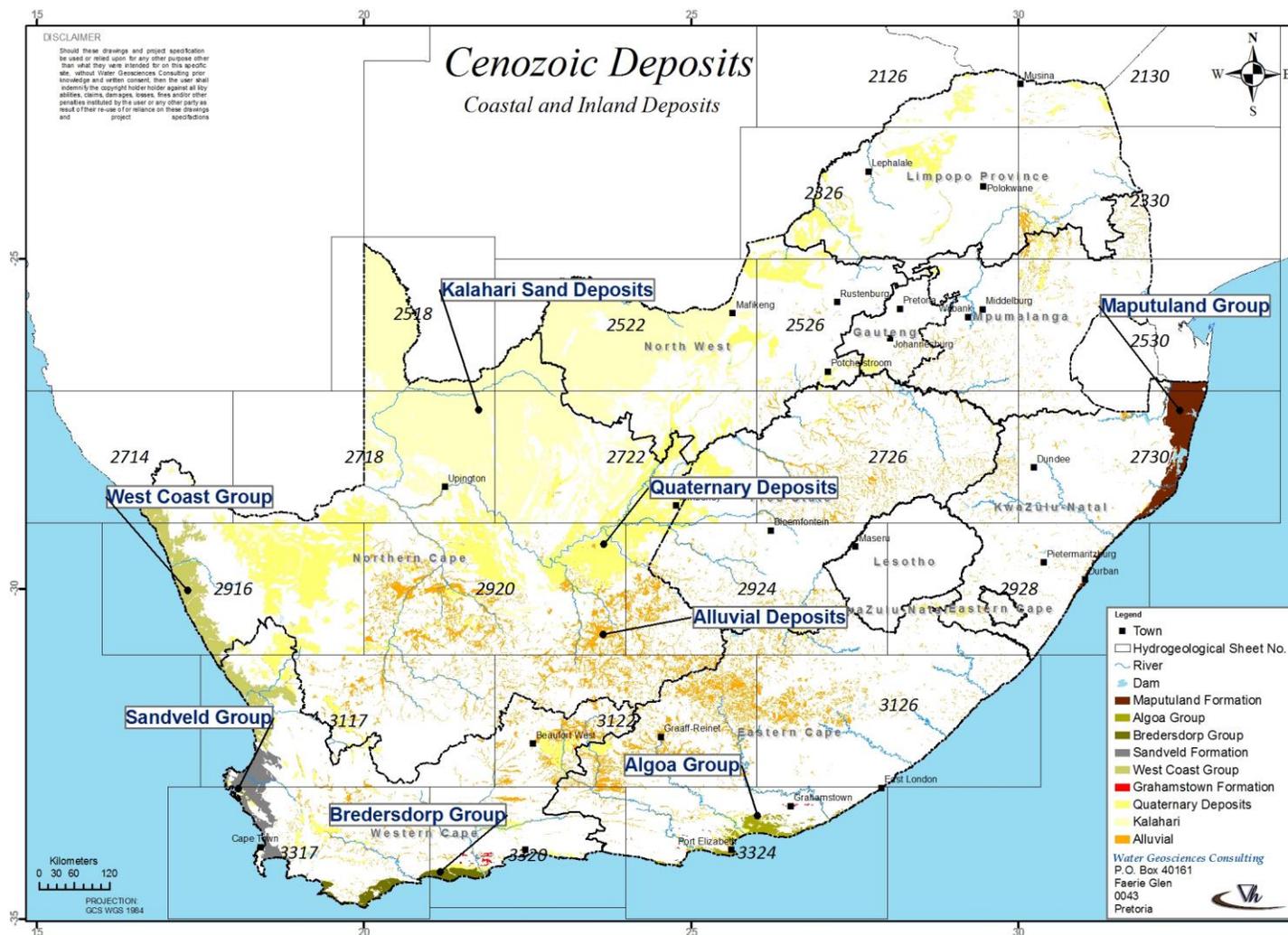


Figure 1-1: Simplified map showing unconsolidated deposits in RSA

## CHAPTER 2. Groundwater Development and Conceptual Understanding of Primary Aquifers

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Existing sources of information on South Africa's hydrogeology can give a good general overview of primary aquifers, but do not include smaller bodies of primary material. Low regional estimates of groundwater potential can mask the locally higher potential of discrete alluvial bodies. Some of these sources are described below:

### 2.1 Sources of information on South Africa's primary aquifers

#### 2.1.1 The National Hydrogeology Maps and booklets

The twenty-one 1:500 000 scale general hydrogeological maps covering South Africa provide an overview of borehole prospects and groundwater quality for the larger areas of primary aquifer in South Africa. Nine of the maps are accompanied by explanatory booklets. The maps and booklets should be consulted at the feasibility / planning stage of any proposed groundwater development. Siting of boreholes and detailed planning of groundwater schemes requires more information, including site investigations and specialist advice. The hydrogeology map series **does not** provide details for smaller areas of primary aquifer, in particular river alluvium and sand rivers – which may nevertheless be locally very important. Several large abstractions depicted on the hydrogeology map series, which appear to be in the country rock or bedrock, are in fact sand abstraction systems associated with river alluvium which is not shown on the map (e.g. on the Vryheid 2730 map sheet). The areas covered by each hydrogeology map are shown on **Figure 1-1**.

#### 2.1.2 South Africa's Groundwater Regions

A long-term project recognising the subdivision of the country into a series of "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). The first order subdivision of the regions is on the type of interstice – i.e. primary or secondary opening. 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. Four of the regions are concerned mainly with primary aquifers, namely Die Kelders Embayment (60), Bredasdorp Coastal Belt (61), Stilbaai Coastal Belt (62) and North Zululand Coastal Plain (65) (Vegter, 2001). So far none of the reports for these primary regions have yet been completed. The other reports do contain some details for the primary aquifers in each particular area.

