Regional Groundwater Monitoring in the Olifants-Doorn Water Management Area

By

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Declaration

I declare that **Regional Groundwater Monitoring in the Olifants-Doorn Water Management Area** is my own work, that it has not been submitted for any degree or examination in any other tertiary institution, and that all the sources I have used or quoted have been indicated and acknowledged by complete references.

PAUL SEWARD

SIGNED …………….

NOVEMBER 2006

Abstract

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Keywords:

groundwater, monitoring, regional, sustainability, strategy, adaptive management, National Water Act.

The aim of this investigation was to provide a framework or strategy for prioritising and implementing regional groundwater monitoring in the Olifants-Doorn Water Management (WMA) area. Regional groundwater monitoring is generally seen as the responsibility of the Department of Water Affairs (DWAF), but there is a huge gap between the resources that DWAF has to do monitoring, and the expectations – often conflicting – from both outside and within DWAF as to what monitoring it should be doing.

The general approach was to attempt to reconcile monitoring requirements with existing resources, while investigating the hypothesis that regional monitoring should focus on resource status monitoring. Regional monitoring in the Olifants-Doorn was considered from different perspectives in an attempt to find common ground and identify priorities.

The aim of regional groundwater monitoring was identified as ensuring the sustainable use of the groundwater resources. However what defines sustainability in any given situation depends heavily on subjective opinions of stakeholders. Groundwater science needs to focus on clarifying the sustainability options available to the stakeholders, and monitoring the chosen option. This can best be done by adopting an adaptive management approach to both the management of the groundwater resources, and the management of the monitoring programme.

The hypothesis that regional monitoring should focus on resource status monitoring could not be proven nor disproven scientifically, although focusing on resource status monitoring was found to be supported by legal, policy, and practical considerations.

The essence of the strategy that was formulated is contained in the following proposals for interventions, in order of priority:

1. Address the need for groundwater use monitoring
2. Establish monitoring committees at the WUA level
3. Improve monitoring information dissemination
4. Encourage/support self-monitoring by groundwater users
5. Compile a monitoring management plan
6. Establish a programme manager to oversee monitoring
7. Focus on groundwater resource status monitoring – non-regional monitoring should be non-regionally funded
8. Revise networks
9. Take cognizance of the likely impacts of climate change

Monitoring data are far less diagnostic than many people realise – for example falling water levels could indicate unsustainable use, or that could indicate the water is being taken from storage as a precursor to the establishment of new equilibrium conditions. Characterisation, conceptual models, and mathematical models are therefore needed to facilitate the interpretation of monitoring data.

Although the monitoring strategy developed appears sufficiently generic to be applicable to other WMAs, this assertion needs to be tested by further investigation, since the combination of socio-economics and climate in the Olifants-Doorn WMA is essentially unique among South African WMAs.

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Paul Seward

Bellville

November 2006

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List of Acronyms

ASCE – American Society of Civil Engineers

CMA – Catchment Management Agency

DAP – Data Analysis Protocol

DWAF – Department of Water Affairs and Forestry

GEOSS – GEOhydrological and Spatial Solutions

GRA2 – Groundwater Resource Assessment 2

IFE – Instream Flow Requirements

ISP – Internal Strategic Perspective

IT – Information Technology

NGA – National Groundwater Archive

NGDB – National Groundwater Data Base

NWA – National Water Act

RDM – Resource Directed Measures

REGIS – REegional Geohydrological Information System

RQO – Resource Quality Objectives

RSA – Republic of South Africa

TMG – Table Mountain Group

UN – United Nations

UN/ECE – United Nations Economic Commission for Europe

UNESCO – United Nations Educational, Scientific and Cultural Organisation

USGS – United States Geological Survey

WMA – Water Management Area

WMS – Water Management System

WUA – Water Users Association

1. Introduction

1.1 Purpose

The overall aim of this study is to identify an appropriate role for the Department of Water Affairs and Forestry (DWAF) in regional groundwater monitoring using the Olifants-Doorn Water Management Area (WMA) as a case study.

The hypothesis investigated is that DWAF regional groundwater monitoring should focus on resource status monitoring, with the intensity of the monitoring proportional to how stressed a given resource is, and/or how vulnerable the resource is to over-utilisation. Resource status essentially means the quality and quantity of water in the resource, and – by implication – the quality and quantity of water discharged from the resource. Discharge can be either natural - for example to aquatic ecosystems, or artificial – for example abstraction to irrigate crops.

1.2 Location of the study area

The location of the study area, and its relation to the other WMAs and the Provinces of South Africa, is shown in Figure 1. The Olifants-Doorn comprises some 56 745 km^2 and is located mainly in the Western Cape Province, but with a sizable proportion in the Northern Cape Province. The closest point of the Olifants-Doorn to Cape Town is approximately 250 km distant.

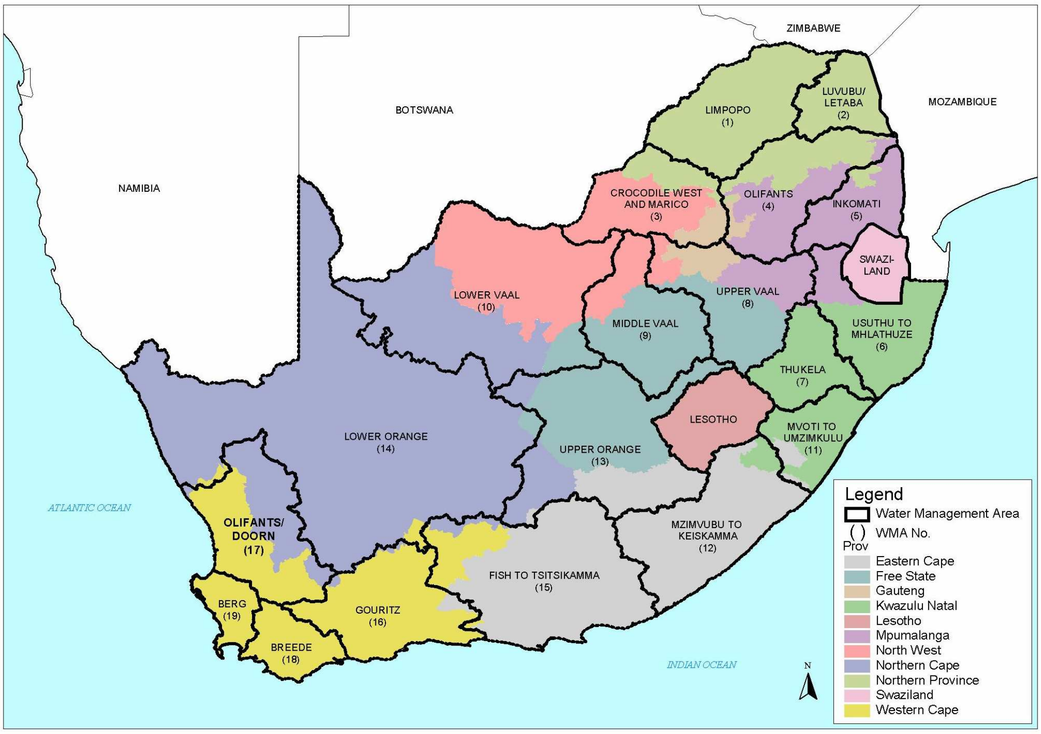


Figure 1: Location of Olifants-Doorn WMA

1.3 Definition of DWAF Regional Monitoring

This study involves an investigation of "DWAF regional groundwater monitoring" in the Olifants-Doorn WMA, therefore it is helpful to be clear from the outset what is meant by this term. For the purpose of this thesis "DWAF regional groundwater monitoring" refers to monitoring that satisfies all of the following conditions:

a) it involves the periodic collection of data – thus once-off surveys are excluded.

b) it is carried out in the Olifants-Doorn WMA (thus monitoring that is carried out by the Olifants-Doorn team in the Berg WMA because it is intimately connected to Olifants-Doorn geohydrological issues is excluded).

c) the monitoring data ends up on a centralized DWAF database such as Hydstra, or DWAF currently believes the monitoring data ***should*** end up on a centralized DWAF database, because – for example – that is what happened in the past. Thus the monitoring data do not have to be physically connected by DWAF – it is the fact that the data end up (or should end up) on a DWAF database that defines "DWAF monitoring." This means that data collected by consultants and Municipalities can be considered to be "DWAF" monitoring in the cases where DWAF believes this data should be captured on a DWAF database. It also means that monitoring as part of a licensing condition would normally be excluded since the usual stipulation is only that DWAF be able to inspect this data – there is usually no stipulation that the data be captured on a central database.

d) the monitoring is ***related to*** groundwater. Thus, besides the more obvious groundwater monitoring attributes such as groundwater levels and groundwater ECs, this definition also permits the inclusion of attributes such as rainfall where this is deemed necessary.

e) the DWAF Regional Office has a responsibility for either collecting or capturing the monitoring data or ensuring that collecting and capturing takes place – thus DWAF National office groundwater quality sampling is also included because the Regional Office physically collects the data.

Thus DWAF regional groundwater monitoring in the Olifants-Doorn WMA could be a summarized as "the periodic collection of groundwater-related data in the Olifants-Doorn WMA that is, or should be, captured on a DWAF central database." It is not claimed that this is a "standard" definition, or that it is in any way more "correct" or "better" than anybody else's. It is merely given here as an aid to communication

1.4 Study rationale

The management of groundwater, as with any resource, requires that it be monitored. The National Water Act (NWA) of 1998 (RSA, 1998) has monitoring requirements, and specifies what must be monitored, but is not specific as to who must do the monitoring, merely requiring the state ensure that monitoring systems are in place and that certain standards are met. The NWA does not specify what – if any – monitoring DWAF must do itself. Despite this many users, researchers, and others seem to believe that it is the duty of DWAF to monitor all groundwater resources in the country. In addition, many investigations and research projects do not budget for whatever groundwater monitoring might be required by their project, and seem to think that if groundwater monitoring is needed, it will automatically get done by DWAF. Investigations involving groundwater frequently conclude with recommendations for monitoring, but without any mention of who will do the monitoring and how it will be funded, assuming – presumably – that DWAF will automatically implement all their recommendations.

