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A Proposed GRA3 Methodology

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Note on the Department of Water Affairs (DWA)

The Department of Water Affairs (DWA) was until recently known as the Department of Water Affairs and Forestry (DWAF). The Department of Water Affairs is part of the Ministry of Water and Environmental Affairs, under a single Minister. The acronyms “DWA” and “DWAF” both appear in this report, the latter mainly as references to past work done when the Department was known as the Department of Water Affairs and Forestry.

National Groundwater Strategy:

A proposed GRA3 Methodology

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EXECUTIVE SUMARY

This report is an output of DWA Project WP9390 "Strategy and Guideline Development for National Groundwater Planning Requirements". It defines a framework for a GRA3 methodology, and is intended to build consensus in the hydrogeological community in South Africa prior to advocacy and implementation. The Groundwater Resources Assessment Project Phase 3 (GRA3) follows the earlier GRA1 and GRA2 groundwater resources assessment projects. Whereas GRA1 and GRA2 concentrated on representing and analyzing groundwater data, GRA3 is a broader methodology ultimately aimed at raising the profile of groundwater in South Africa and ensuring wider and more sustainable groundwater use. Only a part of the GRA3 work will be aimed at representing existing groundwater data. Other components include making recommendations for increasing the quantity and availability of groundwater data in South Africa and suggestions for improving aquifer-scale assessment of groundwater and general operation and maintenance (O&M) procedures for groundwater schemes.

Groundwater data in South Africa is stored in several public sector databases, and also by many private groundwater contractors, drillers and consultants. Increasing the submission of data by the private sector to public databases is a vital issue that can be carried out relatively easily and cheaply by requiring drilling contractors to routinely supply details of boreholes drilled to DWA in line with common practice in many other countries. Integration and upgrading of existing public sector groundwater databases is also necessary.

Although failure of groundwater schemes is often blamed on the resource (the "groundwater dried up", for example), it is usually inadequate operation and maintenance (O&M) of the schemes that is to blame. Broader issues of management and accountability at municipal level have a bearing on continued groundwater O&M, but these are beyond the scope of this document. "Best practice" examples of South African groundwater supply schemes would help to increase knowledge and trust of the resource.

Groundwater assessment at the regional and local level, based on aquifer type and extent, is still not carried out frequently enough or in enough detail in South Africa, yet is very important for groundwater scheme sustainability and management. This document describes some of the basic principles of aquifer assessment, and also introduces the Generic Guideline published by DWAF as well as the Groundwater Regions project, both of which have important information in this regard.

A common reason for favouring surface water over groundwater is that hydrogeologists often cannot give an accurate figure for "assurance of supply", or some measure of how reliable a particular borehole's yield might be based on regional groundwater availability. A methodology is suggested that links the GRA1 dataset (borehole median yields and classes) with the GRA2 dataset (which contains assurance of supply information), in order to produce *a map or maps that would provide the groundwater planner with aquifer type, yield and assurance of supply information. This methodology is designed to "break the logjam" in which calls for more groundwater schemes are met with the response that assurance of supply is still uncertain. At the same time it is recognised that the impacts of groundwater abstraction cannot be calculated with certainty before at least some development takes place – i.e. there is an element of "adaptive management" inherent in all groundwater schemes. It is necessary to keep in mind the uncertainty inherent in all groundwater development, in all countries, when considering wider use of the resource. Finally, the outputs of the GRA3 methodology (likely to be maps) need to be widely and easily available, if they are to achieve wider groundwater use.*

National Groundwater Strategy:

A proposed GRA3 Methodology

1. INTRODUCTION

This report is a deliverable of Project WP9390 “Strategy and Guideline Development for National Groundwater Planning Requirements” coordinated by the Department of Water Affairs (DWA). Following the Groundwater Resource Assessment projects Phase 1 and Phase 2 (known as GRA1 and GRA2 – see WGC, 2009a), there is a need to define a framework and a methodology for Phase 3 of the Groundwater Resources Assessment (GRA3). This report begins with a discussion of some of the background issues relevant to groundwater resources assessment in South Africa, and then proceeds to describe proposed GRA3 components.

An important problem, as identified by many in the South African hydrogeological community, is that groundwater is still underutilized and under-appreciated in South Africa. GRA3 aims to address this problem. This will be done partly by providing a methodology for groundwater assessment in South Africa, based on existing data and the previous GRA phases, which will help to fill perceived gaps (particularly around the issue of assurance of supply).

There is no need for ever more complicated groundwater resource assessments if these move away from the requirements of decision makers and the needs of society. The lack of knowledge of the resource is one reason why groundwater is not more widely used, and better groundwater knowledge is a goal of GRA3. However, the availability and accessibility of existing summaries of groundwater occurrence is also a very important issue – what use are better estimates if these are confined to a small community of specialists? GRA3 therefore needs to have an advocacy component, both to encourage initiatives that will ensure better resource estimates in future (such as wider data collection and sharing), and also to increase awareness of the conclusions which have already been reached with regards to groundwater assessment with decision makers.

The “discourse” of water in South Africa is predominantly that of surface water – that is, we unconsciously adopt a system of thought and a range of assumptions and expectations related to water and water supply which are rooted in surface water and not groundwater. Surface water has traditionally received the most funding, the most expensive and visible infrastructure, and occupied the majority of the time of water planners in this country. There are good reasons for this. Most of South Africa’s large urban centres rely on surface water, and big dams and large inter-basin transfer schemes such as the Lesotho Highlands Water Project have a high profile. Past legislation held that groundwater resources were private and therefore effectively local, making regional groundwater management difficult and fragmented. South African aquifers are also mainly fractured and have relatively low yields, and groundwater can be difficult to manage regionally. The cultural isolation of South Africa in the latter years of apartheid meant less contact with scientists (including hydrogeologists) from the rest of the world than would otherwise have been the case. And it is easier to see and to appreciate surface water compared to the “hidden” resource of groundwater. Whatever the reasons, the South African bias towards surface water often leads to groundwater’s potential being ignored or grossly under-valued. This situation was once recognised in Spain, where surface water was favoured even where groundwater was the more logical option – a situation once called “hydroschizophrenia” (Llamas, 1985). The reality in South Africa today is that around two thirds of people obtain their basic water supply from a groundwater source (Braune and Xu, 2006), and that the total volume of available groundwater in the country is of the same order of magnitude as available surface water (Woodford et al, 2006).

Figure 1.1: Box on South Africa’s water discourse

2. GROUNDWATER DATASETS

2.1 DATA COLLECTION INITIATIVES

2.1.1 NGDB

DWAF maintains a network of boreholes for groundwater level and quality information, and adds this information to the National Groundwater Database (NGDB, soon to be updated to the National Groundwater Archive or NGA) at regular intervals. In theory the NGDB also receives groundwater data from a variety of projects in which the Department has an interest.

2.1.2 WARMS

DWAF also maintains the Water Authorisation and Use (WARMS) database, which gathers together information provided by license holders on groundwater use. Municipalities also collect groundwater use information, and some of this is submitted to DWAF for incorporation into WARMS.

2.1.3 GRIP

The Groundwater Resource Information Project (GRIP) was initiated partly because poor groundwater data holdings are one reason why groundwater has been under-utilised in the past. Recent estimates of groundwater availability in South Africa have large elements of uncertainty, leading to mistrust of the resource. Only better groundwater data can reduce uncertainty. GRIP was originally conceived as a national project to improve data holdings by accessing unpublished or “private” data as well as “new” groundwater data collected by visiting boreholes in the field – particularly in priority areas. GRIP would also develop systems and procedures for the collection and verification of unpublished data. GRIP was originally started in the Eastern Cape and Limpopo Provinces, with later roll-out in KwaZulu-Natal and the Free State (Botha, 2005). All GRIP data would be entered into the DWAF national WARMS database, ensuring its accessibility. To date, GRIP has been most fully implemented in the Limpopo Province, where it has been divided into four phases:

- collection of data (both new field data and data from existing reports)
- assessment of data which has been collected
- drilling and testing of new boreholes in priority areas
- production of a provincial groundwater planning report aimed at decision makers.

The GRIP in Limpopo province began in 2002 and is still underway. More than 2 500 villages have been visited in Limpopo Province, 15 500 borehole sites have been verified and 1 500 additional pumping tests have been added to the provincial database. Limpopo Province now has probably the most extensive and best verified dataset on rural groundwater resources in the country, and enough is known about groundwater in the province to allow it to be much better integrated into general water resource management.