### 2.1.3 ISPs and other planning documents

South Africa is divided into 19 Water Management Areas (WMAs), based on catchment boundaries. 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. They should 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 is necessary 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, better school enrolment, lower health care costs) and these need to be acknowledged. Groundwater development aimed at public water supplies must form part of municipal spatial planning, and consultation with relevant municipal officials is strongly recommended.

### 2.1.4 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

It is recommended that the Toolkit be considered for assisting with groundwater management at municipal level. All of the NORAD outputs are available on the DWA website at <http://www.DWA.gov.za/Groundwater/NORADtoolkit.asp>

### 2.1.5 “Grey” reports

A large number of reports by the Department of Water Affairs (especially the former Directorate of Geohydrology), consultants, universities and others covering primary aquifers in South Africa have been written. These reports can contain useful information which may not be available elsewhere, particularly more detailed information for smaller or local areas of primary aquifer. Unfortunately these reports are not always easy to obtain – sometimes they were published in only limited quantities, or were not intended for public distribution or sale. A searchable list of the official DWA geohydrology reports is available at [www.dwaf.gov.za/geohydrology](http://www.dwaf.gov.za/geohydrology), and many of these can be downloaded in PDF format. Geohydrology reports which are not yet available as PDFs can be obtained by emailing [geo-requests@dwaf.gov.za](mailto:geo-requests@dwaf.gov.za).

The report on coastal aquifers in Southern Africa by Campbell et al (1992) contains a comprehensive reference list of reports on coastal aquifers. The references in Clanahan and Jonck (2005) are useful for anyone interested in alluvial aquifers and sand abstraction systems in South Africa. Both reports are available as hard copies or to download as PDF files from the Water Research Commission in Pretoria at [www.wrc.org.za](http://www.wrc.org.za). Papers in the journal Water SA are also available free of charge as PDFs from the same address.

## 2.2 Properties of primary aquifers

Primary aquifers exhibit mainly intergranular porosity and conductivity – i.e. water is stored and moves in the spaces between the grains. Porosity is the ratio of the total volume of void spaces in the sediment to the total volume of the sediment (Fetter, 1994). Hydraulic conductivity (K) is the volume of water that will flow through a unit cross-sectional area of aquifer in unit time, under a unit hydraulic gradient (Brassington, 1998). Specific yield (Sy) is the ratio of the volume of water released by an aquifer to the total volume of the rock. It is similar to porosity for coarse-grained sediments, but very different for finer material – i.e. finer grained sediments retain water and prevent it from draining freely. See **Table 2-1**.

**Table 2-1: Some properties of unconsolidated materials (after Brassington, 1998)**

	Grain size (mm)	Porosity (%)	Specific yield Sy (%)	K (m/d)
Coarse gravel	16 - 32	28	23	Alluvial gravels: 500 – 10 000
Medium gravel	8 - 16	32	24	
Fine gravel	4 - 8	34	25	
Coarse sand	0.5 - 1	39	27	Alluvial sands: 1 - 500
Medium sand	0.25 – 0.5	39	28	
Fine sand	0.125 – 0.25	43	23	
Silt	3.9 – 62.5 $\mu\text{m}$	46	8	$10^{-2}$ - 1
Clay	> 3.9 $\mu\text{m}$	42	3	< $10^{-2}$

The hydraulic properties of unconsolidated material are greatly affected by the proportions of the different sizes of grains in the material (especially the finer fractions), and for this reason a sieve analysis of representative aquifer material is often carried out. The results of a sieve analysis show the various percentages of aquifer material at

different grain sizes, and can be plotted as a grain size distribution plot. The hydraulic conductivity of sands can be estimated using the Hazen method, if the average value of the grain size at the 10 % value of a grain size distribution plot is known. The formula is an empirical one (i.e. derived experimentally), and depends on a coefficient C which changes according to the material being measured (this can often be estimated in the field - see **Table 2-2**). The Hazen formula is as follows:

$$K = C(D_{10})^2$$

(Where K is the hydraulic conductivity in m/d, D10 is the effective grain size in mm, and C is a coefficient.)

Values for K derived using the Hazen method should be treated as general estimates only, and are not a substitute for a pumping test. It is also important to remember that the sustainability of a resource depends on the geometry of the unconsolidated deposit, recharge and other factors, and may be very limited even where values for K (and hence initial yields) are relatively high.

**Table 2-2: Values of C for different materials (after Brassington, 1998)**

Grain size	Value of C
Very fine sand, poorly sorted	350 – 700
Fine sand with fines	350 – 700
Medium sand, well sorted	700 – 1000
Coarse sand, poorly sorted	700 – 1000
Coarse sand, clean and well sorted	1000 - 1300

## 2.3 Water quality in primary aquifers

### 2.3.1 Water quality standards

The most commonly used standard for benchmarking drinking water quality in South Africa is the South African National Standards Association SANS 241 document, available from the South African Bureau of Standards in Pretoria (SANS, 2005). The document “specifies the quality of acceptable drinking water, defined in terms of microbiological, physical, organoleptic and chemical parameters, at the point of delivery. It describes two classes of drinking water: Class I, that is considered to be acceptable for lifetime consumption, and is the recommended compliance limit; Class II, that is considered to represent drinking water for consumption for a limited period” (SANS, 2005). The standard is available to buy from the SABS in Pretoria. Some parameters are not contained in the SANS 241 document – in these cases the drinking water guidelines issued by the World Health Organisation (WHO) may be useful, available for download free at the following web address:

[http://www.who.int/water\\_sanitation\\_health/dwg/gdwq3rev/en/index.html](http://www.who.int/water_sanitation_health/dwg/gdwq3rev/en/index.html)

### 2.3.2 Natural water quality in primary aquifers

Natural water quality depends to a great extent on the nature of the primary aquifer material, and the length of time that groundwater has been in contact with it. Clean, quartzitic sands can often give good natural water quality with a low mineral content, albeit sometimes with problems of low pH. Iron and manganese concentrations above recommended limits are fairly common in primary aquifers in South Africa. These dissolved elements can also contribute to the problem of biofouling (see below). Salinity can be a problem in some alluvial aquifers, and this can be compounded by cycles of irrigation at inappropriate rates. The natural quality of groundwater in alluvial aquifers which are regularly recharged by ephemeral surface water flows is likely to be greatly influenced by the quality of the surface water. Pollution in the surface water can also rapidly enter groundwater. Water from adjacent aquifers (or the sea) can also enter primary aquifers as water tables decline during pumping, causing changes in water quality.

### 2.3.3 Microbiological quality in primary aquifers

Shallow water tables, proximity to (sometimes polluted) surface water, and proximity to towns can lead to groundwater in primary aquifers having high levels of microbiological contamination. This can make the water unsuitable for drinking water without treatment. Some of the technologies used for abstracting water from primary aquifer systems can also be inherently vulnerable to microbiological pollution (e.g. large diameter wells or shallow adit and well-point systems). Pulses of poorer quality surface water may not be detected by surface water monitoring equipment, but may nevertheless be drawn into sand abstraction systems.

Fouling of water supply infrastructure (e.g. pipes, borehole screens) by various types of naturally-occurring bacteria (biofouling) has been identified as a serious problem (Clanahan and Jonck, 2005). The particular approach to solving such problems depends on the exact circumstances - where biofouling is encouraged by air being drawn into an aquifer, decreasing drawdowns can help, for example. Early diagnosis through adequate monitoring is highly desirable, since treatment can be expensive if the problem is allowed to grow (Bishop, 2006). Shallow adit systems and drains may need to be regularly treated with disinfectants (e.g. chlorine), or physically cleaned using surge blocks or jetting. Pumps may need to be removed for periodic cleaning. Certain rates of flow through screens and pipes can contribute to bacterial growth, and systems may have to be designed or modified to try to prevent this. Professional advice is strongly recommended, particularly for larger abstractions. The reader is referred to Bishop (2006) for case studies and information on strategies to minimise clogging and biofouling.

DWA published a 'Policy and Strategy for Groundwater Quality Management in South Africa in 2000 (DWA, 2000). The mission statement for groundwater quality management is set in the context of the water resources mission and is as follows: "To manage groundwater quality in an integrated and sustainable manner within the context of the National Water Resource Strategy and thereby to provide an adequate level of protection to groundwater resources and secure the supply of water of acceptable quality".

## 2.4 Sand abstraction systems

One of the most common and productive ways of extracting groundwater from primary aquifers in South Africa is by the family of systems known as “sand abstraction systems”. A sand abstraction system is a system which is designed to abstract water from sand – often sand associated with a river (i.e. an alluvial aquifer), although these methods can often be used in regional primary aquifers too. Many sand abstraction systems are designed to draw water from ephemeral rivers, using water stored in the dry river bed. The more extensive the sand and the greater the recharge, the more chance there is of obtaining a reliable, perennial supply (Hussey, 2007). Rivers which are dry for most of the year are known as “sand rivers”, and these are common in arid and semi-arid parts of southern Africa. Sand rivers in very dry areas are known as “wadis “ – they may have no headwater or outlet, and contain surface water only rarely and in discrete stretches following isolated heavy rain (Hussey, 2007). Sand abstraction systems are also used to abstract water from beneath the river bed of perennial rivers, since the sand removes much of the turbidity from the water making treatment easier and cheaper. They range in size from small, basic systems for rural areas and emergency situations to sophisticated systems for town supplies (see **Figure 2-2**). The filtering effect of sand can also remove microbiological pathogens. Abstracting water from river sand or alluvium is not restricted to dry areas - large systems installed in the permeable banks of major rivers are used in large cities world-wide (e.g. Budapest and Vienna), where the resulting “bank filtration” is effectively the first stage of the water treatment process.

Much of the discussion of sand abstraction systems in South Africa is taken from Clanahan and Jonck (2005). Anyone considering working on or installing such a system is strongly advised to consult this publication (available free of charge from the Water Research Commission in Pretoria), since it contains detailed information on the different types of systems, common problems with the systems, and optimal installation and management methods.

Sand abstraction systems are designed to exploit the often limited thickness of saturated sand in a river bed, and many have horizontal collectors of some kind to improve yields. Sand abstraction systems in southern Africa can be divided into various types (Clanahan and Jonck, 2005):

- **“Traditional”** systems are shallow, often hand-dug, wells in dry river beds, which have been used for thousands of years. They are usually only a few metres deep, and are often fenced off to keep animals out. Traditional systems are often destroyed when the river floods, or during the rainy season, and must be re-dug every year. They can be protected and improved where resources permit (Figure 3 2).
- **Infiltration wells** are large-diameter wells (often around 3 m in diameter), in which the large surface area of the well allows improved flow of water into the well. They may be built using permeable concrete blocks, perforated concrete rings, or other casings (forming a “caisson”) which allow water to pass into the well. They can be constructed either in a river bed, or on the bank of a river. Large diameter wells can often be constructed using mainly manual labour - successive concrete rings or corrugated steel hoops can be “sunk” until the well is of sufficient depth. It is even possible to use old tractor tyres, perforated and bolted together, as casing. The large storage of the well is helpful when yields are especially low; allowing water to accumulate overnight for example, ready to be used in the morning. In some cases