At the same time, DWAF has very limited resources to carry out any monitoring, and the perception is that funding for monitoring is more likely to be cut than to be expanded.

To resolve these disparate issues requires a clear strategy, or framework, regarding what groundwater – and related – monitoring DWAF should be doing, so that limited resources can be used to optimal effect. Identifying this monitoring strategy is the key research issue addressed in this study.

1.5 Research approach and thesis structure

The broad approach followed was to:

- Summarize the theory and principles of monitoring from literature studies so as to get an insight into the state-of-the-art of current groundwater monitoring and thinking, but with emphasis on the more strategic, rather than technical, aspects, based on a literature review – chapter 3

- Describe and discuss the monitoring requirements emanating explicitly from the National Water Act (NWA) of 1998, and implicitly from various monitoring strategies adopted or advocated in the implementation of the NWA, based on a literature review – chapter 4

- Discuss recent recommendations for monitoring in the Olifants-Doorn WMA using a literature review – chapter 5

- Investigate the issue of sustainability using a literature survey, since this is a key facet of monitoring and management – chapter 6

- Describe and assess the monitoring currently taking places in the Olifants-Doorn WMA, including the information management aspect of monitoring, and not just the physical collection of data – chapters 7 and 8
- Sift through the key issues from the preceding chapter to formulate a monitoring strategy for the Olifants-Doorn WMA

1.6 Previous Investigations

No comprehensive assessments of regional groundwater monitoring in the Olifants-Doorn WMA have yet been carried out. A number of broad-scale investigations in the area have made groundwater monitoring recommendations, but have not addressed the overall context in which monitoring takes place. For example practicalities such as who establishes the required monitored network, who does the monitoring, where the data are to be stored, who analyses and disseminates the data, which decision-makers will be making use of the monitoring information, were generally not considered. Broad-scale investigations that provide groundwater monitoring recommendations include, inter alia:

- Citrusdal Artesian Groundwater Exploration (Umvoto, 2000)
- Groundwater situation assessment in the Olifants-Doorn WMA (Titus, et al., 2002)
- Olifants-Doorn Internal Strategic Perspective (DWAF, 2005)
- Groundwater Resource Directed Measures – E10 GRDM study (Parsons and Wentzel, 2005)
- Groundwater Reserve Determination required for the Sandveld, Olifants-Doorn WMA (GEOSS, 2006)
- Groundwater Reserve Determination Study for the Olifants-Doorn Catchment (Fortuin and Woodford, 2006)

2. Overview of the Area

2.1 Introduction

Groundwater use, management, monitoring and research clearly cannot take place in isolation, but are interconnected with the social and physical fabric of an area. The purpose of this chapter is, therefore, to provide an introductory sketch of the social, physical and economic characteristics of the study area, so that groundwater monitoring and related issues can be seen in their regional context.

2.2 Demography

The Olifants-Doorn is the least populated WMA in the country with approximately 0.25% of the national population residing in the area. In 1995 approximately 113 000 people were identified as living in the area. More than half of the population live in urban or peri-urban areas. The general trend of an increasing urban population and associated decreasing rural population is anticipated to continue (DWAF, 2005).

2.3 Economic Development

The economy of the Olifants-Doorn WMA contributes 0.3% to the national Gross Domestic Product (GDP), the lowest of any WMA in the country, but roughly proportionate to the population levels (0.25% of the national population). The importance of agriculture to the regional economy can be seen in Figure 2, which shows that agriculture contributes some 43.3% to the local economy. The corresponding national figure for agriculture is 4.6%, virtually a factor of ten less than that of the Olifants-Doorn. While these figures emphasize the importance of the agricultural sector to the local economy, they also reflect the relatively low level of activity in the other economic sectors (DWAF, 2003).

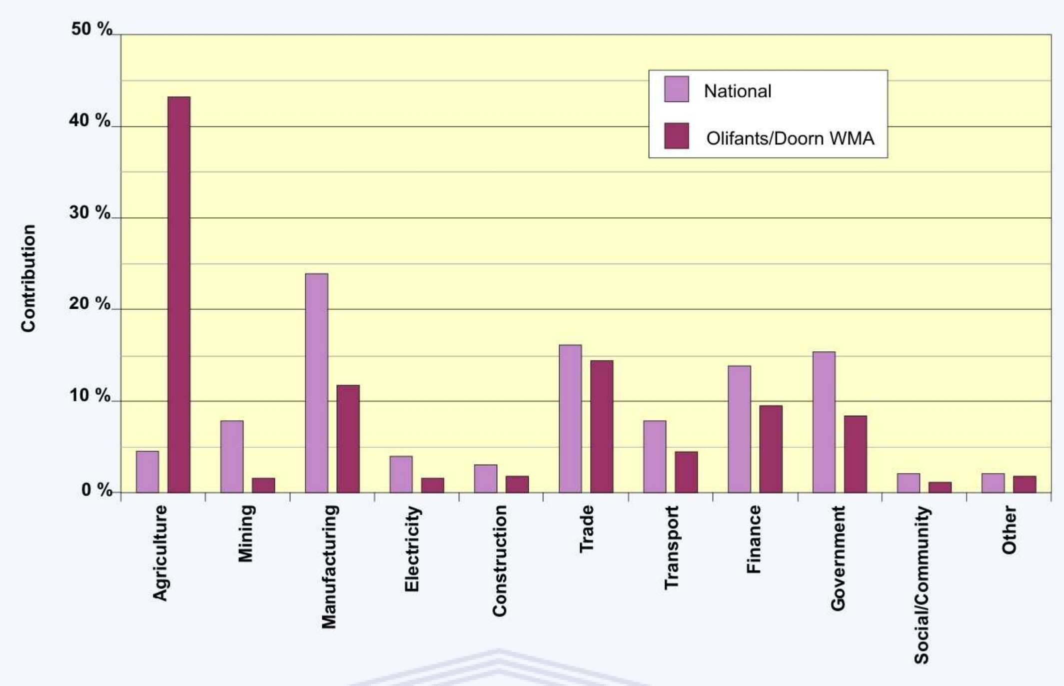


Figure 2: Relative contributions of various sectors to the regional economy

The importance of agriculture can also be seen in the employment figures, which indicate that some 50% of those in formal employment are involved in the agriculture sector. Unemployment, at 8%, is the lowest for any WMA in the country (DWAF, 2003).

Ownership of land is dominated by white farmers. Non-white, resource-poor farmers have limited access to good quality agricultural land and have historically been sidelined in terms of access to water. Although local authorities and provincial departments of land and agriculture have programmes in place to transform this ownership pattern, progress has been slow (DWAF, 2005).

2.4 Water Use

In addition to being the largest part of the regional economy, agriculture is also the largest user of water in the study area. The Olifants-Doorn ISP (DWAF, 2005) gives a figure of 356 million m^3/a for total irrigation use for the year 2000, of which 42 million m^3/a is from groundwater. The total water use from all the other sectors combined is only 5% of the irrigation use. While these figures are not up to date, they do give a comprehensive overview of the pattern of water use per sector.

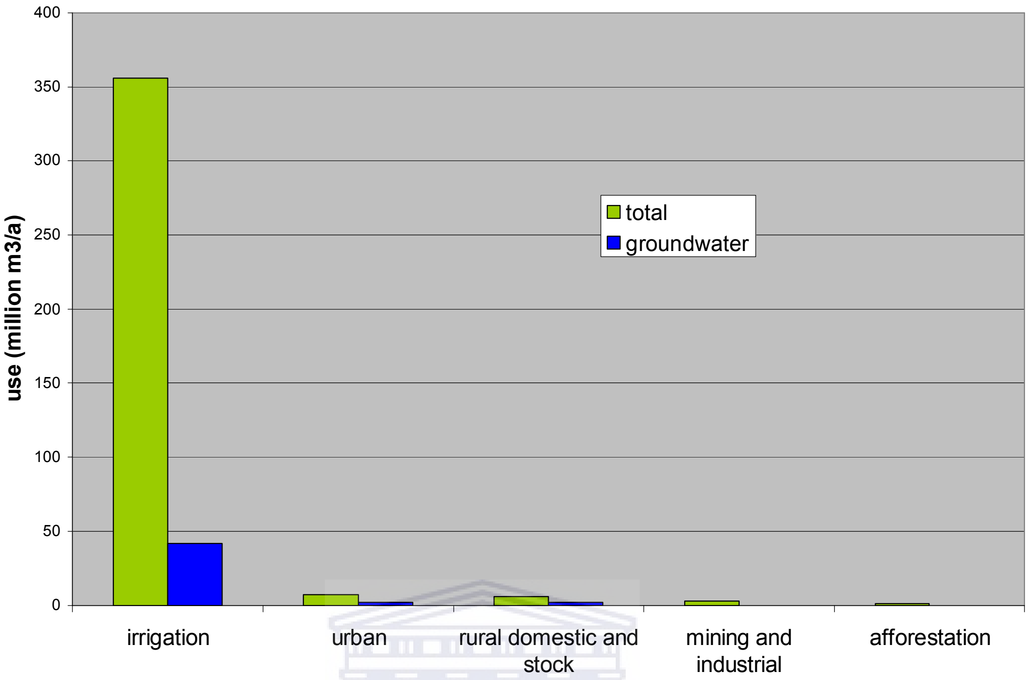


Figure 3: Total water and groundwater use per sector

The main user of groundwater for irrigation is potato farming, typically with 2 crops grown per year. Elsewhere in the area the use of groundwater for irrigation tends to be erratic, especially in the case of fruit crops, with groundwater only being used when surface water supplies have dried up.