Table 2-1: Available groundwater datasets in South Africa

Name	Administered by	Data type	Number of entries	Comments
NGDB	DWAF	Boreholes and geosites	Estimated 225 000 boreholes	Variable accuracy, especially regarding borehole location
NGA	DWAF	Boreholes and geosites	Not yet operational	Web-enabled update of NGDB. Due to go live in 2009.
REGIS	Old system, now discontinued.			
GW H-Regions	A provincial numbering system, not a database. Used to be held at provincial level. Now partially or fully integrated into the NGDB.			
WMS	Institute for Water Quality Studies within DWAF	Point-source water quality information		Good data quality. No details on borehole construction etc.
WARMS	DWAF	Boreholes and geosites		Licensed groundwater users must supply abstraction information to WARMS
GRIP	Provincial DWAF or WMA	Boreholes and geosites		Operational in E Cape, KZN and Limpopo
Private Sector	Various companies	Large variety of data sources in various formats	Unknown, likely to be very high	Large amount of privately collected data, and “grey” reports.

2.1.4 Private and municipal data holdings

The private groundwater sector (including private drilling contractors) in South Africa is responsible for a huge amount of groundwater data collection, storage and interpretation, via work done as part of both commercial and government-funded projects. The proportion of “private data” collected in comparison with data collected by the state is probably rising. Unless contracts specifically state that data must be handed over by private consultants or contractors to the state for inclusion into (for example) the WARMS database, little of this data becomes effectively freely available either to the state or to other private consultants and contractors. If private drilling contractors are included in estimates, far more groundwater data is generated by the private sector than is collected by the state, yet very little of this data finds its way into state databases and becomes part of national groundwater estimates or other projects designed for the “national good”. At present most groundwater consultants and contractors maintain extensive private databases for their own use, in a variety of formats and standards. There is also evidence that municipalities that collect groundwater data retain it for internal use and are not aware of the requirement for wider distribution.

2.2 SCALING UP GROUNDWATER DATA COLLECTION

2.2.1 Introduction

Assessment, Planning and Management of groundwater resources depends totally on adequate groundwater data. Improving groundwater monitoring and increasing groundwater data collection is probably the most important message to come out of the GRA3 process.

2.3 COLLECTING PRIVATE AND MUNICIPAL SECTOR DATA

Although hydrogeological consultants collect and process much groundwater data, the primary source of “private” groundwater data would be private drilling companies. If drilling companies were incentivised or required to submit drilling records to the state for inclusion into the public databases, the amount of data captured would grow enormously, as would the potential ability of the state to estimate groundwater resources and plan groundwater projects. This data need not be onerous to collect – even basic data (for example, an accurate borehole location, depth, water strikes and water level) would greatly improve national data holdings. The following recommendations are made:

- Drillers should be required to submit basic records of all boreholes drilled to DWA. This could be part of their license conditions or a pre-requisite for eligibility for state drilling contracts. In return, drillers would be able to access a larger and improved state borehole database, allowing them to better anticipate drilling conditions and plan accordingly.
- Hydrogeological consultants should also be required to submit basic records of boreholes constructed in the course of their work, as well as monitoring records for existing boreholes. This would need to be done with permission of the client – although it is anticipated that most borehole records will not be confidential or sensitive.
- Pumping test contractors should submit copies of their data to DWAF, on a similar basis to that of drillers.
- State-administered contracts should all include a clause requiring that copies of all data collected or generated in the work be surrendered to the state.
- In return, DWAF would invest in their groundwater database, making it easily accessible on-line and collating data in such a way as to be useful to the private sector.

2.3.1 Integration and strengthening of databases

Data on groundwater in South Africa exists in various different databases held by a variety of organizations and individuals. Many of these databases are inaccessible (e.g. those held by private companies) or are difficult to access (e.g. groundwater data held at a provincial level). Combining databases would make groundwater planning easier and cheaper. The process should start by integrating those databases that are already publicly available (in theory), and later address the problem of “private” groundwater data. The forthcoming National Groundwater Archive (NGA) recognises many of these aims, and will endeavour to consolidate much groundwater data held by DWAF into a single database. The NGA will also have a facility that allows users to “upload” groundwater data – designed to encourage the submission of data generated by private work and which would not normally be seen by DWAF.

One of the limitations of existing groundwater databases is the high level of uncertainties associated with abstraction volumes. Several projects have shown that the data held in the WARMS database can either overestimate abstractions (e.g. in cases where users have applied for a maximum abstraction volume as part of a license application, but only use a fraction of this) or underestimate abstractions (e.g. in cases where large abstraction boreholes do not appear on the WARMS database at all, for example high volume irrigation in the Delmas or Tarlton dolomite aquifer areas in Gauteng).

Improved institutional arrangements for data collection are required. Existing data needs to be verified, and existing databases need to be integrated.

2.3.2 Data accessibility

The disinclination to use groundwater may in fact be because the existing data (including the GRA1 and GRA2 outputs) is not yet sufficiently accessible, rather than insufficiently detailed. The problem may be more that data is not being interpreted and communicated in a way that is meaningful to decision makers. The GRA3 process will aim to ensure that project outputs are accessible and widely disseminated. Much groundwater data is held by private sector organisations and by private individuals – effectively placing it beyond the reach of state planners. Greatly improved public access to South African groundwater data is desirable.

AQUIFER SCALE ASSESSMENT

2.4 INTRODUCTION

Sustainable groundwater abstraction usually relies on an assessment of the aquifer or aquifers which are being exploited, and which can change as new information becomes available. This is different to a national assessment of groundwater availability, being more detailed and designed for a specific purposed. The first step in a technical groundwater assessment is normally the collection of groundwater data and a review of literature and other material relating to the aquifer in question. This is often followed by field assessments such as drilling and pumping tests, and the consequent collection of new data. The aim is to determine, as far as possible, aquifer parameters (depth, extent, T, S, porosity, etc) as well as the availability of groundwater in terms of both quantity and quality. An aquifer assessment would normally lead to the development of a conceptual model. Flow patterns, recharge, response to pumping, impact on groundwater-dependent ecosystems, pollution threats, and other factors are often considered at this stage, depending on the aquifer, its size, and the envisaged abstraction. In some cases numerical groundwater models are developed to assist in the prediction of environmental impacts, the evolution of water quality and other factors.

Data collection and assessment are sometimes considered to be an iterative process – the act of assessment and conceptual model development helps to identify data gaps, leading to the collection of new data. The new data, in turn can alter the conceptual model. Aquifer assessments can be done over a variety of timescales – a rapid assessment may take only a few days or weeks, whilst a more comprehensive assessment can take months or longer, and is sometimes coupled with partial groundwater development. As groundwater is abstracted, so conditions change and new data may be collected. This informs the management of the groundwater resource, and changes to abstraction regimes may be recommended. The process in which aquifer parameters are refined and adjustments made to management practises as groundwater exploitation proceeds is sometimes referred to as “adaptive management” (Seward et al, 2006).

An aquifer assessment should be accompanied by an evaluation of current and future water demand. Technology choices and management plans can depend on future demand predictions – for example by selecting borehole designs that might one day accommodate artificial recharge, or by planning water treatment facilities which could be upgraded to treat poorer quality water drawn from deeper down in the aquifer in the future. Technology choices should also be subject to an assessment of the human and managerial resources which will be available to operate and maintain them over the medium and long term. In this way the hydrogeological or “technical” aquifer evaluation cannot be divorced from the social and administrative conditions. An understanding of both is needed for optimum resource exploitation.

Vegter (2001) goes into some detail regarding the assessment of groundwater resources, including the various techniques (geophysical logging, mathematical modeling, isotope analysis, etc) that may be brought to bear on the problem. According to Vegter (2001), the characterisation of groundwater should ideally include the following:

- Ascertaining the hydrogeological characteristics of groundwater occurrence;
- Delineating hydraulic groundwater units;
- Determining the hydraulic characteristics – transmissivity, storage, etc;

- Estimating groundwater recharge and discharge;
- Ascertaining chemical composition and potability of groundwater;
- Establishing the current state of and potential for development;
- Predicting the effects of groundwater exploitation on the environment and of environmental change on groundwater availability and quality.