- infiltration wells can have a borehole drilled at the bottom of the well into underlying solid rock to improve yields.
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  - **Infiltration galleries** are horizontal installations (e.g. pipes, brick tunnels or gabions) installed below the water table and leading to a common sump from which water can be pumped. The sump can be next to the river out of the way of flooding. The construction of infiltration galleries can be as simple as trenching in the river bed below the water table, and installing perforated pipes surrounded by a gravel backfill. Increasing demand for water can be met by constructing additional horizontals, provided the total supply potential of the resource is not exhausted.
  - **Collector Wells** are similar to infiltration galleries in that they consist of a sump or well (usually concrete lined and sealed at the bottom) from which horizontal adits are drilled or jacked radially into the surrounding sand. The collector well can be situated either in or adjacent to the river. Its diameter must allow for the necessary equipment to install the collectors. These systems can be costly to install.
  - **Well point systems** generally consist of a series of small diameter tubes or wells, which are driven or jetted into unconsolidated sediment where water tables are shallow. They are usually linked to a common manifold, and suction is used to abstract the water. They can be cheap and quick to install, and can sometimes be repositioned if necessary.
  - **Screened tube wells** are comparable to ordinary boreholes, in which PVC or steel casing and screen is installed to a suitable depth in the sand, and a submersible pump is used to abstract water. Screened tube wells in unconsolidated sediments may require specialist drilling techniques and construction methods (see later in this document, and **Figure 2-1**). They require a relatively large saturated thickness (more than about 7 m) to function efficiently, but can often cope with fairly large fluctuations in water level.
  - **Sand Storage Dams** use artificially accumulated deposits of sand to store water. They usually consist of dam walls or weirs placed across a river, behind which the sand accumulates. Sometimes the weir is constructed in stages, to help retain only coarse material from successive flood events (finer material is carried over the weir). Water stored in the sand can then be abstracted or drained. The sand is

recharged during flood events. They are particularly effective in hot, dry areas where evaporation from a normal dam would be a problem, or where normal dams quickly fill with sediment. The sand also offers some protection to the stored water from pollution. They can be seen as a form of artificial recharge of groundwater.

### 2.4.1 Design and construction of sand abstraction systems

The system chosen depends on the volume of water required, the type and thickness of the sand, the quality of the water in the sand, the frequency and magnitude of flood events, the available budget and the level of accessible technical and management expertise, amongst other considerations. Shallow wells, trenches and other simple systems can sometimes be constructed by hand in primary aquifers. Augering, trenching and jetting are also possible techniques, depending on the circumstances. Clanahan and Jonck (2005) discuss the design and construction of sand abstraction systems in more detail, and the reader is referred to this publication for more information. It is recommended that any but the smallest and simplest systems be designed by an experienced team, including input from a hydrogeologist. This will save money and improve reliability in the long-run.

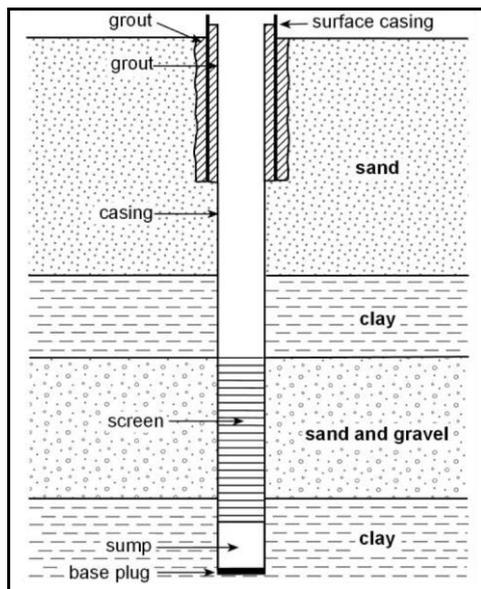


Figure 2-1: Schematic borehole design in unconsolidated sediments (after MacDonald et al, 2005)

### 2.4.2 Operation of sand abstraction systems

Whilst sand abstraction systems are usually reliable and need little maintenance if properly designed, Clanahan and Jonck (2005) warn that problems (particularly biofouling) should be tackled as soon as they appear otherwise rapid deterioration in system performance can easily happen. The characteristics of sand abstraction systems (e.g. water quality, state of the infrastructure, water availability, etc) often depend on the magnitude and frequency of surface water flows in the system. Floods can destroy systems, and pulses of poor quality surface water can rapidly enter the water supply. As with other abstraction systems, regular data collection is absolutely vital. Reductions in

yields may be an early sign of biofouling, which can be very expensive to remediate if allowed to develop (Bishop, 2006).