With agriculture such an important part of the Olifants-Doorn economy, and with irrigation of vital importance to agriculture, it is clear that the sustainable use of water – be it surface or groundwater – is of crucial importance in the study area. Of paramount concern, therefore, is the overall availability of water in the study area versus demand. The ISP (DWAF, 2005) suggests that total water use in the area is 373 million m^3/a, while the assured yield of existing supplies (surface and groundwater) is given as 327 million^3/a, a shortfall of 46 million m^3/a. One strategy put forward to address this shortfall is to consider using deep groundwater from the TMG since this is a relatively underdeveloped resource.

Although the amount of groundwater used for town supplies is relatively small – some 2 million m^3/a – most of the towns in the area are either totally or partially dependent on groundwater as a source of water.

2.5 Physical Geography

The topography of the Olifants-Doorn WMA is shown in Figure 4.

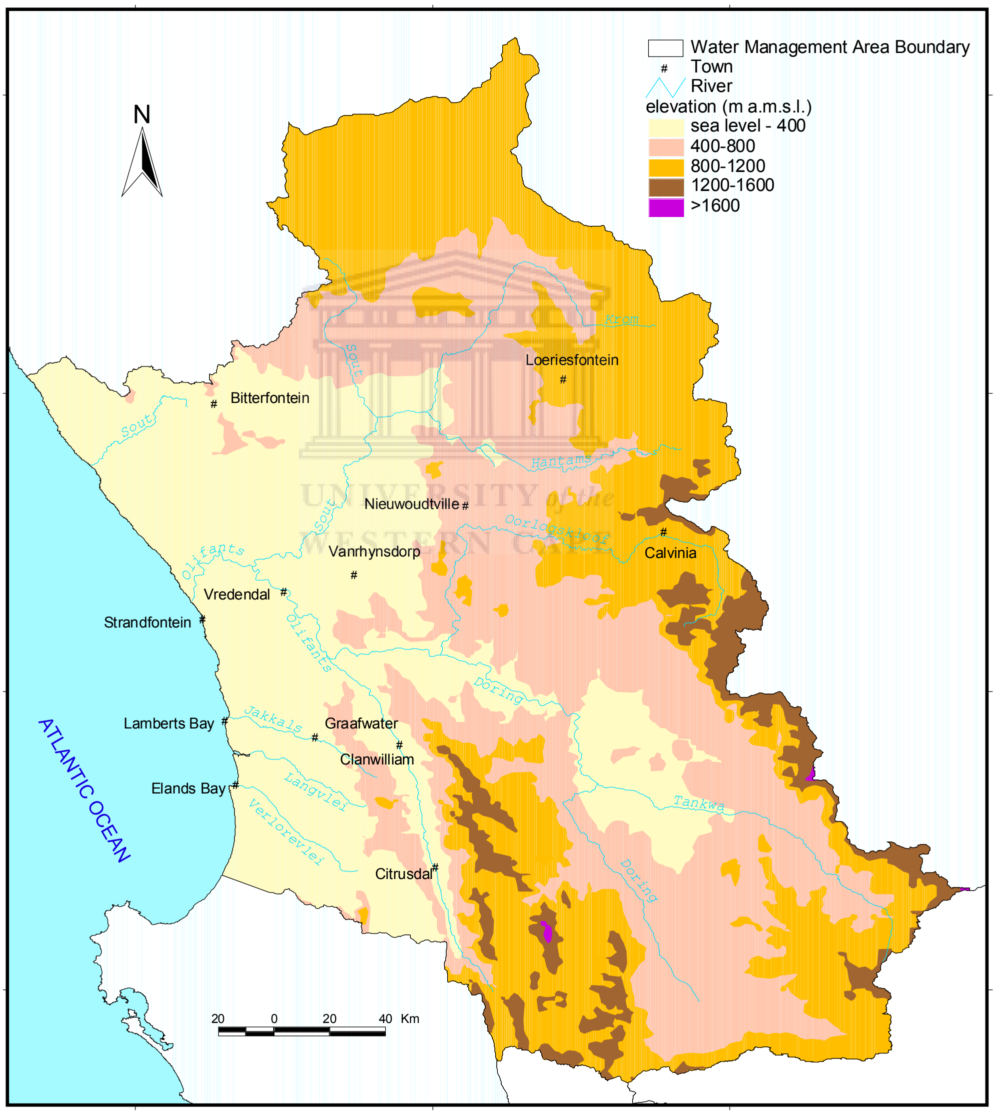


Figure 4: Physical Geography

The physiography is characterised by rolling hills and sand dunes in the west, rugged mountains with peaks rising to over 2000 m a.m.s.l. in the south, and plains with rocky hills and mountains in the remainder of the area.

The major rivers in this area are the Olifants and its tributaries the Doring and Sout. (A second Sout River is shown on the map – this is not a cartographic mistake.) While the Olifants is regarded as a perennial river by some (gauge station data on flows is not conclusive, and therefore the river's perenniality is open to debate), flow in the Doring River is highly variable, and only small occasional flows occur in the Sout Rivers.

2.6 Climate

Climatic conditions in the Olifants-Doorn study area vary considerably, largely as a result of the variation in topography. Minimum temperatures in July range from -3°C to 3°C and the maximum temperatures in January range from 39°C to 44°C.

The area lies in the winter rainfall region with the majority of the rain occurring between May and September each year, although occasional summer thunderstorms do occur, mostly in the north-eastern parts of the study area. For most of the area, the mean annual precipitation is less than 300 mm (Figure 5), although a small area of the southern mountains receives up to 1500 mm/year.

Average gross mean annual evaporation ranges from about 1500 mm in the south to about 2600 mm in the north and south-east. Thus for large parts of the study area annual evaporation exceeds annual rainfall by more than an order of magnitude.

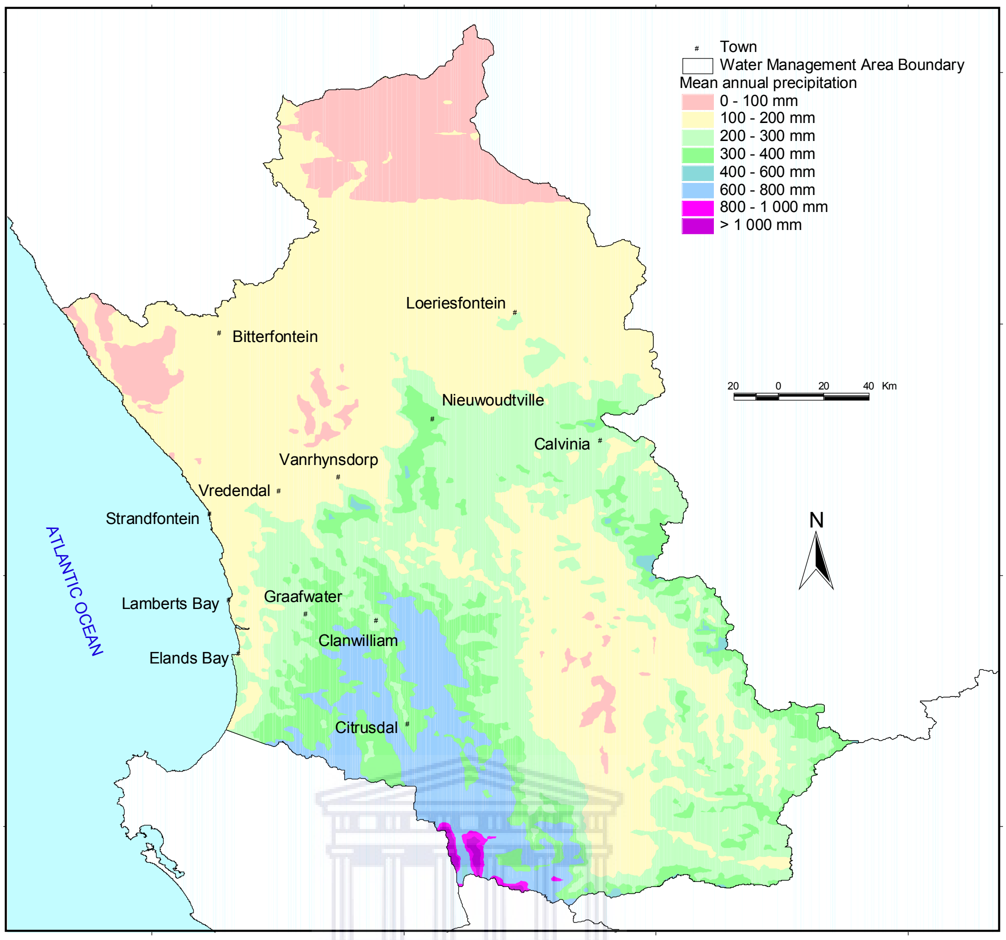


Figure 5: Mean annual precipitation

2.7 Geology

The simplified geology of the area is shown in Figure 6 according to predominant geological units. This geological information is based on data used for the DWAF 1:500 000 hydrogeological map series, in particular the Calvinia sheet (Zenzile, 2002).