2.5 THE DWAF GENERIC GUIDELINE

The Department of Water Affairs and Forestry (now DWA) published a document entitled “A Guideline for the Assessment, Planning and Management of Groundwater Resources in South Africa” in 2008 (DWAF, 2008), which amongst other things lays out generic guidelines and recommendations for aquifer assessment in South Africa. The guideline is based on an earlier guideline aimed at groundwater management in dolomite aquifers in South Africa (DWAF, 2006). The objectives of the new guideline are to provide assistance and guidance to those involved with the assessment, planning and management of groundwater resources in South Africa, particularly with regard to the correct processes to follow (DWAF, 2008). Assessment, Planning and Management of groundwater are related steps, each one of which has a bearing on the others in an iterative way. A lack of effective assessment, planning and management of groundwater resources can result not only in poor service delivery to water users, but also to significant detrimental impacts on the aquifer systems themselves. For example, unmanaged and uncontrolled abstraction and/or dewatering of the aquifers can lead to boreholes, wetlands and springs drying up; and in the case of karst aquifers, sinkhole formation (DWAF, 2008). The Generic Guideline is considered to be consistent with Integrated Water Resources Management (IWRM) principles. The three steps are summarized as follows. (The first step equates to aquifer-scale assessment.)

2.5.1 Assessment

Assessment determines the current groundwater situation in a study area, both in terms of groundwater quantity and quality. This step also summarizes the existing water requirements for all sectors in the study area. Assessment also ensures that information is in the correct format, and of the right level of detail, depending on the size of the area under consideration (DWAF, 2006). The assessment step makes use of existing groundwater and water-use data, although it is common for more data to be required than is immediately available. Collection of new data may need to take place.

2.5.2 Planning

The planning step involves matching water availability with water requirements, by investigating development options. Part of the planning process is also to make all information available and clear to decision-makers, enabling a ranking, summarizing and costing of available options. Planning also provides rules and guidelines to enable sustainable water use, locates groundwater within the bigger water-use "picture", and functions as a motivation for funding (DWAF, 2006). Planning in a catchment needs to take account of all water resources, not just groundwater.

2.5.3 Management

The aim of management is to ensure that water resources are used sustainably – in other words, the basic integrity of the resource must not be compromised. Management tries to avoid the negative impacts on people and the environment of over-abstraction or pollution. Management is enabled by the availability of quantity and quality information over time, so that interventions and strategies can be refined. An important part of management is the setting of "management objectives" at different levels (national, catchment and local levels). The on-going monitoring enables the progress made towards reaching the management objectives to be monitored (DWAF, 2006). Action plans may be put in place where strategic goals are not being reached. Good management saves both time and money.

2.6 SOUTH AFRICA'S GROUNDWATER REGIONS

Conceptualised in the late 1980s, a long-term project based on the division of South Africa 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 opening – i.e. primary or secondary) as well as on lithostratigraphical, physiographical and climatic considerations (Vegter, 2001). Groundwater in a region is not necessarily part of the same hydraulic or hydrological unit. 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. A number of groundwater issues including methods for geophysical exploration, recharge, hydrochemistry and the siting of boreholes are included in the reports. A total of 64 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) in Pretoria. These studies are good examples of detailed regional aquifer assessments, but do not necessarily contain details of current and predicted water demand, or management institutions and capacity.

2.7 EXISTING GROUNDWATER RESOURCE ESTIMATES IN SOUTH AFRICA

The first comprehensive national estimates of how much groundwater is available in South Africa were provided by a series of national groundwater maps in 1995 (Vegter, 1995). Not long after this, the Department of Water Affairs and Forestry (DWAF, now DWA) began the Groundwater Resources Assessment phase 1 (GRA1) process which by 2003 had produced a set of twenty one hydrogeological maps (sometimes known as the "general" maps or the "hydrogeological map series") at a scale of 1:500 000 covering the country. Each map will have an explanatory booklet, although to date not all booklets are complete. Vegter's national maps and the GRA1 process did not however make estimates of the total volumes of groundwater which could be used annually in South Africa, particularly when various constraining factors such as "extractability", recharge and water quality are taken into account. In 1998 Baron et al compiled a national "Harvest Potential Map" which did seek to estimate total groundwater availability per unit area in South Africa. The Groundwater Resources Assessment phase 2 (GRA2) process, which began in 2003, aimed to update the Harvest map as well as producing a "planning potential" map, quantifying recharge and groundwater/surface water interaction, classifying aquifers, and making more accurate estimates of groundwater use. For more comprehensive information on GRA1 and GRA2 see WGC, 2009a.

GRA1 and GRA2 had their foundations in essentially the same groundwater and related datasets – including the National Groundwater Database or NGDB maintained by DWAF, geological and topographical information, rainfall measurements, recharge estimates, water quality data, water use data, regional studies, and the water management system (WMS) database. Although the outputs of the two phases are different, they have the same roots. New data available for a third phase of the Groundwater Resource Assessment project is limited to additions made in the last few years, plus any private reports and datasets that may have become available since GRA2. There is no substantial new database on which to build GRA3. Evidence from projects including the Department of Water Affairs Project 14/14/5/2 "Implementation of Generic Dolomite Guidelines" shows that, in some areas anyway, groundwater data collection is in fact declining, and modern estimates of groundwater conditions must be made using a decreasing number of boreholes. There are several reasons for this, which are discussed elsewhere (e.g. WGC, 2008a). However, this reinforces the conviction that the amount of groundwater and related information held by the state and its affiliates today is not substantially larger than it was when GRA2 was completed.

3. GRA3 METHODOLOGY

3.1 ASSURANCE OF SUPPLY

3.1.1 Background

Surface water planners consider the “assurance of supply” (assured or firm yield) of a surface water resource, or the percentage likelihood that the source will fail, as very important. Required assurance of supply levels depend on the user, with 98 % regarded as the minimum figure before surface water resources can be harnessed for public supply, while for example the national electricity utility ESKOM requires a 99.8 % assurance of water supply (and uses about 2 % of the country’s water).

Surface water assurance of supply is based almost entirely on statistical analysis of rainfall-runoff figures in a catchment – most particularly using long-term time series of rainfall. This data is linked to the volume of surface water storage available in the catchment (dams), and a calculation is then made which estimates what percentage of the time the system will fail to supply a particular amount(e.g. 98% assurance means the required yield will on average not be met for 2 out of every 100 years). Put another way, there is a one in fifty chance in any year that the required yield will not be met. The DWAF surface water resources yield model has a strong emphasis on available volumes of surface water, and how these change with variations in precipitation, evapotranspiration and storage capacity.

Hydrogeologists, who complain that groundwater is given too little attention in national water planning, are often asked about the assurance of supply for a given groundwater resource. This question is more difficult to answer for hydrogeologists than it is for surface water specialists, since groundwater availability depends not only on rainfall (and its varied and complex relationship with recharge), run-off and storage capacity, but also on accurate estimates of aquifer properties and aquifer boundaries. Such data is rarely available, particularly where groundwater abstraction is still being considered and has not actually begun.

Beyond the challenges of determining recharge, outflows or available underground storage in order to arrive at an assured yield on an aquifer scale, the assurance of supply is also intractably linked to the assurance of a single borehole yield. This duality of assurances of yields on an aquifer as well as on a borehole scale is a major differentiating factor compared to surface water management, where the point of abstraction has only very limited influence on the total yield of a catchment (with conveyance and evaporation losses being the determining factors). For groundwater on the other hand the spatial distribution and design of abstraction boreholes has a major impact on the overall yield of an aquifer (similar to the Average Groundwater Exploitation Potential in GRA2), with parts of an aquifer being for example already over-utilized while the aquifer as a whole can still sustain a number of sustainable and assured yields. The sustainable, assured yield of a single borehole can furthermore vary by orders of magnitude over short distances due to the heterogeneity of South African fractured aquifers, requiring site-specific and detailed assessments for single boreholes while taking cognizance of the assured yield of the aquifer as a whole. Other complicating factors include water quality issues and how the quality might change with long-term abstraction through for example saline intrusion into coastal aquifers. The risk of sinkhole formation in dolomitic aquifers, impacts on surface waters/wetlands or more general the protection of the groundwater reserve are other limiting factors for the single as well as aquifer assured yield (similar to the Utilisable Groundwater Exploitation Potential in GRA2).