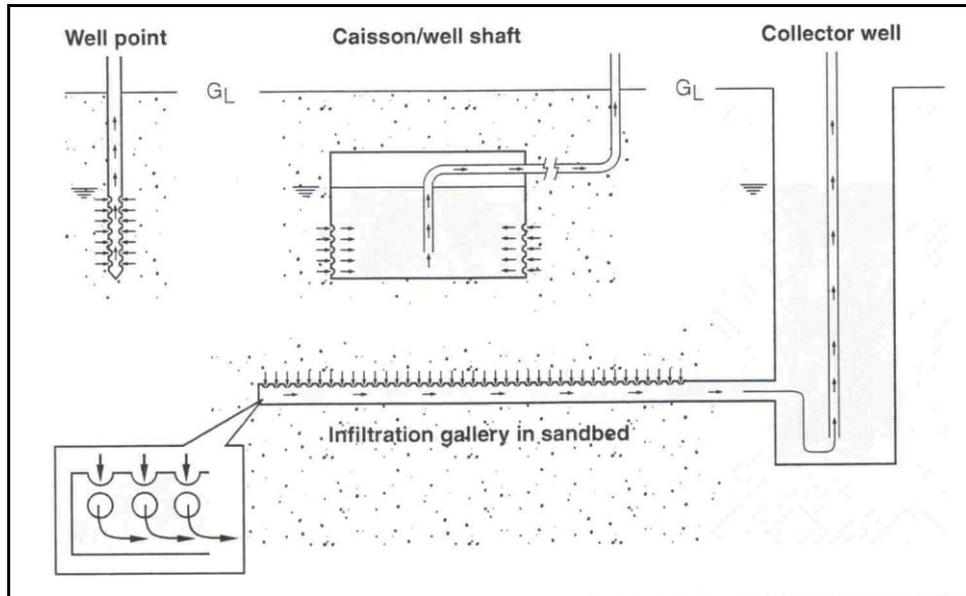


Figure 2-2: Different types of sand abstraction systems (after Hussey, 2007)

## 2.5 Groundwater exploration in primary aquifers

Primary aquifers associated with rivers or dry river beds in South Africa are often small. The thickness and area of the primary aquifer is one of the main controls on how much water can be abstracted sustainably (i.e. in the long term), particularly if the aquifer is recharged only infrequently by surface water. As Hussey (2007) puts it, “a small [sand] river generally indicates a small water supply”. The area of small sand aquifers can often be estimated using maps and aerial photographs, combined with field investigations. The thickness of alluvium can change over short distances, with thicker areas (and better water storage) building up against the outer banks of meanders, or against igneous dykes or other structures that may impede river flow, for example. Aquifer thicknesses can be estimated by augering or trenching, or sometimes even by pushing a steel rod into the sand, until it hits bedrock. A series of such “soundings” can allow a thickness profile to be built up. Geophysical profiling (e.g. Lund resistivity or EM-34 conductivity) can also be carried out, but the results should be interpreted by an experienced geophysicist. Water levels in small alluvial aquifers can also fluctuate considerably, depending on recharge, and water levels may be the main control on the feasibility of developing a supply.

Larger primary aquifers in South Africa should be assessed by following the steps in the main part of the DWA Guideline, together with a review of literature, available data and a hydrocensus. Geophysics and exploratory drilling are recommended for larger schemes.

## 2.6 Drilling and borehole construction in primary aquifers

“Conventional” boreholes in primary aquifers can be complex to drill and construct since they may collapse easily and must often be cased or screened throughout. A gravel pack is often needed to keep out fine material, or to act as “formation stabiliser”, and the drilled diameter must take this into account. In true unconsolidated aquifers ordinary down-hole hammer drilling is not possible and special drilling bits (e.g. drag and tricone bits) must be used. Cable-tool percussion drilling is also sometimes used in unconsolidated sediments, since although it is slow it can cope with collapsing aquifer material. In some cases mud rotary drilling (a special mud is pumped down the drill rods to return the cuttings and stabilise the hole) or even reverse-circulation drilling (the drilling fluid is pumped back up through the drill rods) is necessary to support the sides of the hole whilst casing is installed, although drilling rigs capable of these techniques are relatively rare in South Africa. Removing mud cake or other drilling fluids from the hole after drilling can be problematic. For an introduction to the various drilling methods, the reader is referred to MacDonald et al (2005).

Depending on the nature of the unconsolidated material, it may be possible to develop a “natural” gravel pack against the screens of boreholes by over-pumping. In other cases, and where boreholes are intended for production, an artificial installed gravel pack is recommended. In some cases a graded gravel pack may be necessary, calculated following a sieve analysis of representative aquifer material. Attention to the details of borehole construction and gravel pack can make large differences in the long-term yield of boreholes, and professional advice is needed for all but the simplest of systems.

Development of boreholes in primary aquifers is particularly important, as it helps to flush fine material out of the aquifer in the vicinity of the borehole, to remove drilling fluids, and also to set the gravel pack. Development can be carried out in a variety of ways (e.g. surging, over-pumping, air-lifting, or jetting), and the reader is referred to Clanahan and Jonck (2005) for more information. Boreholes are often disinfected (e.g. by using sodium hypochlorite) following drilling and development, and periodically thereafter.

### 2.6.1 Data collection during drilling

As with all boreholes, data collection during drilling in primary aquifers is very important. Good data collection is needed for planning borehole construction and estimating yields and operational characteristics, and also helps greatly when trying to diagnose the causes of any later problems. Data is also fundamental to the general conceptual model of groundwater for the area. Data from dry boreholes is equally important and must be recorded. At the very least, the following data should be recorded during drilling and borehole construction and a copy handed to the Department of Water Affairs:

- Exact location of borehole using a GPS (including datum and coordinate system)
- Drilling technique (e.g. mud rotary) and drilling fluid used (e.g. air, mud or foam)
- Water strikes and blow yields, including final blow yield during development
- Penetration rate, including presence of hard / lithified horizons
- Logging of chip samples, and lithological description
- Full details of borehole construction, including depth, diameters, casing / screen types, slot sizes, gravel pack depth, etc
- Details of surface completion (e.g. locked cover)
- Final rest water level after drilling and construction completed

### 2.7 Pumping tests in primary aquifers

Whilst primary aquifers are most similar to the “classic” aquifer models of the textbooks in terms of hydraulic properties, they are rarely homogeneous. They may also be of limited surface extent, bounded by less permeable material. For these reasons pumping tests need to be interpreted with care, and with professional advice. Saturated thicknesses of primary aquifers are often low, and water quality problems can also be caused by over-pumping (up-coning of poorer quality water from underlying rocks or seawater intrusion, for example). These factors make pumping test interpretation and the final choice of sustainable pumping rate very important. Over-pumping can also introduce air into the aquifer and encourage biofouling.