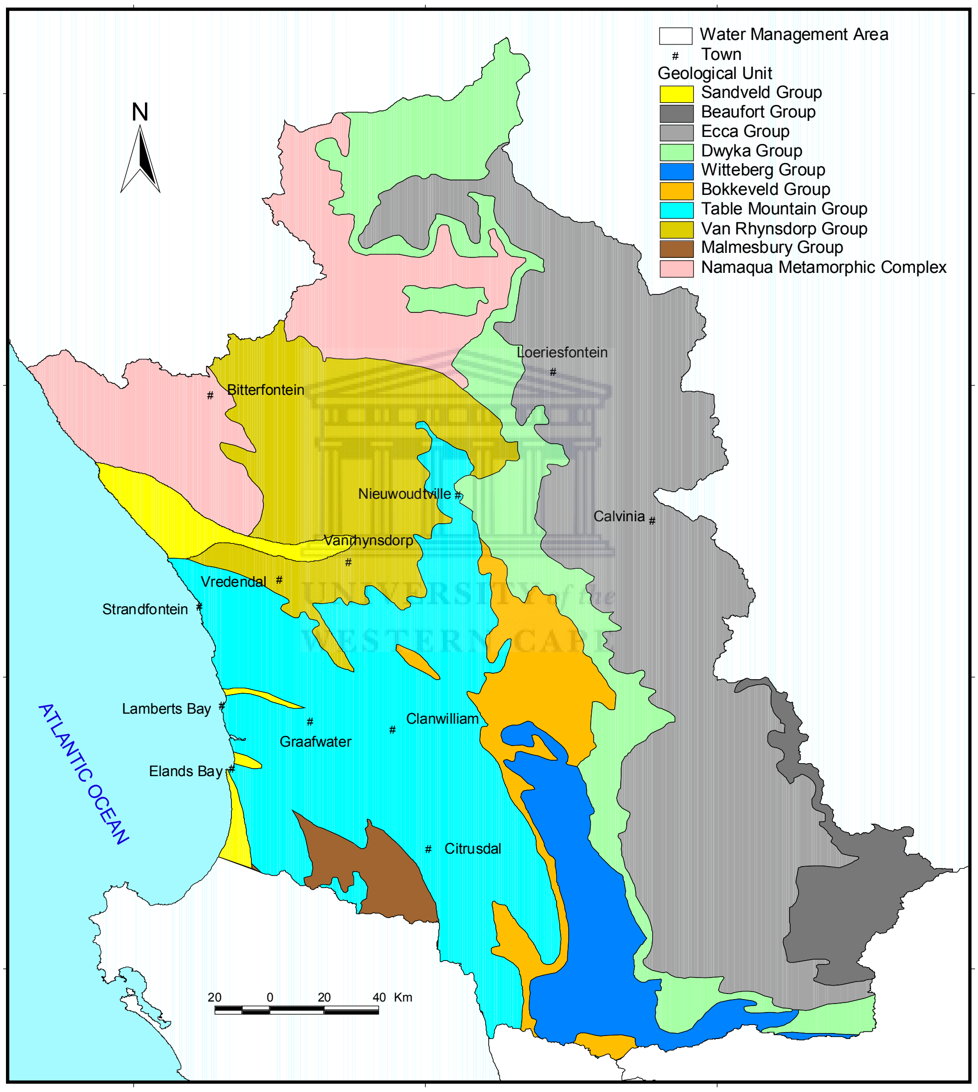


Figure 6: Geology

In the N.W. quadrant of the area the geology is dominated by metamorphic rocks of the Namaqua Metamorphic Complex, by arenaceous sedimentary rocks of the Table

Mountain Group in the S.W. quadrant, and argillaceous sedimentary rocks of the Ecca Group in the eastern half of the study area (Table 1).

Table 1: Simplified Geology of the Olifants-Doorn area

Geological Unit	Dominant Lithology
Sandveld Group	Aeolianite, sand, limestone, alluvium
Beaufort Group	Mudstone, sandstone; intruded by dolerite dykes and sheets
Ecca Group	Shale; intruded by dolerite dykes and sheets
Dwyka Group	Tillite with subordinate sandstone, mudstone, shale; intruded by dolerite
Witteberg Group	Quartzitic sandstone, shale
Bokkeveld Group	Shale, siltstone, sandstone
Table Mountain Group	Quartzitic sandstone, sandstone, subordinate shale
Van Rhynsdorp Group	Sandstone, shale, siltstone, limestone, dolomite, quartzite, schist
Malmesbury Group	Schist, phyllite, phyllitic shale, shale
Namaqua Metamorphic Complex	Gneiss, granite, metasediments, lava, tuff, volcaniclastic rocks

2.8 Groundwater quality

Groundwater quality as indicated by electrical conductivities (ECs) shows a strong correlation with geology in the study area (Figure 7). Groundwater from aquifers of the Table Mountain and Witterberg Groups generally has an EC of less than 70 mS/m. It can be seen that the poorest quality water is generally found in the north and the north-west of the study area.

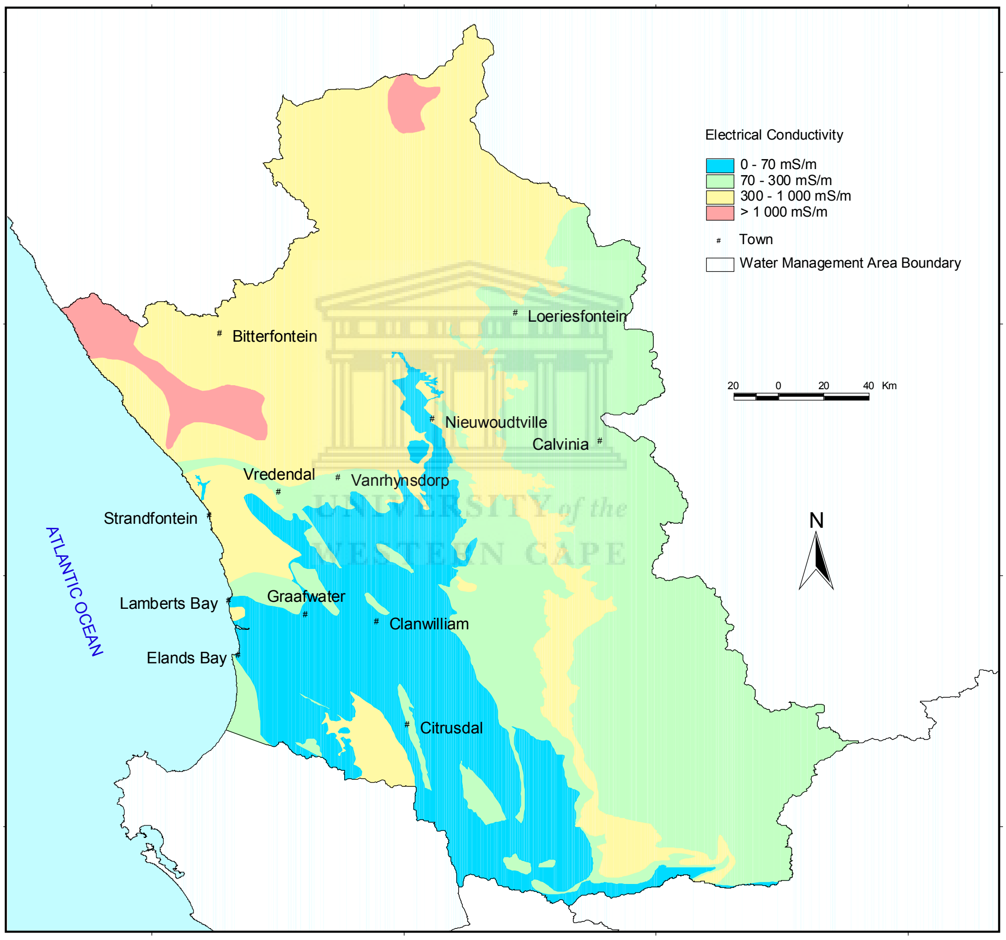


Figure 7: Groundwater electrical conductivity

2.9 Borehole yield and aquifer type

Figure 8 shows borehole yields and aquifer types, based on the data set used for Calvina 1:500 000 map sheet (Zenzile, 2002). A conservative approach to yields was used in the 1:500 000 maps series, with the depicted yield ranges tending to be based more on actual borehole yield data, and less on the potential of a given aquifer system to deliver high yields. Thus potentially high-yielding, but relatively un-developed aquifers, such as those of the Table Mountain Group are possibly given too low a yield rating. Despite this, the TMG is generally associated with higher yields in the study area.