Given these circumstances, hydrogeologists usually cannot give assurances of supply which can compete with surface water and rather opt for a precautionary approach with lower yields to ensure a 100% assurance of supply. An obvious way around these shortcomings is the enforcement of adaptive management practices, i.e. an initial assurance of a lower yield could be raised once more monitoring data become available. While this puts the monitoring burden on the groundwater user, it can benefit the user in way of higher yields if the user can show negligible or manageable impacts. However, while such approach is recommended for the management of a single borehole or well field, it does not assist in the prediction of the impacts of climate change nor with a reasonable regional/national estimation of groundwater resources as requested by DWA.

3.1.2 Principles

It is proposed that GRA3 uses the following principles for regional estimations of assured yields:

- Neglecting the often considerable available storage in an aquifer, the currently estimated yields are based on mean annual recharge figures, which have a typical recurrence interval of 2 years and therefore translate to an approximately 50 % assurance of supply (depending on the underlying distribution). It must be emphasized that such simplistic view does not account for the considerable storage of groundwater in the aquifer, which can be utilized in times of droughts and replenished in wetter years, i.e. the buffer capacity of an aquifer similar to the storage volume of a dam. If no further data are available for an aquifer, the yield should strictly be given at a 50 % assurance. However, basic assumptions can be made about aquifer storage that raise this assurance considerably.
- Yields of an **aquifer unit** should be based on rainfall-recharge statistics to arrive at an assured yield based on recharge probabilities for different meteorological conditions.

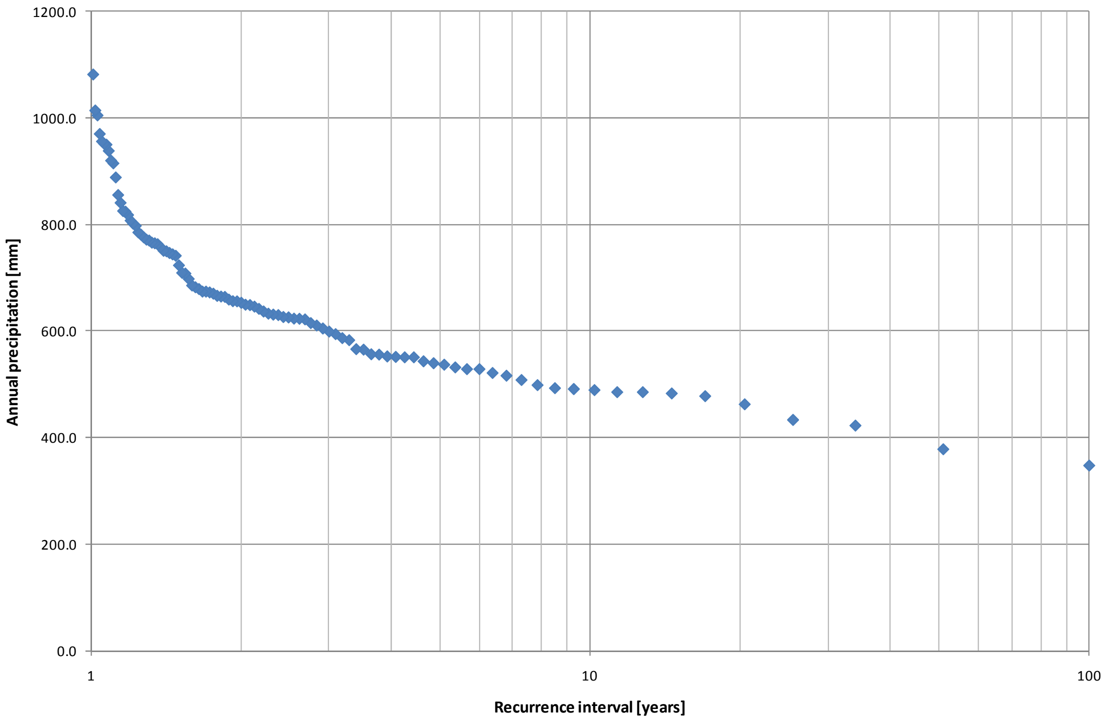

Figure 3.1: **Rainfall probabilities as recurrence intervals for the Tarlton area (mean annual presipitation = 669.6 mm)**

- While the Aquifer Assured Yield Model, a simple single-cell, lumped-parameter model currently developed by Woodford, Ravenscroft and Murray (WRC project K5/1763), can serve as a first blueprint for the methodology development, it needs to be modified to consider also shallow, porous, unconfined aquifers (currently strictly not applicable) as well as the considerable time lag between re- and discharge in aquifers.
- It is important to understand that rainfall-recharge relationships for catchments are often non-linear and auto-correlated, i.e. rainfall of preceding months influence recharge values for the current month. If such relationships are not yet established for a catchment, linear relationships (i.e. recharge as % of precipitation) should be used as a first approximate and flagged as such while the relationships are established.
- The sum of sustainable, assured yields of all boreholes targeting an aquifer unit must be lower than the sustainable, assured yield of that unit. The assessment thereof must also consider potential current or future abstractions under the general authorization.
- Sustainable, assured yields of single boreholes should be assessed with suitable pumping tests utilizing monitoring boreholes (for the determination of storativity/specific yield values) and analytical or numerical models

applicable to the specific hydrogeological setting of the borehole. Impacts of single abstraction points on nearby surface water resources can be quantified using a range of analytical or numerical models (Witthüser 2006).

- More groundwater data is needed, particularly long-term abstraction and use data, in order to enable better estimates of assurance of supply for an aquifer unit. These “outflow terms” are needed to arrive at a “current assured yield” in addition to a “natural assured yield” of an aquifer unit (pre groundwater development). While the latter is used to assess the potential natural situation of an aquifer unit as a reference condition, it is of limited use in the quantification of currently still available and allocatable groundwater resources.
- Assurance of supply depends on adequate infrastructure, and proper funding for borehole siting, drilling, construction and development. Too often, groundwater schemes are implemented on a shoestring budget, which does not allow the aquifer to be effectively understood and exploited.

3.1.3 Impact of Climate Change

If the sustainability of groundwater supplies and the “assurance of supply” are linked primarily to recharge, and recharge is a function of rainfall, then predicted changes in rainfall (volume and intensity) over the medium to long term in South Africa as a result of climate change will have a direct impact on the viability of groundwater supplies. “The South African Water Act (1998), for example, states that only if recharge exceeds the sum of basic human and environmental needs in a catchment plus groundwater outflow necessary to sustain the same needs downstream, may groundwater be allocated for other uses” (Xu and Beekman, 2003). Possible impacts due to climate change will need to be incorporated into assurance of supply figures for GRA3 via predicted changes in rainfall. Early forecasts of climate change impacts in southern Africa refer to drier climates, and shorter and more intense rainfall events. The buffering capacity of many groundwater systems, due to high storage and low rates of evaporation, may favour groundwater over surface water as the effects of climate change take hold.

3.1.4 Assurance of groundwater supply, and O&M

It is important to make the distinction between assurance of supply assuming perfectly functioning infrastructure and management systems, and assurance of supply in the “real world”. Assurance of supply is of course dependent on the mechanical integrity of the infrastructure (boreholes, pumps, etc) and on adequate maintenance and management arrangements. These depend on adequate operation and maintenance (O&M) of the complete groundwater supply system. However, many groundwater schemes are assumed to need very little monitoring and maintenance, and it is not surprising when they fail. As mentioned above, such failure is often wrongly blamed on the resource. Surface water supplies need constant inputs of time, personnel and funding, and groundwater schemes should be no different. Groundwater may even have an advantage over surface water in terms of the role of operation and maintenance in assurance of supply, since several boreholes can operate more or less independently – a single mechanical failure cannot knock out the entire supply (as opposed to, for example, a failure at a centralized surface water treatment works). It is very important that assurance of supply as determined by the level of O&M is not confused with the state of the groundwater resource.