Primary aquifers can also act as reservoirs of stored groundwater, often of limited extent, overlying secondary aquifers with relatively low storage. Fractures or other high conductivity features in the secondary aquifers conduct water from the primary reservoir to the borehole. A change in the rate of decline of water level during a constant rate pumping test may indicate that storage in the primary material has been exhausted. **Figure 2-3** shows a pumping test carried out on a borehole sited on a small dry drainage channel, with alluvium of a few meters thick, overlying igneous rock of generally poor hydraulic properties. A marked decline in water level is apparent at about 1 100 minutes, which was interpreted as the effect of storage in the alluvium becoming exhausted.

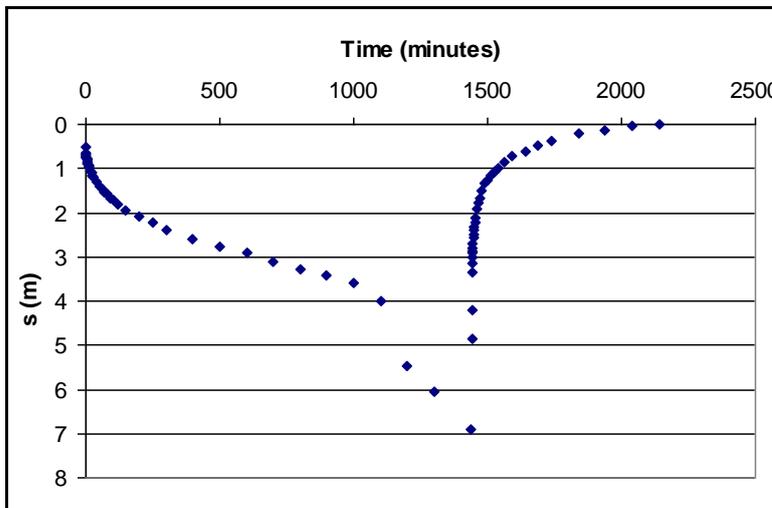


Figure 2-3: Pumping test on a small alluvial aquifer

### 2.8 Artificial recharge in primary aquifers

Artificial recharge is the process whereby surface water is transferred underground to be stored in an aquifer (DWA, 2007). This allows excess surface water to be captured in times of plenty and kept for drier periods. It is an efficient way to store water since evaporation losses are greatly reduced, and the water is protected to some extent from pollution. The injection and re-abstraction of water can also improve its quality. Artificial recharge as a technique in water resource management is growing internationally, and may be particularly suited to countries like South Africa with high evaporation potentials

and cycles of excess surface water followed by drought. Artificial recharge is also used seasonally – for example in the Cape where winter rains and good surface flows can be used to ensure aquifers are full before the drier summers begin.

Artificial recharge is particularly suited to primary aquifers, due to the relatively high storage potential of primary aquifers and the fact that some primary aquifers (e.g. alluvial aquifers) are often sited near surface water courses. South Africa's oldest, largest and most successful artificial recharge scheme, at Atlantis in the Western Cape, is sited on an extensive primary aquifer. Some primary aquifers, whilst having excellent hydraulic properties, contain only relatively small amounts of water since they are of limited size. Sand dams, infiltration basins or injection wells in these aquifers can ensure that surface water flows are not wasted.

Any abstraction from a primary aquifer of limited extent in South Africa, or sited in an arid area, should at least consider artificial recharge of groundwater as part of a wider water management strategy. However, artificial recharge systems need expert advice - technical and operational problems specific to artificial recharge schemes can bring such schemes to a standstill unless correctly handled. A feasibility study done at an early stage can save large amounts of money later on. An Artificial Recharge Strategy has already been published by the Department of Water Affairs (DWA, 2007), and is available at [www.artificialrecharge.co.za](http://www.artificialrecharge.co.za). This document has valuable information for planners or managers considering an artificial recharge scheme. Potential sites for implementation of artificial recharge in South Africa have been identified at pre-feasibility level.



## CHAPTER 3. GROUNDWATER PROTECTION AND VULNERABILITY

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### 3.1 *Abstraction system design*

Abstracting groundwater from primary aquifers can be done using a wide range of technologies, from simple dug wells to complex collector wells and multi-point abstraction systems. All systems should be designed in such a way as to minimise the chances of polluting groundwater via the system itself. 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 an abstraction system is to ensure that it is constructed properly and securely. Boreholes need 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. A concrete “apron” around the well-head is also recommended to stop pooling of surface water. All installations should also be securely capped and locked to prevent any contaminants being put into them, and ideally should be fenced off and locked to discourage vandalism. These basic precautions can save large amounts of time and money.

### 3.2 *Groundwater protection zones*

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 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 are usually based on “travel times” – i.e. the time it takes for water to get to a borehole through the aquifer. A forty-day zone is the area within which water recharging the aquifer will reach the borehole in forty days or less, for example. Protection zones 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 that four source protection zones (see below). Other countries adopt slightly different categories.

It is easier to estimate travel times in extensive primary aquifers than it is in fractured or secondary aquifers since groundwater generally behaves in a more predictable way. Where primary aquifers are extensive and relatively thick, calculating protection zones may be relatively straightforward. The problem is that many primary aquifers in South Africa are of limited depth and extent (e.g. sand rivers), and their properties can be complicated by layering (e.g. less permeable clay horizons). Primary aquifers may also be acting together with an underlying or surrounding “country rock” aquifer to supply

water to an abstraction system. These issues can make protection zones much harder to calculate. Irregular surface water flow in sand rivers and river beds complicates the situation. It is suggested that protection zones be first estimated based on the conceptual model of groundwater occurrence, coupled with analytical calculations (e.g. time of travel down a sand river, if K and gradient can be estimated). Later, if necessary, numerical modelling can be carried out, but only if hydraulic characteristics are known with confidence. The inner zone or zones are the most important, and these are likely to be relatively less complicated to calculate. Professional assistance is highly recommended.