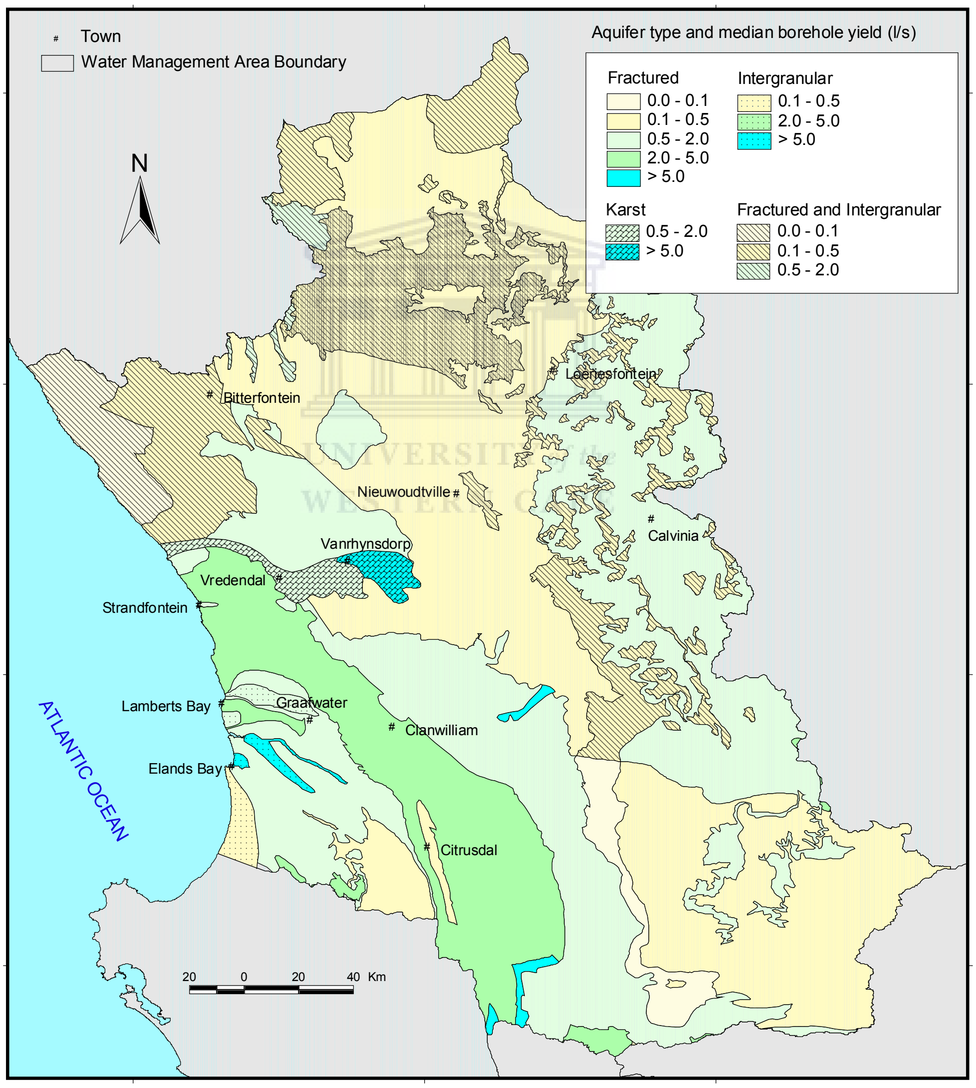


Figure 8: Aquifer types and median borehole yields

It should be noted that the map depicts a median yield ***class*** for a given area and not a yield ***range***. Thus an area with a median yield class of, for example, 2.0 – 5.0 l/s might contain individual boreholes with yields much lower than 2.0 l/s and much higher than 5.0 l/s. It also implies that an area with one very high-yielding borehole of say 100 l/s could still end up being mapped with a low or moderate yield class because of the low or moderate yields of the bulk of the boreholes in that area.

The aquifer type generally refers to the principal aquifer – the aquifer with the highest yield and/or freshest water that is closest to the surface. It can be seen from the map that the Fractured and Intergranular aquifer type is generally lower yielding than the other three aquifer types.

2.10 Climate Change

According to a report prepared for the Provincial Government of the Western Cape (Midegely, et al., 2005), there is clear evidence that climate change is already occurring in the Western Cape, and the likely future scenarios are increased temperatures, reduction in rainfall, a weakening of winter rainfall seasonality and a shift to more irregular rainfall, but with the proviso that a lot more data are needed before predictions about the future can be made with confidence. Being part of the Western Cape, the Olifants-Doorn WMA is also vulnerable to these predicted changes.

The report (Midegely, et al., 2006) also suggests that stronger management methods will be needed to reserve water for important ecosystems that are in danger of being destroyed by climate change and the resultant increased competition for a scarce resource. The report is also of the opinion that the equitable sharing of the water resources will require considerable skill, and a key adaption that will be needed is the reduced use of water by agriculture.

2.11 Groundwater contribution to base flow

Baseflow refers to the sustained low flow in a river during dry periods. This can be derived from phraetic water in the vadose zone, or from groundwater in the saturated zone. Figure 9 shows the estimated baseflow for the area, as used in the Groundwater Resource Assessment 2 (GRA2) project (DWAF, 2006a). The data used here are derived from modelled flow data since there is a paucity of gauged data. It can be seen that baseflow is nil over much of the study area. Significant baseflow is occurs in mountainous areas dominated by the TMG and Witteberg Group rocks.

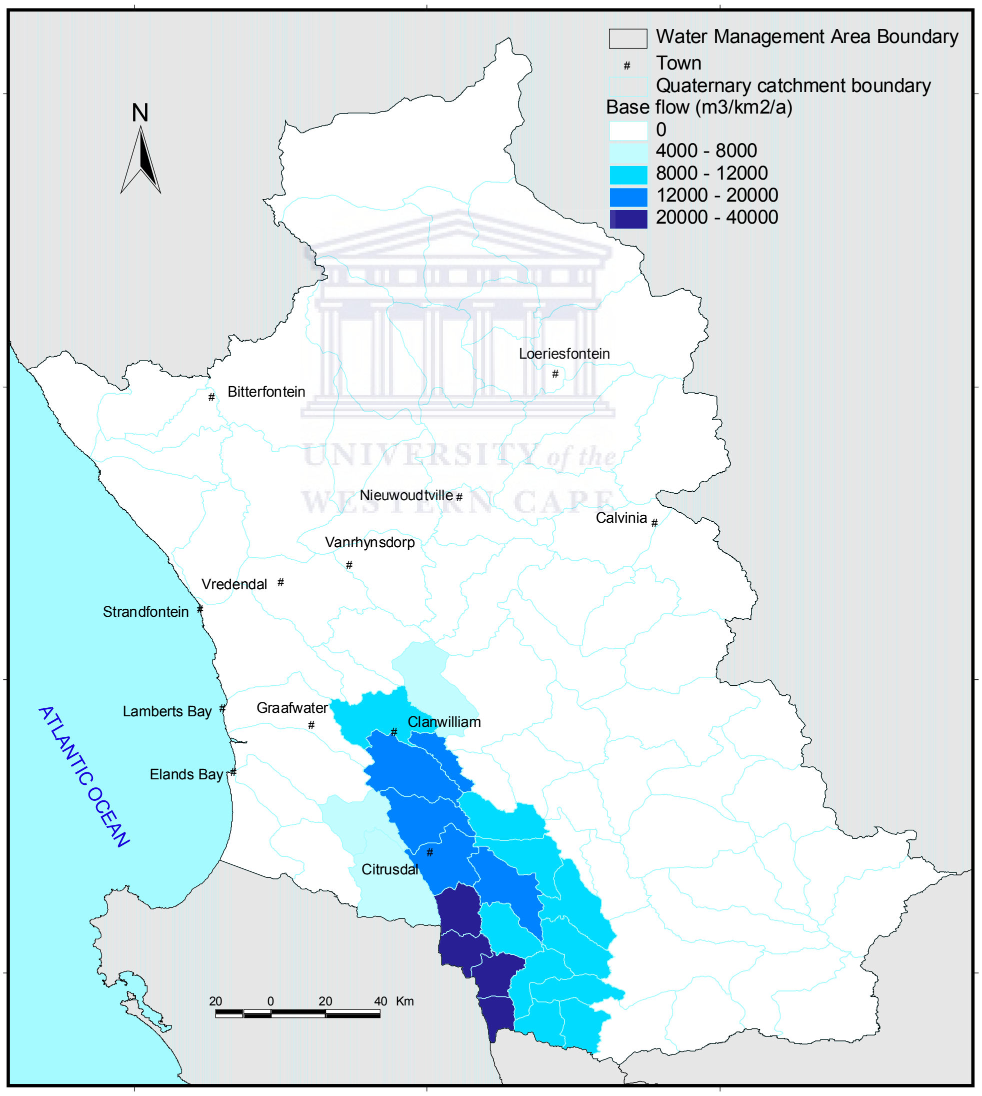


Figure 9: Baseflow in each quaternary catchment

3. Monitoring strategies: the state of the art

3.1 Introduction

Groundwater monitoring is often thought of in a very limited way as the selection (or drilling) of monitoring boreholes and the collection of monitoring data. There is, however, little sense in a beautifully designed and operated monitoring network (operational decision-making) if there were no serious issues that information from the monitoring network could help resolve. The focus of this chapter is, therefore, to put monitoring in a broader context so that it can be viewed more strategically.

The specific purpose of this chapter is to introduce the major components of groundwater monitoring strategies. Seen in their entirety, these components give an insight into the wide-ranging context or framework of groundwater monitoring. On their own, the individual components help form criteria against which groundwater monitoring in the Olifants-Doorn WMA can be evaluated.

A literature review is used to illustrate the various contexts in which groundwater monitoring takes place, to outline the objectives of monitoring, and to describe strategies that can be used to meet those objectives. The literature review focuses on texts that deal with monitoring as part of integrated water resource management, and are therefore strategic or general in nature, in preference to literature that deals with cases of very local and/or highly technical monitoring network design. General texts were sought covering different geographic areas and different institutions that could reasonably be assumed to give an authoritive perspective of what is the “state of the art” in groundwater monitoring. This was a somewhat intuitive process, but it is clear that some texts are cited more than others, and it seems reasonable to assume that these texts are more authoritive and carry more weight than less-cited texts.

3.2 Definitions of Monitoring

According to the Concise Oxford Dictionary (ed. Sykes, 1978) the word monitor comes from the same Latin root as *admonish* (to reprove), and *monition* - a formal warning from a member of the clergy requesting a person to refrain from some offence. The original Latin root of monitor means to warn. Thus to monitor, based on its original meaning, entails not just observing, but observing so as to warn of - and prevent - unacceptable behaviour, or as an early warning of impending danger. Therefore the original meaning of monitoring, if applied to groundwater, might include a management response to the data collected, and not just the data collection.