3.2 MONITORING

The following recommendations are made with respect to improving monitoring of groundwater systems in South Africa:

- Recognition of lateral and vertical heterogeneity of aquifer systems, i.e. borehole clusters targeting different aquifers overlying each other, enabling differentiation of water level and quality data for each aquifer unit as well as the determination of leakage factors, i.e. the hydraulic interaction between these aquifers.
- A higher density of rainfall stations for important catchments is needed
- Determination of specific yield/storativity values will require neighbouring boreholes within the same aquifer unit (vertical and horizontal)
- Monitoring boreholes drilled and equipped according to best practice (e.g. no-casing, steel, PVC or stainless steel casing, gravel packs, screening depth and prevention of hydraulic shortcuts between aquifers)
- Strategic review of existing monitoring borehole network (spatial distribution and sampling frequency) to increase efficiency of spatial coverage (i.e. some neighbouring BHs might be omitted while others should be drilled)
- Randomly drilled boreholes for unbiased estimates of aquifer properties
- Usage of springs as integral monitoring point (discharge and quality) for upstream catchments (requires additional early warning boreholes)
- Long-term monitoring must continue (no model will ever replace measurements)

3.3 TRENDS

It is envisaged that GRA3 provides a national characterization of the water quality and availability which considers the current state as well as identified trends to be used for forecasting. In order to identify and describe trends in a sequence of observations (water quality and water levels), the pattern of an observed time series must be described. Time series pattern can typically be described as the sum (additive model) of several components:

$$y(t) = T(t) + C(t) + S(t) + R$$

Where T(t) is the trend component, C(t) the cyclic component (e.g. drought cycles, can be interpreted as a seasonal component of higher order), S(t) the seasonal component and R the irregular component accounting for unexplained variations or randomness in the data (noise). The most prominent components in time series patterns are usually the trend and seasonal components (if e.g. quarterly samples were taken). While trends account for systematic linear or nonlinear (e.g. exponential) changes over time which do not repeat (for a given time range or parts thereof), a seasonal component repeats itself in systematic intervals over time, typically over a hydrological year. If these components are removed from a time series, cyclic components of a higher order might become apparent (e.g. drought cycles).

The estimation of a trend component in the time series requires smoothing or local averaging of the data to eliminate non-systematic or seasonal components. The moving averages replace the single values of a time series by using the average of neighbouring elements within the “smoothing window”. If the width of the smoothing/averaging window equals the cycle period for time series with constant seasonal figures (or multiples thereof), both seasonal and random components are removed from the smoothed time series. The trend component of the time series can then be described with a linear function (transformations might be necessary for monotonous nonlinear (e.g. exponential) trends) and the significance level of the regression coefficient (the slope) given using Student’s t-test.

A time series might have different trends over time (e.g. a decreasing trend following a time of increasing trend due to intervention measures) and these different sequences need to be identified and evaluated separately using the method described above.

3.4 SURFACE WATER GROUNDWATER INTERACTION

The recognition of the unity of the water cycle as a common resource, the call for Integrated Water Resource Management in the National Water Act (1998) and most important the often close linkage of groundwater and surface water yields call for a better quantitative description of interactions between surface water and groundwater (SW-GW) in South Africa. While for a single groundwater use licence application the potential impacts on surface water resources (baseflow reduction) are the prime focus and theoretically (see overview of methodologies in Witthueser 2006) relatively well understood (though case studies and monitoring networks are clearly missing), the overall contribution of groundwater to surface water yields per aquifer unit remain a challenge in regional assessments. To complicate matters, no clear guideline to quantify SW-GW interaction (and related impacts) exists and current concepts as well as terminology differ. Surface water planners in DWAE currently use the WRSM2000, which includes a SW-GW interaction model developed by K. Sami, but reviews by hydrogeologists questioned its applicability (Dennis 2005, Sami & Witthüser 2006). One recommendation of the review was the adoption of internationally proven and accepted SW-GW modelling packages like MIKE-SHE (developed by DHI) or GSFlow (developed by the USGS) to quantify SW-GW interaction.

A general challenge for the quantification of SW-GW interaction is the different nature of SW and GW resources with regard to residence times (days to weeks versus years to millennia) and spatial distribution (single channel versus ubiquitous three-dimensional aquifer unit). While the time scale complicates numerical coupling of SW and GW in combined models as well as the impact predictions of GW abstractions due to often long time lags, the spatial scale of aquifers is especially challenging for monitoring and characterisation tasks, not to mention independent forward predictions of GW contributions to baseflow. If hydrogeologists are requested to quantify SW-GW interactions independently (i.e. without a river hydrograph), they would have to characterise and model an entire heterogeneous aquifer unit along with all its recharge and discharge variability based on a handful of monitoring boreholes and pumping test results. It is obvious that the confidence of such assessment is negligible.

More reliable regional quantifications of SW-GW interaction can be achieved by gauging catchments and applying suitable low flow or baseflow recession analysis methods, preferably in combination with a chemograph to allow for better separation of different baseflow components.

Such approaches give a net assessment of SW-GW interaction over the gauged catchment, i.e. the net groundwater contribution to baseflow as the sum of potential gaining and loosing river stretches over the catchment. Potential effects of artificially increased upstream storage with delayed release into river channels due to the considerable number of farm dams in South Africa must be taken into account. For the assessment of single river stretches, changes in discharge along the river stretch (transmission gains and losses) need to be quantified. After consideration of evaporation effects or abstractions the net difference indicates gains or losses along the river stretch. As with baseflow recession analysis, sufficiently long time series are required to account for seasonal and cyclic changes. It is obvious that any GW contribution to baseflow assigned to an upstream river stretch or catchment must be deducted downstream to avoid double accounting.

A nationwide selection of river stretches to be assessed should be based on an earlier proposed national river classification, following the approaches of Vegter & Pitman (2003) and the Environment Agency (2002).

3.5 GROUNDWATER RECHARGE

Groundwater recharge is the most important factor in the determination of available and sustainably usable groundwater resources in the country. Despite its importance there are currently no reliable national recharge estimates available, though very accurate but only local recharge figures are often available.

Recharge figures in GRA2 are based on the chloride mass balance (CMB) method, but their reliability is hampered by an insufficient national coverage of chloride measurements in rainfall as well as errors inherent in the method (e.g. indirect recharge from surface waters or irrigation return flows, use of groundwater instead of deep interstitial soil water samples, assumption of vertical seepage/piston flow, single instead of average chloride values, other sources of chloride like connate water, plant uptake or runoff). Especially in arid environments like large parts of South Africa direct recharge from rainfall is of decreasing significance (Kinzelbach et al. 2002) and contributions from localised as well as indirect recharge need to be taken into account. Another shortcoming in recharge estimates is the determination of a mean annual recharge figure based on mean annual precipitation, while significant recharge typically results from infrequent events, which might not have necessarily left their signature in the chloride content of samples groundwater. Similarly, if rainfall and subsequent soil-moisture figures are below specific thresholds, no recharge will occur at all. In order to describe such recharge behaviour, non-linear relations between rainfall and recharge including recharge threshold values are required and can obviously not be derived from a single chloride measurement.

It is therefore recommended to use the CMB method only as a first estimate of recharge ranges and to rather use one or preferably a combination of different methods with higher accuracy ratios (Kinzelbach et al. 2002) like the

- Earth method,
- Cumulative Rainfall Departure (CRD) method,
- Water Table Fluctuation (WTF) method,
- Saturated Volume Fluctuation (SVF) method, or
- Groundwater modelling.

The different methods are described in detail in Beekman and Xu (2003) or Kinzelbach et al. (2002).

Most of these methods allow the determination of non-linear relationships between rainfall and recharge and can therefore be easily linked to rainfall probabilities, hence arriving at recharge statistics as a function of climatic variations and changes.

3.6 ARTIFICIAL RECHARGE

The topic of Artificial Recharge (AR) in South Africa, and its role in the National Groundwater Strategy, is covered elsewhere in the project (roll-out of the artificial recharge strategy component, or ROARS). The reader is referred specifically to the deliverables of the ROARS activities (AR awareness, AR planning, AR strategy implementation and AR awareness), which are currently in progress.

3.7 GROUNDWATER TECHNICAL WORKSHOPS

Five technical workshops were held on the role of groundwater, its availability, monitoring and management, with respect to the National Groundwater Strategy. The workshops were held in November 2008 and in April 2009, on the following topics:

- Groundwater Management
- Groundwater Monitoring
- Groundwater – Surface Water Interaction
- Groundwater and Water Resource Planning
- Groundwater Source Protection Zones

The reader is referred to the Workshop Report (one of the NGS project deliverables) for further details, including the briefing material made available to workshop participants, the workshop agendas and the workshop presentations.