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 in particular is potentially very large, this probably needs to be implemented at the discretion of the supervising hydrogeologist, using common sense. It is also usually sensible to fence off an area of at least ten metres radius around a public water supply system (where possible) and prevent any unauthorised access (including animals) into this area, in addition to the implementation of protection zones.

### **3.3 Vulnerability mapping**

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 (vulnerability in theory changes depending on the properties of the contaminant being considered).

The often shallow depth to groundwater and the high infiltration capacity of unconsolidated material makes primary aquifers quite vulnerable to surface

contamination. On the other hand, groundwater flow in a primary aquifer is often slower than in fractured aquifers meaning more chance of pollutants being degraded before reaching an abstraction.

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.
- 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).

### **3.4 Groundwater pollution in primary aquifers**

Areas of primary aquifer are often also prime agricultural land (e.g. river flood plains), and there is therefore a higher risk of agricultural contaminants (e.g. nitrate or pesticides) entering the groundwater. Primary aquifers are also often associated with surface water flows, either perennial rivers or rare episodes such as flash floods. Surface water can carry pollutants which easily percolate into the groundwater. Flooding is also often associated with deterioration in surface water quality as water treatment plants struggle to cope with the increased volumes. As with any aquifers, the most important issues to consider regarding pollution in primary aquifers will depend on local circumstances. The regular collection of monitoring water quality data in primary aquifers is necessary to establish “background” water quality conditions. Any pollution events can then be assessed with reference to the known background records. This is particularly important when trying to identify the sources of pollution, or trying to establish and prosecute liability for pollution.

Primary aquifers on the coast are important to the water supply of many small towns. Over-pumping in these aquifers can cause seawater to be drawn into the aquifer, potentially compromising the water supply. Monitoring of salinity levels at various points in the aquifer helps to give early warning of this problem, and allows management actions to be “tuned” so as to avoid this problem.

## CHAPTER 4. SPECIAL RECOMMENDATIONS

These site-specific special recommendations add to the information on assessment, planning and management of groundwater resources. The recommendations should be read together with the information in Chapters 2 and 3, and follow the headings given 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 may be available. Privately-held “grey” data (e.g. held by mines or consultancies) is valuable, but negotiations may be needed to obtain this data. Many areas of primary aquifer are too small to have been considered separately in reports or studies, and any assessment needs to take this into account. Professional hydrogeological assistance is recommended.

#### 4.1.2 Identify areas for additional work

Due to the small extent of many alluvial systems, fieldwork is likely to be necessary even to gain a rough idea of the potential yield from a primary system. Similar systems in the area of interest can provide a good idea of yield, but don't forget that they are competing for what may be a very limited resource.

#### 4.1.3 Hydro census

A hydrocensus needs to be careful to distinguish between boreholes in surrounding or underlying “country” rock, and those drawing water directly from a primary aquifer. In some areas, prolific primary aquifers are surrounded by low yielding secondary aquifers. This may depend on the details of the borehole construction – i.e. where it is screened – and this information can be difficult to access. Early public consultation in parallel with the hydrocensus, as laid down in Chapter 2, is highly recommended.

#### 4.1.4 Siting of exploration / monitoring boreholes

Depending on data availability, exploration boreholes may not be necessary for more homogeneous areas of primary aquifer material. Augering and trenching are cost effective methods of exploring the groundwater potential of alluvium. Monitoring boreholes need to be sited in the same hydraulic system as the planned abstraction – primary aquifer material may be separated by impermeable layers, or from hydraulically isolated “pockets”. 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](http://www.dtsc.ca.gov/SiteCleanup/upload/SMP_Monitoring_Well_Design.pdf)

#### **4.1.5 Drilling and testing of exploratory / monitoring boreholes**

Borehole construction in primary aquifers can be costly and require specialist techniques such as mud rotary drilling. Gravel packs may be required. Comprehensive data collection during and after drilling is required, and professional advice is recommended.

#### **4.1.6 Prepare a conceptual groundwater model**

Conceptual models in primary aquifers need to be sensitive to the possible limited extent of primary material, and any uncertainties associated with this. The contribution of the surrounding or underlying hard rock needs to be considered, and this might be via discrete pathways such as dykes or fractures. Primary aquifer material can vary in composition over short distances, and uncertainties in this respect must be taken into account. The quality of groundwater in larger primary aquifers can also vary quite widely, depending on local characteristics, pollution sources, etc.

#### **4.1.7 Risk assessment**

Primary aquifers are often at risk of agricultural contamination, and contamination by polluted surface water. Whilst the intergranular flow can retard pollutants, shallow water tables make primary aquifers particularly vulnerable. A risk assessment in primary aquifers will influence various other issues, such as protection zone policy, borehole design, and monitoring frequency. In general, professional advice is recommended.

#### **4.1.8 Surface / groundwater interaction**

Links between surface water and groundwater are often closer and more direct with primary aquifers compared to most other aquifer systems. In many primary aquifers, surface water flows (even infrequent ones) may be the main control on groundwater availability and water table depth. Conversely, abstraction from primary aquifers can have a large effect on nearby surface water sources and associated ecosystems. Some sand abstraction systems on perennial rivers are designed to abstract surface water through the river bed, effectively filtering surface water through unconsolidated material.