The United Nations / Economic Commission for Europe (UN/ECE, 2000) gives a slightly different interpretation than the Oxford Dictionary and distinguishes between monitoring, assessment and surveys:

- Monitoring is the process of repetitive observing, for defined purposes, of one or more elements of the environment according to pre-arranged schedules in space and time, and using comparable technologies for environmental sensing and data collection. It provides information concerning the present state and past trends in environmental behaviour.
- Assessment is the evaluation of hydrological, chemical and/or micro-biological state of the groundwater in relation to the background conditions, human effects, and the actual or intended uses, which may adversely affect human health of the environment.
- Survey: a finite duration, intensive programme to measure, evaluate and report the state of the groundwater systems for a specific purpose.

3.3 Objectives of Monitoring

3.3.1 Overall Objectives

“Before any groundwater monitoring can start the objectives should be clear.” (Van Lanen and Carrillo-Rivera, 1998)

According to the UN/ECE the overall purpose of monitoring is to ensure the sustainable development of groundwater and related resources (UN/ECE, 1999a). A widely cited definition of sustainable development is that which "meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development, 1987)

Taylor and Alley (2001) also base the objectives of monitoring on sustainability when they state that: "Long-term data are fundamental to the resolution of many of the most complex problems dealing with ground-water availability and sustainability."

3.3.2 Detailed Objectives

According to Taylor and Alley (2001) some of the detailed objectives of water level monitoring are:

> Long-term, systematic measurements of water levels provide essential data needed to evaluate changes in the resource over time, to develop ground-water models and forecast trends, and to design, implement, and monitor the effectiveness of ground-water management and protection programs.

Some of the detailed objectives presented by Taylor and Alley are echoed and expanded on, under the umbrella of sustainable development, by the UN/ECE (2000) which identifies four broad categories of monitoring:

- Basic/reference monitoring: this type of monitoring creates long-term records to identify trends caused by non-local anthropogenic and natural impacts. For example, declining water levels caused by climate change would be non-local, whereas declining water levels caused by abstraction would be local.

- Monitoring linked to functions and uses (compliance): this type of monitoring addresses the issues of whether groundwater use complies with regulations and standards.

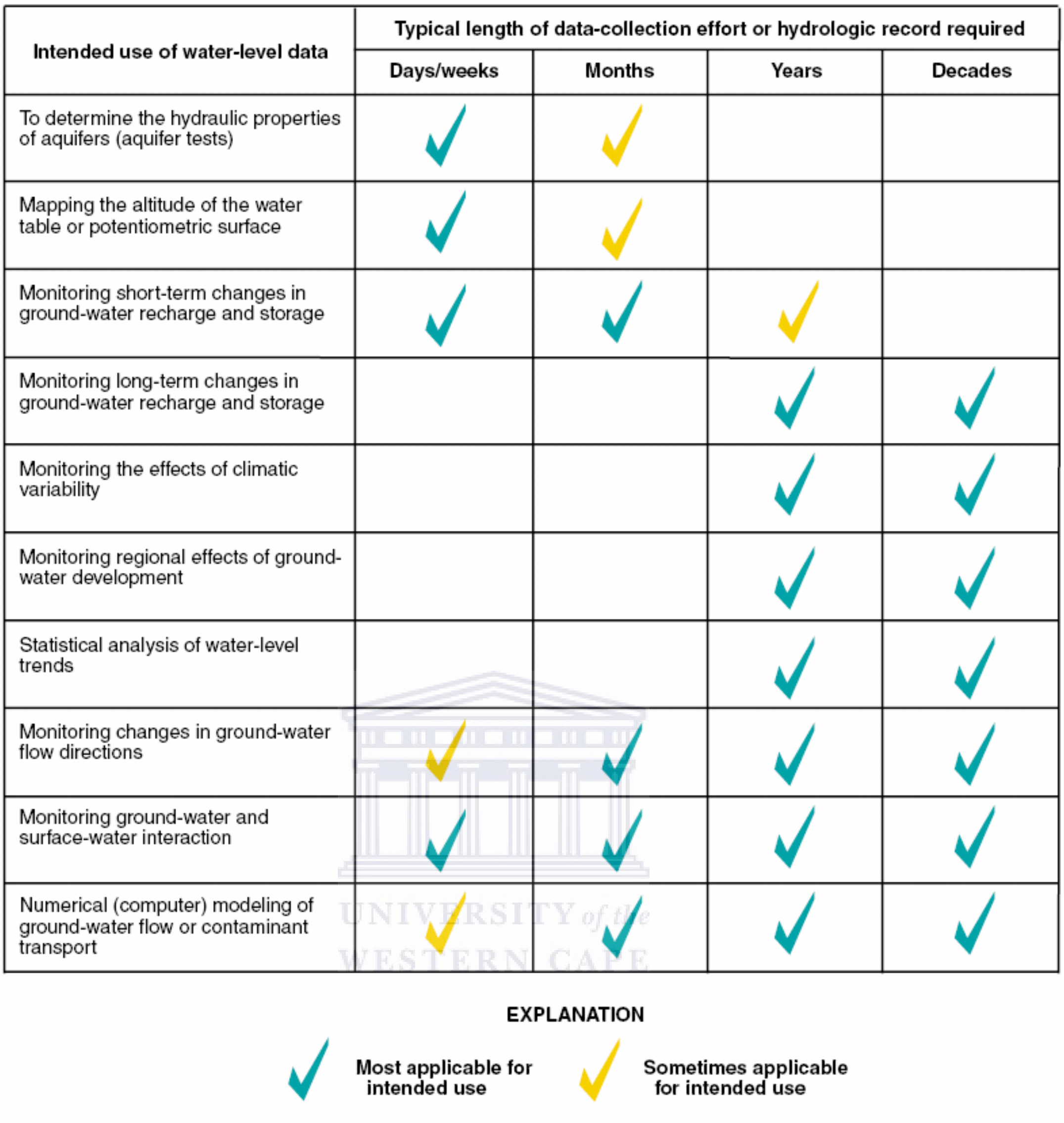
- Monitoring for specific purposes: this applies to monitoring that is more "research" related, e.g. the development and evaluation of protection zones, the investigation of the interconnection between surface and groundwater, checking the modelling to predict the migration of contaminants, etc.

- Early-warning and surveillance: this appears to refer primarily to groundwater quality issues, and is connected to issues such as: whether accidental spills of pollutants might affect drinking water, checking that waste disposal sites do not pose a health hazard, or to determine the source of groundwater quality deterioration so that remedial action can be implemented.

Van Lanen (1998) simplifies the classification of monitoring objectives into either “background” or “specific” monitoring. Their definition of background monitoring is similar to the “basic/reference” monitoring as defined by the UN/ECE, and refers to natural changes in waterlevels and groundwater quality before significant development of the resource occurs. The “specific” monitoring of van Lanen (1998) refers to the monitoring needed when a groundwater resource is developed.

Taylor and Alley (2001) take a more wide-ranging look at monitoring objective and compares the types of water level monitoring that may be undertaken with the length of the monitoring period (Table 2).

Table 2: Length of water-level-data collection versus intended use of the data (after Taylor and Alley, 2001)



Intended use of water-level data	Typical length of data-collection effort or hydrologic record required			
	Days/weeks	Months	Years	Decades
To determine the hydraulic properties of aquifers (aquifer tests)	✓	✔		
Mapping the altitude of the water table or potentiometric surface	✓	✔		
Monitoring short-term changes in ground-water recharge and storage	✓	✓	✔	
Monitoring long-term changes in ground-water recharge and storage			✓	✓
Monitoring the effects of climatic variability			✓	✓
Monitoring regional effects of ground-water development			✓	✓
Statistical analysis of water-level trends			✓	✓
Monitoring changes in ground-water flow directions	✔	✓	✓	✓
Monitoring ground-water and surface-water interaction	✓	✓	✓	✓
Numerical (computer) modeling of ground-water flow or contaminant transport	✔	✓	✓	✓

EXPLANATION

✓ Most applicable for intended use

✔ Sometimes applicable for intended use

3.4 Characterisation of Groundwater Systems

Some form of characterisation or pre-assessment of the systems under consideration is needed before proceeding with the monitoring programme (UN/ECE, 1999b). This could be a simple conceptual model based on existing maps, reports and database information, or a more complex model based on field surveys. Such characterisation should include factors such as flow conditions, recharge and discharge areas, abstraction, aquifer boundaries, evolution of groundwater quality. Any gaps in knowledge, and uncertainties, should be specified (UN/ECE, 1999b) since monitoring might need to be tailored to fill those gaps.

Van Lanen and Carrillo-Rivera (1998) also point out the need for characterisation, although they refer to it as “pre-monitoring research,” the overall aim of which is understanding the groundwater system as far as possible utilizing existing data and information.

The rationale behind characterisation is that it is needed to be able to select representative monitoring points and to be able to sensibly interpret the monitoring data (UN/ECE, 1999b). For example, if the objective was to monitor a major aquifer’s response to abstraction, it would be necessary to know the extent of the aquifer, and so avoid siting the monitoring points in an unrepresentative aquitard. In addition, waterlevels will have different meanings, depending on, inter alia, the transmissivity of the aquifer, the location of boundaries and the location of abstraction points. For example a sharp drop in waterlevels at a pumphole will often be less critical than a smaller drop in waterlevels outside the sphere of (direct) influence of abstraction points.

3.5 The Monitoring Cycle

3.5.1 Overview of the Monitoring Cycle

There are many facets to monitoring, and it can become a very complex topic, thus the potential to over-emphasize one aspect of monitoring while losing sight of its overall objectives are exceedingly high. Therefore some sort of structure that can pull all the issues and processes together, and help make sense of them, is therefore very helpful. The monitoring cycle (UN/ECE, 2000) provides such a structure or framework (Figure 10).