4. INFORMATION

4.1 BACKGROUND

GRA1 concentrated on geological or aquifer boundaries, and GRA2 is based on quaternary catchment boundaries. Both sought to present the available data, but both are currently seen as of only limited use to the water planner at the local or regional level. The reasons for this probably go beyond inherent limitations of the methodologies, and involve difficulties in accessing the maps and data, lack of training, lack of awareness, and several other factors. Nevertheless, neither addresses the issue of assurance of supply per aquifer (or per borehole).

The GRA3 methodology should start from the point of view of the requirements of the planner, municipal manager, or other person responsible for water supply (e.g. a Water Service Provider). What does such a person require to make decisions about water supply options? What sort of tool is needed to increase the attractiveness of groundwater and reduce fears of unreliability?

Another major issue that GRA3 needs to consider is the unit area that will be used. GRA1 used aquifer boundaries based on yield class, whilst GRA2 used quaternary catchments. Aquifer boundaries make sense from a hydrogeological point of view, but do not give information on long-term sustainability. The GRA2 data, based on quaternary catchments, includes a measure of sustainability (harvest potential) but the data is difficult to depict on a map in a simple form, and the quaternary catchments in any case may cut across aquifers. The figure for sustainable groundwater yield per quaternary catchment is of limited use to the local water planner, since it is very unlikely that the catchment can be covered evenly with enough boreholes to exploit this amount.

4.2 REPORTING OF WATER RESOURCES

It must be acknowledged that groundwater is a renewable resource “hidden” in the subsurface, i.e. it is notoriously difficult to quantify available resources at a given point in time and space along with a measure of confidence. The absence of such quantification of available groundwater resources is often seen as a limiting factor for the consideration of groundwater for public water supply. GRA2 tackled this problem partially by assigning different potentials like resource, exploitation or potable groundwater exploitation potential to aquifers, but the derived volumes are often questioned and seldom used. One reason for neglecting the given figures might be the multitude of different “potentials” assigned to the same resource, which are not necessarily intuitive and often confuse experts as well as non-experts.

A potential solution to the problematic reporting of not directly measurable groundwater resources is the adoption of the South African code for reporting of mineral resources and mineral reserves (the SAMREC code – see SAMREC, 2007). The SAMREC code is applicable to all minerals as defined in the Minerals Act (Act No 50 of 1991) for which JSE requires public reporting of exploration results, mineral resources and mineral reserves. While a mineral is defined as any solid, liquid or gaseous substance, occurring naturally in or on the earth, it explicitly excludes water (as a resource common to all, which use is subject to national control).

However, the guiding principles of the SAMREC code, i.e. transparency, materiality and competence, are obviously desirable for the reporting of groundwater resources, especially in the context of water supply infrastructure investments: “Transparency requires that the reader of a Public Report is provided with sufficient, clear and unambiguous information to understand the report and is not misled. Materiality requires that a Public Report contains all the information which investors and their professional advisers would reasonably require, and reasonably expect to find in the report, for the purpose of making a reasoned and balanced judgement regarding the mineralization being reported. Competence requires that the Public Report be based on the work of a suitably qualified, responsible and experienced person who is subject to an enforceable professional code of ethics” (SAMREC 2007).

The terminology used in the reporting of resources as well as reserves is not only very well established (along with statistical procedures for their differentiation), but also easily transferable to groundwater resources if recharge is added as a “modifying factor” for the conversion of a resource into a reserve (see Figure 5 1). The differentiation between the resource and reserve based on “modifying factors” agrees in many instances with current practices of groundwater resource estimations, where terms like “groundwater harvest potential”, or “exploitation potential” under consideration of the exploitability or socio-economic considerations are derived. The SAMREC (2007) code even acknowledges that the factors affecting extraction “should in most instances be estimated with input from a range of disciplines”, i.e. highlighting essentially the triple bottom line in exploitation considerations. The clear differentiation between a resource and the CURRENTLY extractable part of the resource under these considerations is intuitive, easily conveyable to the public and allows for future changes in extractability due to e.g. technology or price changes.

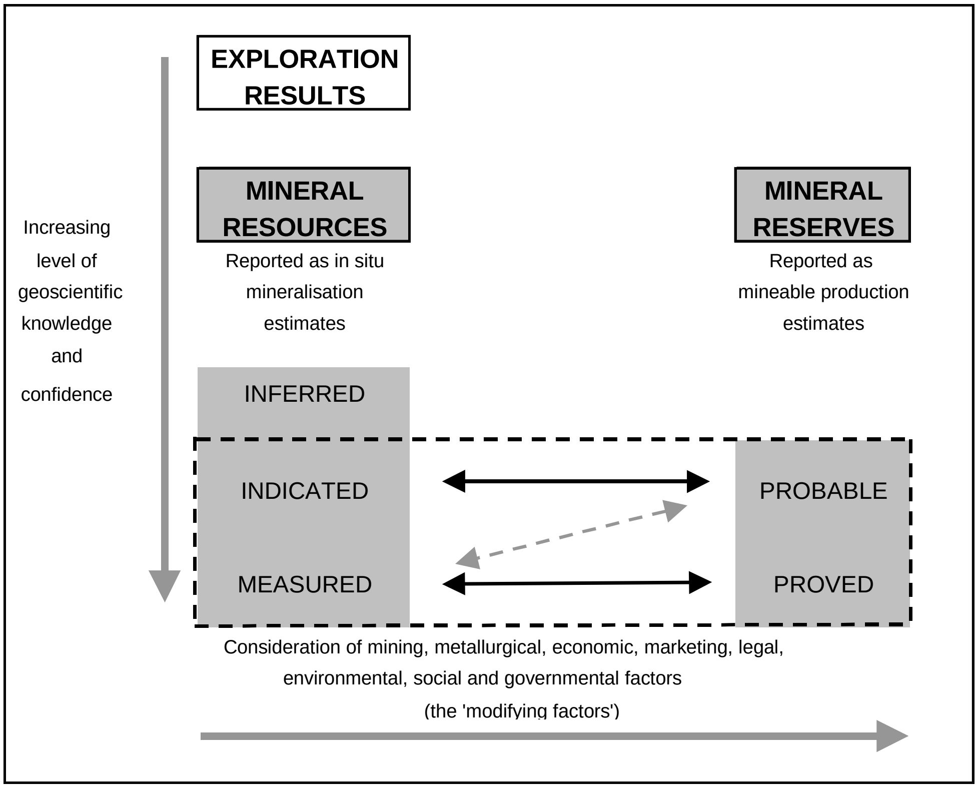

Figure 4.1: **Relationship between Mineral Resources and Mineral Reserves (from SAMREC 2007)**

The application of the SAMREC code requires however some adaptations with regard to the subdivision of resources and reserves. In the following the SAMREC (2007) definitions of the resource subsets are given and adaptations to groundwater resources indicated.

- **Inferred Mineral Resource:**
  Part of a Groundwater (Mineral) Resource, for which borehole yield (other key hydrogeological parameters such as recharge and transmissivity could also be considered for inclusion) can be estimated with **a low level of confidence**. It is inferred from hydrogeological (geological) evidence and assumed but **not verified** hydrogeological (geological and/or grade) **continuity**. It is based on information gathered through appropriate techniques from locations such as boreholes and springs (outcrops, trenches, pits, workings and drill holes) that may be limited or of uncertain quality and reliability.
- **Indicated Mineral Resource:**
  Part of a Mineral Resource for which borehole yield can be estimated with a **reasonable level of confidence**. It is based on exploration, sampling and testing information gathered through appropriate techniques from locations such as outcrops, trenches, pits, workings and drill holes. The locations are too widely

or inappropriately spaced to confirm geological and/or grade continuity but are spaced closely enough for **continuity to be assumed**.

- **Measured Mineral Resource:**
  Part of a Mineral Resource for which borehole yield can be estimated with **a high level of confidence.** It is based on detailed and reliable exploration, sampling and testing information gathered through appropriate techniques from locations such as outcrops, trenches, pits, workings and drill holes. The locations are spaced closely enough **to confirm** geological and grade **continuity**.