#### **4.1.9 Present to stakeholders and obtain input**

This should be done clearly and honestly, in line with the recommendations in the main body of this report. Input from stakeholders needs to be taken seriously.

#### **4.1.10 Numerical modelling in primary aquifers**

Numerical modelling in primary aquifers needs to take account of the high heterogeneity in morphology and grain size. Assumptions of uniform aquifer properties should be treated with caution. The effects of surrounding or underlying hard rock need to be taken

into account (e.g. leakage). Models relying on only a small number of water levels for calibration may not be reliable. It is also difficult to model the effects of irregular “extreme” surface water flows, which may occur in many primary systems. 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. Expectations should be kept realistic. It may be necessary to discuss alternative sources of water or conjunctive use schemes at this stage. Many primary aquifer bodies may be suited to artificial recharge. In some cases, sand abstraction systems are designed to enhance artificial recharge (e.g. building of weirs across dry river beds). It is recommended that artificial recharge be considered at an early stage, and initial feasibility investigated.

### **4.2 Site-specific planning**

#### **4.2.1 Summarise required data / information**

Primary aquifer systems in particular can have important linkages with other sectors (e.g. farming, ecological flows in rivers, and supplies to springs). Information related to these needs to be collected.

#### **4.2.2 Prepare feasibility level design and costs**

A range of technical options may be applicable to primary aquifers, such as large diameter wells, wells with adits or well-point systems. Storage of water in sand dams may also be possible. Artificial recharge options should be explored from an early stage - the DWA Artificial Recharge Strategy (DWA, 2007) provides further information. System design must take into account not only cost, but also the necessity for on-going operation and maintenance, and the associated resources and skills needed.

#### **4.2.3 Confirm extent of monitoring programme**

Monitoring systems in primary aquifers must take account of the sometimes complex morphology. It may be necessary to include surface water monitoring in those cases where rivers provide recharge to the primary aquifer, or where abstraction is from a river through its bed. Structures in surrounding or underlying hard rock should be considered, since they may act as preferred pathways for flow into the primary aquifer. Environmental flows are also important and surface water features maintained by groundwater in primary aquifers and their associated ecosystems (e.g. small lakes overlying the KwaZulu Natal Coastal Aquifer) need to be monitored too.

#### **4.2.4 Arrange interaction meetings**

Chapter 2 has extensive details on stakeholder interaction (DWA, 2008), which should be consulted. Stakeholders may be prepared to assist with regular monitoring of

groundwater, surface water linked to the groundwater, and groundwater-dependent ecosystems.

#### **4.2.5 Prepare tender drawings and specifications**

All potential technology options should be considered, especially where sand abstraction systems are envisaged. Some of these are very cost effective. Long term maintenance and running costs (e.g. biofouling and clogging remediation) need to be considered.

#### **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**

Chapter 2 lists the following site-specific management tasks:

- Collection, collation, storage and assessment of monitoring data within, and surrounding the water use(s)
- Implementation of water development options identified as part of the planning process
- Supervision, or implementation, of the remedial measures identified as part of the monitoring and management function
- Operation and maintenance
- Control of specific water uses
- Reporting

A groundwater 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.

#### **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

Operation and Maintenance of infrastructure is possibly the most important factor for long-term success in groundwater schemes. A responsible person or organisation must be clearly identified, tasks agreed, and some way of checking these devised. In most areas, provision for staff training must be made, to compensate for staff turnover. 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. Primary aquifers can have quite complex abstraction schemes, which require specific skills to operate and maintain. O&M tasks include maintaining infrastructure (cleaning of biofouled screens and 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 many 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 dipmeter or electronically with pressure-sensitive data loggers or “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.

Once the desirable parameters (water levels, water quality, pumping regimes, etc) have been set, operation and maintenance must be 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. It is often budgetary, institutional, human capacity and other less obvious issues that control the final success or 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 for months or even years. In some cases outside technical assistance may be necessary (e.g. to clear biofouling, or advise on growing water quality problems).

#### **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. 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 Chapter 2). 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 [Chapter 2](#). This should follow the same format each month, in order to make comparing the data as easy as possible.

## CHAPTER 5. CONCLUSIONS

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Primary aquifers in South Africa can provide copious supplies of high quality water, if managed correctly. These aquifers are commoner than many people realise, since even small bodies of alluvium can yield useful water supplies. There is also tremendous potential for increased abstraction from primary aquifers. Large bodies of unconsolidated material close to the coast are not yet fully exploited or even understood, and large amounts of fresh groundwater are currently discharged to the sea. The Cape Flats aquifer is hardly used for water supply, despite good storage and recharge, due partly to poor quality in some places.

Primary aquifers are in many cases suited to artificial recharge, which is especially suitable for those areas where occasional surpluses of surface water go to waste. Typical water quality problems in primary aquifers include biofouling and high concentrations of certain natural elements such as iron, as well as vulnerability to pollution due to shallow water tables.

This document provides some specific advice on primary aquifers, but is not intended to replace professional assistance. It is recommended that professional hydrogeological assistance is sought for all but the smallest groundwater abstraction schemes in primary aquifers. This should lead to lower costs and fewer delays in the long term.

In addition to the special recommendations in this document, it is recommended that primary aquifers in general are given more attention in South Africa, since they represent considerable resources of fresh water. More data needs to be collected, and better monitoring systems should be installed. The interaction of groundwater in primary aquifers with aquifer-dependent ecosystems is still not well understood, and monitoring of groundwater and ecosystem conditions is needed to improve our understanding. Hydrogeological capacity (both skilled people and systems/policy) at all levels is a concern in most parts of South Africa, and improvements here will most likely translate into better utilisation and management of these aquifers.

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