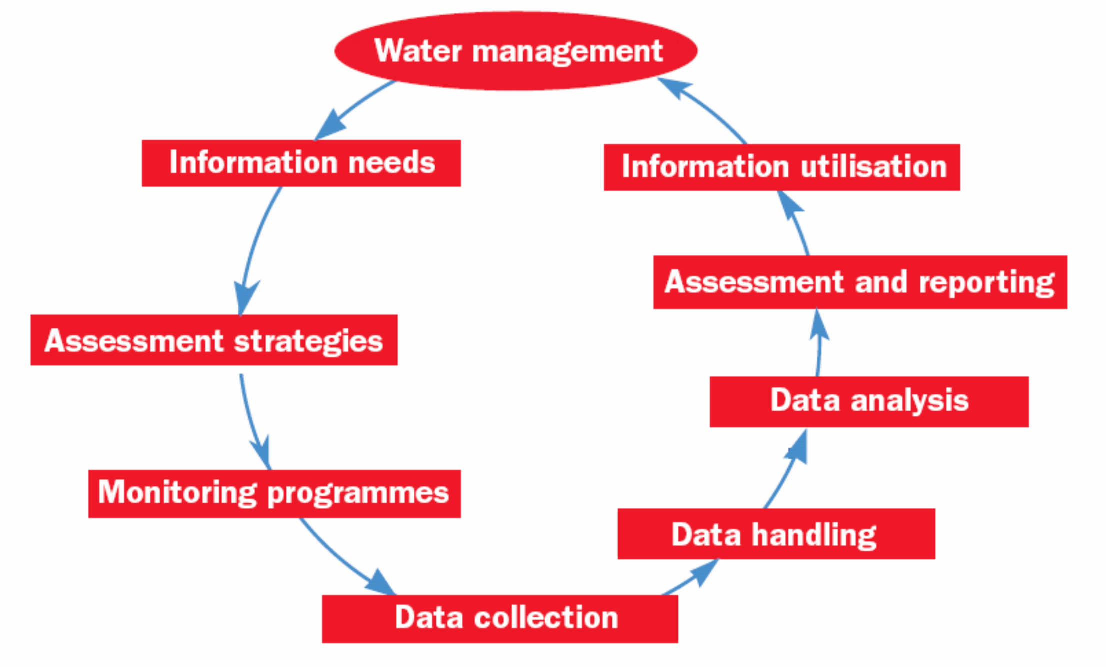


Figure 10: The Monitoring Cycle (UN/ECE, 2000)

According to the monitoring cycle:

- The starting point for the monitoring process is water management issues (this includes links between groundwater and surface water)
- Information needs are determined by the management issues
- The network design (monitoring programmes) is determined by the information needs
- Data management is an integral part of the monitoring cycle
- Monitoring must lead to information that can be used in the water management process

This monitoring cycle makes it clear that that monitoring systems are not seen as something static, but need to be continually assessed in the light of how useful the information collected is in aiding decision-making in groundwater management (UN/ECE, 2000).

3.5.2 Identification of Groundwater Management Issues

In practice groundwater monitoring is routinely added to groundwater investigations, and it seems so obvious that monitoring is both necessary and useful for increasing groundwater knowledge and managing groundwater resources, that it is very easy to lose sight of the specific objectives of the monitoring. According to the UN/ECE (2000) the core elements (Figure 11) in groundwater management are the FUNCTIONS AND USES of the groundwater bodies, the PROBLEMS or ISSUES related to groundwater, and the impact of MEASURES on the overall functioning of the groundwater body. Monitoring must satisfy the information needs of these core elements. Thus monitoring is seen as a tool of groundwater management and not a goal in itself.

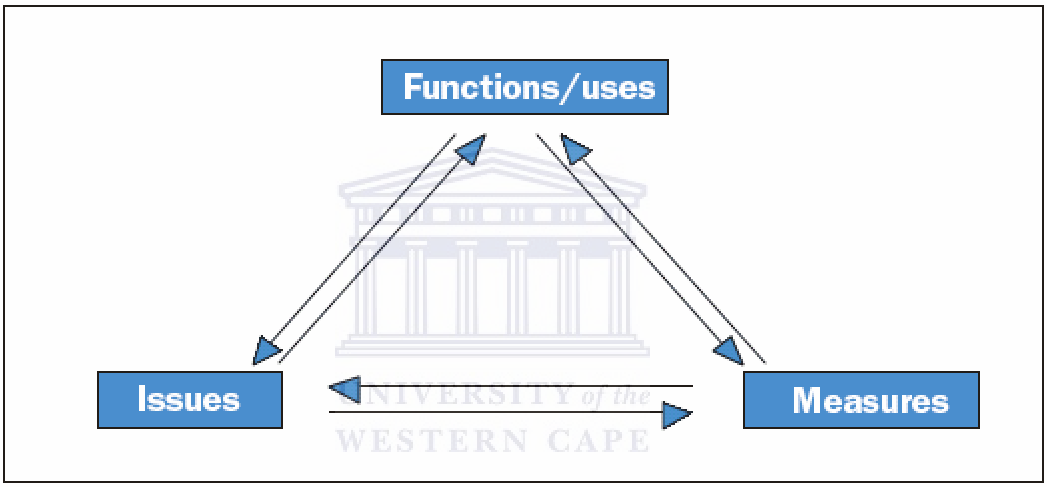


Figure 11: Core elements of water management (UN/ECE, 2000)

Examples of these three elements:

- FUNCTIONS/USES might include conservation of wetlands, maintaining drinking water quality, maintaining irrigation water availability
- PROBLEMS/THREATS/ISSUES might include declining watertables, pollution with hazardous substances, loss of groundwater flows to aquatic ecosystems
- MEASURES might include steps to limit abstraction, artificial recharge, remediation of pollution (ibid)

The ISSUES need to be prioritised, since they determine the information needs that will (or should) form the basis of monitoring (ibid).

3.5.3 Identification of Information needs

It is very tempting, once the management issues have been identified, to rush straight into designing the monitoring network. However the data needed might already exist – e.g. be collected by other institutions. More importantly WHAT data are needed? According to the UN/ECE (2000) the information needs and monitoring need to be tailored to what stage the issue is in the policy life cycle (Figure 12).

The policy cycle is split into four stages

1. Problem recognition. The question at this stage is whether there really is an environmental problem. Research, inventories, surveys and risk assessments are done to obtain basic data that is adequate enough to identify the scale and nature of the problem, and suggest probable causes.

2. Policy formulation. If there is an admission of a problem, the focus shifts to formulating policies to solve the problem, with more research and surveys done to help shape the policy.

3. Policy implementation. Measures are taken to solve the problem. Detailed monitoring of temporal and spatial trends takes place, so that detailed data can be obtained and the effectiveness of various measures to solve the problem can be assessed.

4. Results evaluation. The effectiveness of various measures is evaluated. Compliance monitoring is the main type of monitoring at this stage.

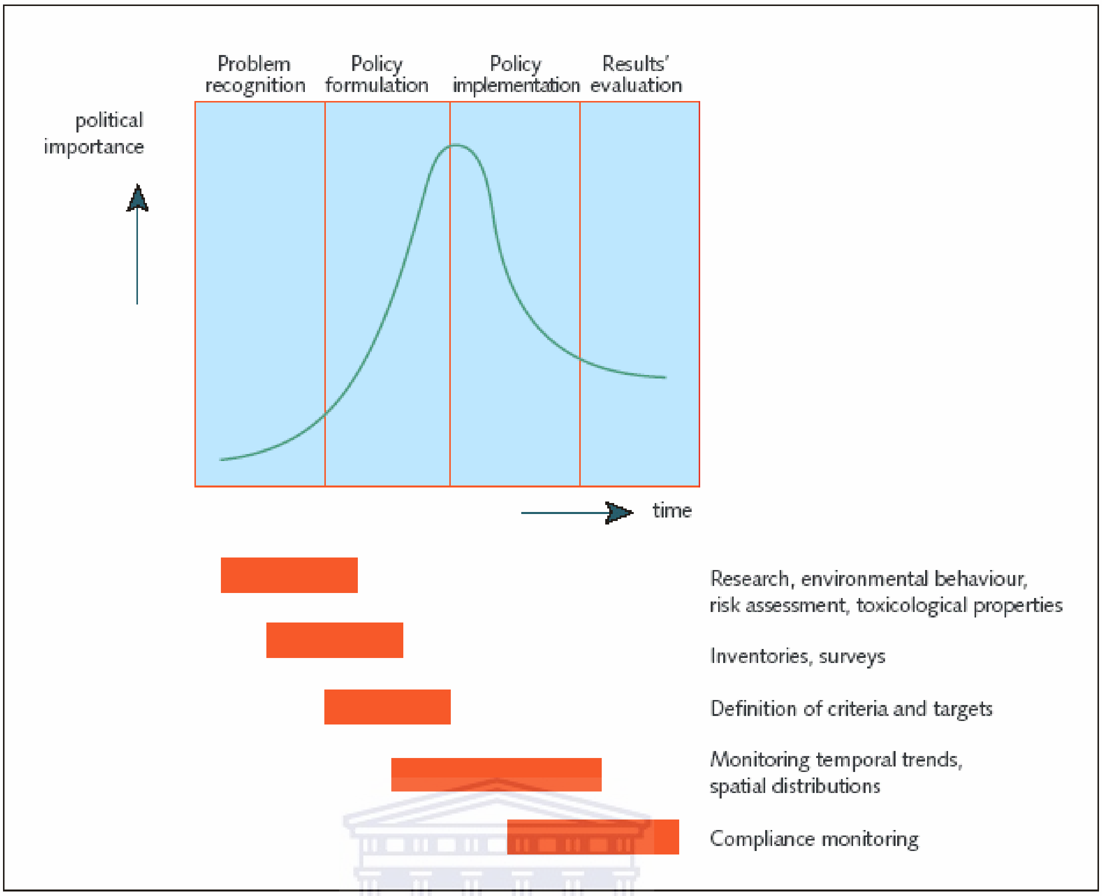


Figure 12: Policy Life Cycle (UN/ECE, 2000)

The policy life cycle can help suggest general approaches to determining information needs. When looking at a specific issue, information is required on the origins and effects of the problem, and the measures taken to resolve it. This can lead to the following steps (UN/ECE, 2000) to specify groundwater monitoring information needs:

1. Establish a function-issue table to see whether the issues are in conflict with the functions of the groundwater systems. Management objectives should be formulated and agreed upon to protect these groundwater resources. When budgets are restricted, a function-issue table can be used as a tool for priority setting. The urgency of a problem and the available (technical and financial) means determine priorities.