A major challenge for the application of the reporting practice to groundwater resources is to define the different levels of confidence (low, reasonable, high) on a physical and defendable basis as well as the question of continuity of a water resource. While levels of confidence for mineral resources are typically based on variance criteria (e.g. sample errors or kriging variances) derived from an intense drilling

Table 4-1: Resource confidence levels

Resource part	Confidence level	F. Camisani (@ 90 % level of confidence)
Inferred	low	$t.\frac{s}{\sqrt{n}} > 0.15\bar{x}$
Indicated	reasonable	$0.15\bar{x} > t.\frac{s}{\sqrt{n}} > 0.10\bar{x}$
measured	high	$0.10\bar{x} > t.\frac{s}{\sqrt{n}}$

- **Mineral Reserve:**
  The economically mineable material derived from a Measured and/or Indicated Mineral Resource. It is inclusive of diluting materials and allows for losses that may occur when the material is mined. Appropriate assessments, which may include feasibility studies, have been carried out, including consideration of, and modification by, realistically assumed mining, metallurgical, economic, marketing, legal, environmental, social and governmental factors. These assessments demonstrate at the time of reporting that extraction is reasonably justified. Mineral Reserves are sub-divided in order of increasing confidence into Probable Mineral Reserves and Proved Mineral Reserves.
- **Probable Mineral Reserve:**
  The economically mineable material derived from a Measured and/or Indicated Mineral Resource. It is estimated with a lower level of confidence than a Proved Mineral Reserve. It is inclusive of diluting materials and allows for losses that may occur when the material is mined. Appropriate assessments, which may include feasibility studies, have been carried out, including consideration of, and

modification by, realistically assumed mining, metallurgical, economic, marketing, legal, environmental, social and governmental factors. These assessments demonstrate at the time of reporting that extraction is reasonably justified.

- **Proved Mineral Reserve:**
  The economically mineable material derived from a Measured Mineral Resource. It is estimated with a high level of confidence. It is inclusive of diluting materials and allows for losses that may occur when the material is mined. Appropriate assessments, which may include feasibility studies, have been carried out, including consideration of and modification by realistically assumed mining, metallurgical, economic, marketing, legal, environmental, social and governmental factors. These assessments demonstrate at the time of reporting that extraction is reasonably justified.

4.3 INTERIM SUSTAINABLE YIELD MAPS

It is proposed that on the basis of sustainable yield figures from the GRA2 dataset, all quaternary catchments are assigned a “sustainability class”, numbered from one to seven (one being the lowest sustainability class, and seven being the highest). See Table 5 2. This sustainability class, overlain by the GRA1 aquifer type and median yield classification, will provide an estimated median borehole yield plus aquifer type, as well as a rough measure of how sustainable that yield will be. The highest median yield classes should be marked as such, and the user alerted to the need for more detailed local hydrogeological information before sustainability can be estimated.

It is expected that the derivation of “sustainability classes” will be subject to discussion and change, and will depend on underlying assumptions in the GRA2 algorithm as well as data availability. The following methodology is suggested: According to the GRA2 dataset, South Africa has 1947 quaternary catchments. The mean and median areas of a quaternary catchment are 651 km2 and 437 km2 respectively. Quaternary catchment areas range in size from 48 km2 to 18096 km2. Total “utilisable groundwater exploitation potential in a dry season” for all quaternary catchments together is about 7 535 615 955 m3/annum, or about 7.5 cubic kilometres per annum. This, in theory, is the amount of groundwater that could be sustainably used in South Africa every year without impacting the environment or existing users. If the “utilisable groundwater exploitation potential in a dry season” for each catchment is assumed to be distributed evenly across the catchment, and if each catchment had one borehole per km2, then the utilisable exploitation potential (“sustainable yield”) of each borehole can be easily calculated by dividing the total catchment utilisable potential by the area of the catchment in km2. According to the figures for “utilisable groundwater exploitation potential in a dry season”, 79 quaternary catchments have negative values and a further 79 have zero values for sustainable yield. Of the remaining 1789 quaternary catchments, the mean value for sustainable yield is 0.34 L/s per square kilometre if pumping continuously. The median value is 0.19 L/s, pumping continuously.

In all cases where groundwater supplies for public water supply are being considered, specialist advice and field study is recommended regardless of sustainability class or median yield class. This is because local geological conditions, local groundwater quality, local pollution threats and existing groundwater users cannot be predicted using a national dataset or national map.

Table 4-2: Assurance of Supply classes for South African aquifers

Assurance of Supply class	Sustainable yield value (GRA2) per bh per km^2	Number of quaternary catchments	Notes
1	Negative or zero	158	Fragile groundwater assurance of supply, approach with care, specialist advice needed.
2	Less than 0.068 L/s	350 (350)	Limited groundwater assurance of supply, select low pumping rates. Specialist advice recommended.
3	0.068 – 0.15 L/s	374 (724)	Over-pumping could easily cause aquifer to be depleted. Limited groundwater volumes available.
4	0.15 – 0.25 L/s	327 (1051)	Fairly good groundwater assurance of supply, adaptive management based on monitoring needed to determine appropriate pumping rates.
5	0.25 – 0.5 L/s	384 (1435)	Borehole yields likely to be limited by the aquifer properties rather than long-term sustainability. Adaptive management based on monitoring needed to determine appropriate pumping rates.
6	Above 0.5 L/s	354 (1789)	Relatively abundant renewable groundwater is indicated, high yielding boreholes possible where aquifer properties allow.
7	n/a, see general maps for aquifer type		Karst or other high-yielding aquifer present, or special conditions such as high number of known users or high potential for pollution. Specialist advice required to determine sustainability.

The 1:500 000 scale hydrogeological maps (hydrogeological map series) produced by the SA Department of Water Affairs and Forestry (now Department of Water Affairs or DWA) characterise groundwater occurrence in South Africa by an alphanumeric code based on aquifer type and borehole yield class, as shown in **Table 2-1** below.

Table 4-3: Aquifer classification as per the DWAF hydrogeology map series

Aquifer Type	Borehole Yield Class* (L/s)				
	Class “1” 0 - 0.1	Class “2” 0.1 - 0.5	Class “3” 0.5 - 2.0	Class “4” 2.0 - 5.0	Class “5” >5.0
Type “a”: Intergranular	a1	a2	a3	a4	A5
Type “b”: Fractured	b1	b2	b3	b4	B5
Type “c”: Karst	c1	c2	c3	c4	C5
Type “d”: Intergranular & fractured	d1	d2	d3	d4	D5

* Median borehole yield, excluding dry boreholes

The hydrogeological maps rely on colour to distinguish between aquifer type (e.g. purple for intergranular, green for karst), and intensity of colour to signify borehole yield class (e.g. dark green for a karst aquifer with median borehole yield of more than 5 L/s). Apart from colour and intensity, the hydrogeological maps are also ornamented (e.g. hatching or dots) to show the lithology (e.g. diagonal crosses indicate basic intrusive rocks such as dolerite). It is proposed that the colour and intensity is retained, but that the ornamentation is changed to reflect the assurance of supply class. The density of the ornament for each **assurance of supply class** should be similar, so as not to affect the shade of underlying colour. The term “assurance of supply” is preferred to “sustainability”, since various definitions of sustainability exist encompassing socio-economic as well as technical criteria. (See Kalf and Woolley (2005) for more information.)

Figure 4.2 and **Figure 4.3** depict the combination of the GRA1 and GRA2 data using the methodology described above. All areas with a yield class of 5 (median yield of >5 L/s or higher) have been shaded in red to emphasise that specialist advice is recommended for groundwater development in these areas.

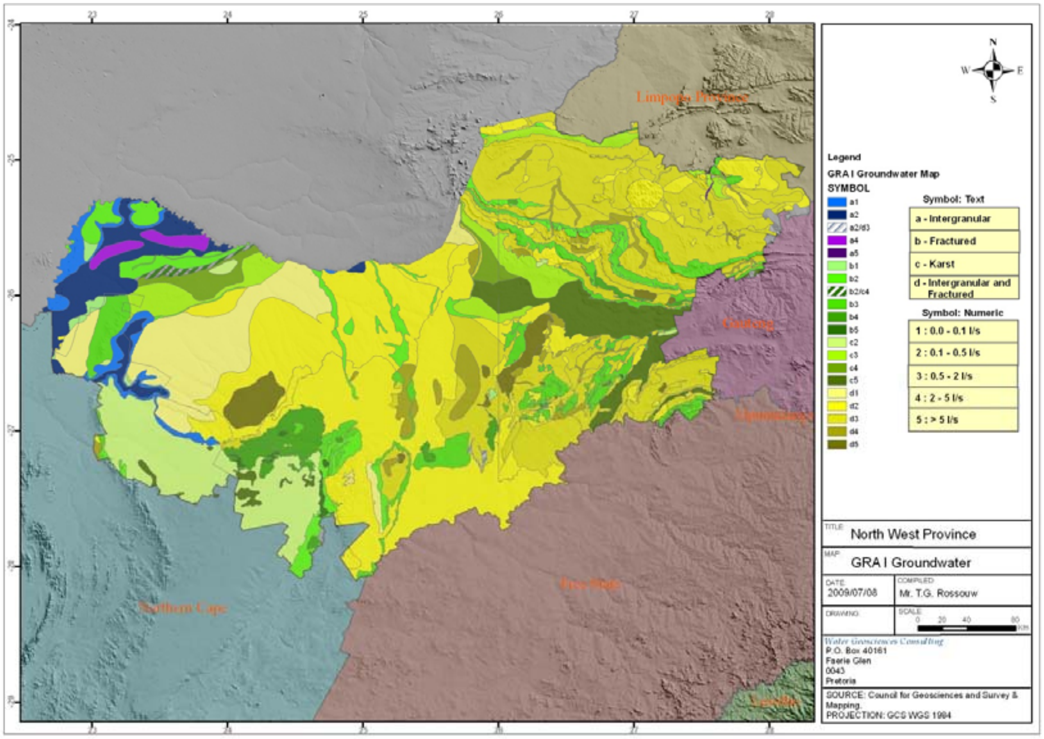

Figure 4.2: **North West Province GRA1 (Hydrogeology Map) data**

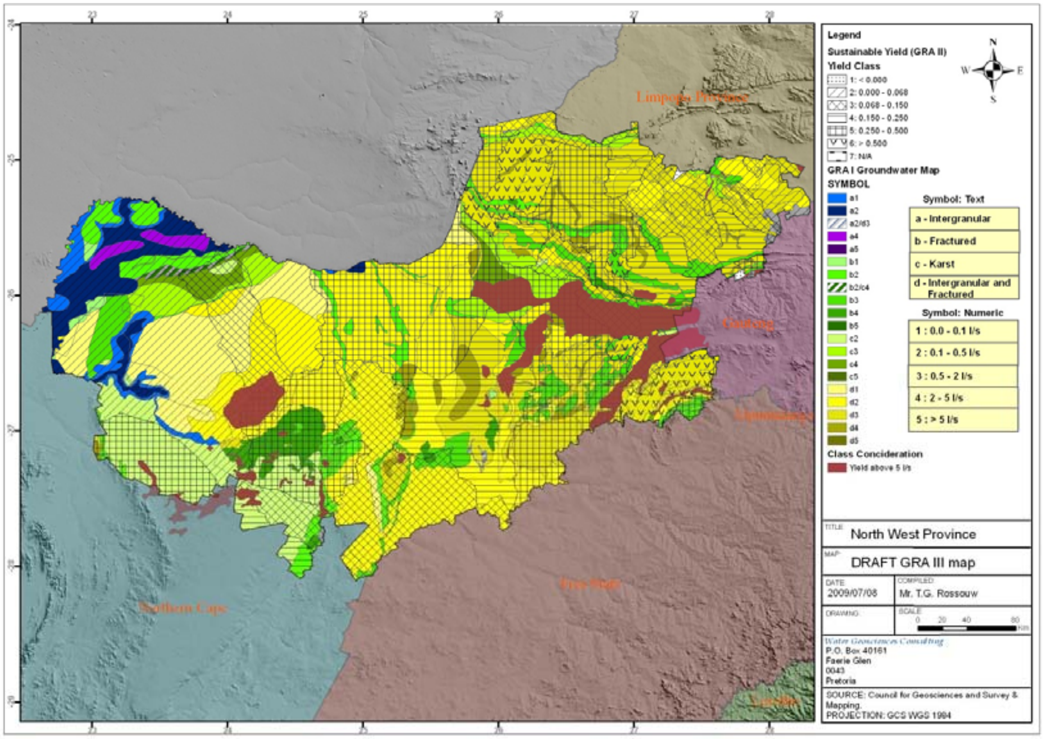

Figure 4.3: **North West Province GRA1 and GRA2 data combined**

Natural groundwater quality is depicted on the 1:500 000 hydrogeology maps on an inset map showing four electrical conductivity classes (0-70 mS/m, 70-300 mS/m, 300-1000 mS/m, and over 1000 mS/m). According to the SANS 241 Guideline (SSA, 2006), water with a conductivity of between 150 and 370 mS/m is classified as Class II (maximum allowable level for a limited duration). If Harvest Potential is used as the proxy for assurance of supply rather than “utilisable groundwater exploitation potential in a dry season” or some other category where groundwater quality is already covered, it is suggested that those areas where groundwater quality falls into either of the two more saline groundwater quality classes on the hydrogeology maps be depicted on the GRA3 maps with an additional ornament or colour.

Note that the depiction of the GRA1 and GRA2 data depends on the exact definition of the “sustainability classes”, which are still subject to agreement and depend on exactly how assurance of supply is defined. This issue needs further discussion, but it is hoped that the underlying concept of an “assurance of supply” index of some sort overlying the GRA1 General maps will be adopted.

4.4 AVAILABILITY OF THE OUTPUTS

Probably the most important concern is that the outputs (likely to be maps, but could also be a database) of the GRA3 sustainable yield methodology to be made widely and easily available to planners. At present the GRA2 data, on which this methodology is based, is not wholly in the public domain. An agreement will need to be reached with the Department of Water Affairs regarding availability of GRA3. This may require that caveats regarding data reliability in certain parts of the country are included in the final outputs (unreliable information is one of the main reasons the GRA2 data is not widely accessible). If the GRA3 outputs are not made widely available, it is likely to suffer the same fate as GRA2 – being confined to a small community of experts with little traction in the wider planning and water supply community. Ideally the outputs should be publicised.

4.5 NATIONAL GW AVAILABILITY AND PLANNING (YIELD VS. DEMAND) MAPS

Given sufficient data, it should be possible to depict demand for water on a national map, or on maps of Water Management Areas. From that point it should be relatively easy to match areas of high demand with areas of high groundwater supply potential (including good assurance of supply), and therefore prioritise areas for groundwater development projects.

4.6 TREND AND STRESS INDEX VS. WATER LEVEL MAPS

Again, with sufficient data on temporal trends in groundwater levels and quality, it should be possible to show the level of “stress” of a particular aquifer (based on an evaluation of water level changes over time, taking into account seasonal and drought-cycle fluctuations). This is useful in that it can provide early warning of possible groundwater supply problems.

4.7 WATER QUALITY MAPS

The GRA1 maps (national hydrogeological map series) include basic water quality information as inset maps of groundwater conductivity. It would be fairly easy to depict basic water quality parameters on the GRA3 maps, either as an inset or incorporated into the map itself. The main problem is that limited groundwater quality data, combined with the heterogeneity of groundwater quality across the country, would make the utility of such maps questionable for all but very broad-scale planning. There is little information on some water quality parameters (such as F or As) which can potentially render groundwater undrinkable without treatment.

5. CONCLUSIONS

GRA3 is more than a different way of depicting data, or a response to calls for the depiction of assurance of supply. It is a strategy – part of the bigger National Groundwater Strategy - designed to support better and wider use of groundwater. The outputs of the GRA3 strategy include the following:

- A map or series of maps designed to be used by planners, incorporating an index for assurance of supply. These will represent the GRA1 and GRA2 data;
- The suggestion that the SAMREC code for estimating mineral resources be applied to groundwater resources, to improve confidence levels in the resource and highlight areas of data scarcity.
- A series of recommendations for gathering more hydrogeological data, especially from the private sector, and for integrating existing data;
- Recommendations for aquifer level assessment of groundwater;
- A recommendation that best practice examples (such as Beaufort West) be supported, which can act as “shop windows” for reliable groundwater supply.

The implementation of GRA3 will need political and institutional support. Strategies for implementation will need to be discussed, but first a general agreement between groundwater specialists is required. This document suggests the terms of such an agreement, and is intended to function as a way of building consensus between groundwater specialists. Agreements reached by way of this document should go forward into implementation strategies.

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