2. Collect at least the following information about place- and time-dependent factors:

    - the hydrological and geochemical functioning of the groundwater system

- spatial and temporal scales
- chemical, physical and biological processes
- the users of information (policy makers and/or managers at the operational level)
- the stage of the management (problem identification, policy development, policy implementation and control)

3. Tailor it at the organisational level, by using the policy life cycle. Information needed for policy-making differs from information needed for the evaluation of restoration measures.
4. Make a checklist with criteria that have to be met, linked to the factors mentioned in 3.

As monitoring evolves, and water management develops, and targets are attained or policies change, there will need to be a regular re-thinking of monitoring and information-gathering strategies to reflect the evolving situation. What was useful at one stage might be overkill at another stage. However adjustments should not be carried out recklessly and must take into account the long residence times of groundwater and the time lag before the impact of human activities is observed (ibid).

3.5.4 Monitoring Strategies

Once the management objectives and broad information needs of monitoring have been established, a further step is needed (UN/ECE, 2000) before the actual monitoring network can be designed. This step is the creation of strategies to turn the objectives into reality. An obvious example is a funding strategy - the objectives will remain mere objectives if no funding for the monitoring is forthcoming. Monitoring implementation strategies encompass a variety of elements (UN/ECE, 2000):

- **Inventories and preliminary surveys:** this includes a screening of existing information, and additional surveys where necessary. The aims of this preliminary work are to (a) check if information is available from other sources, and thus avoid unnecessary duplication, and (b) to ensure that the groundwater system is sufficiently well understood to enable a monitoring network to be designed that is both effective and efficient.

- **Types of monitoring:** will this be a short or long-term programme? What is the area to be covered?

- **Monitoring techniques**: this revolves around determining the available and suitable monitoring techniques.

- **Step-wise approach**: This approach starts with a simple, basic monitoring programme to get a broad, overall picture, and then progresses in a step-wise fashion, towards fine-tuned diagnostic features. In this approach an evaluation of whether or not each step met the required information needs is done before moving to the next step. This approach can lead to a reduction in information requirement and an increase in cost-effectiveness. In many cases the step-wise approach is the only viable option as there are no long-term data available to establish base-line conditions.

- **Responsibilities:** Who will be responsible for what? What individuals and which institutions will be responsible for driving the monitoring programme?

- **Financial and human resources:** What financial and human resources can be made available? A long-term financial commitment to monitoring will usually be required. Will this be forthcoming?

- **Models:** Models, especially mathematically models, can have one or more roles in monitoring strategies:

    - Assisting in flow analysis so as to build a clearer conceptual picture before planning monitoring networks

    - screening alternative policies

    - optimising monitoring network design

    - assessing the effectiveness and efficiency of the results of the monitoring programme

Taylor and Alley (2001) stress the importance of the relationship between mathematical models and monitoring, specifically how monitoring data are needed to calibrate models, and how calibrated models can be used to identify the most critical monitoring needs, and bemoan the fact that the step of using models to refine monitoring is rarely taken.

- **Integrated Approach:** Effective monitoring should not only harmonise surface and groundwater monitoring, but also look for the best way to link the various types of monitoring (e.g. reference monitoring and compliance monitoring). However it is unwise to try to integrate surface and groundwater monitoring at too early a stage because this can lead to an over- or undersizing of monitoring networks.

- **Aquifer Vulnerability Mapping:** Although the term vulnerability is widely used by groundwater scientists, there is no standard definition of its meaning. Here vulnerability is taken to mean: "a relative measure of the susceptibility of a groundwater body to be contaminated by anthropogenic activities; governed by the physical, chemical and biological properties of the soil and rock" (Parsons 1995). In this definition vulnerability is an intrinsic quality of the physical system, and the physical system includes what overlies the aquifer, and not just the aquifer itself. A potential source of contamination nearby would increase the risk of pollution, but not the vulnerability.

  In general aquifers, or parts of aquifers, that are more vulnerable will require more intensive monitoring. Thus vulnerability mapping could be used to prioritize monitoring. Vulnerable areas where an impact is most likely to occur would be the highest priority.

- **Risk assessment**: The traditional definition of risk is "a combination of two factors: (1) the chance that an adverse event will occur and (2) the consequences of that event." (Dennis, van Tonder, and Riemann, 2002). Current thinking (International Strategy for Disaster Reduction Secretariat, 2002) recognizes that communities have the ability to reduce the consequences of an adverse advent.

Capacity can then be added as third variable in the "risk equation":

Risk = Hazard (H) x Vulnerability (V) / Capacity (C)

Risk assessment can be used as another tool to help prioritize monitoring. For example the risks associated with an insignificant aquifer in sparsely populated area with an abundance of surface water would be very low. In such cases the monitoring effort could justifiably be scaled down.

- **Selecting indicators:** In the water-monitoring field (especially in the water quality field), indicators are taken to mean something more than just variables or parameters. In essence indicators are observable and measurable variables that reveal more about the resource than what is obvious from their face value (UN/ECE 1999a). For example in Egypt increased salinity is used as an indicator that abstractions exceeds recharge and that there are resource quantity problems (UN/ECE 1999a). In other words an indicator can be used to both identify groundwater management issues, and to measure progress towards meeting management goals, as well as communicating that progress to decision-makers.

  Choosing appropriate indicators is a compromise between the information needs of the decision makers, and the costs and other limitations of obtaining the monitoring data. This compromising can only be done once the hydrological and geochemical characteristics of the groundwater system are known.

3.5.5 Monitoring Network Design

According to the UN/ECE (2000) once the management objectives of monitoring have been established, information needs identified established, and general strategies developed for acquiring the desired information, THEN the actual design of monitoring networks can be considered. This includes (UN/ECE 2000) taking the following factors into account:

- **network density:** In general the more complex the system, the greater the number of monitoring points that will be required. Basic/reference monitoring will normally have the lowest density networks, early-warning will have the highest density, while compliance monitoring and monitoring for specific purposes will have an intermediate density.

- **location of monitoring points:** having established information needs earlier in the monitoring cycle programme, specific sites need to be selected that (a) are representative of aquifer conditions (for example, water levels at a pumped well would not be representative of water levels for the aquifer as a whole), and (b) allow spatial trends to be deduced on the required scale.

- **monitoring parameters:** the choice of monitoring parameters is determined directly from the information needs. A lot of groundwater quantity issues can be investigated by simply monitoring water levels and abstraction.

- **types of monitoring points:** pumped wells are acceptable for groundwater quality monitoring, but not - generally – for groundwater quantity monitoring. The use of springs should be considered as representative data can be obtained relatively cheaply.

- **quantity measurement and sampling procedures:** groundwater levels need to measured in relation to a fixed reference point. There are normally quality sampling protocols that have to be observed, depending on what parameter is sampled, whether the parameter is measured in the laboratory or in the field

- **the measuring and sampling frequency:** this is determined by the accuracy required in identifying fluctuations; whether those fluctuations are seasonal or long-term; and the availability of resources. Low accuracy fluctuation detection, long-term fluctuations, and low budgets will lead to the lowest frequency monitoring

- **statistical versus "hydrogeological" approach** (UN/ECE 1999a) Monitoring is done at a specific point in time, and at a specific point in space. To be useful, the point data need to be converted in three-dimensional spatial data and continuous time data. Thus some form of interpolation is needed to generate estimated values between the monitored points. The difference between the estimated value and the actual value is known as the estimation error. In the **statistical approach** this error is explicitly calculated, and the number of samples iteratively increased until the desired accuracy is obtained, using techniques such as Kriging.

With the **hydrogeological approach** no explicit quantification of uncertainty is made. Instead expert judgement is applied to the local hydrogeological conditions to empirically design a monitoring network. While the statistical approach might appear more accurate than the more intuitive hydrogeological approach, this is often not the case because simplifying assumptions have to be made in the representation of the hydrogeology and the management objectives. The hydrogeological approach is used where there insufficient real data to evaluate the monitoring density and frequency.

- In order to overcome the lack of real data, some from of **groundwater model** can be used to simulate data, which can then be used in statistical interpolation techniques to quantify errors and thus to determine a network within acceptable error limits. Simulations from a groundwater model can also be used to assist the hydrogeological approach to designing a monitoring network.
- **indirect methods:** the use of ground resistivity, for example, might be used to monitor the spread of saline water in an aquifer. If an indirect method is used, some form of control or calibration by direct sampling is always required
- **costs:** it is easy to forget that monitoring has to be funded by someone, and that sustainable monitoring requires a sustainable commitment to funding

3.5.6 Data Management

Data management is an aspect of monitoring that is often overlooked, or at least not properly addressed. It is easy to assume that, once the monitoring network has been designed, and regular measurements are being taken, there is nothing more to worry about. This is far from the truth. There is no point in establishing a monitoring network and then starting to think about data management, because without data management there is in effect no monitoring programme

According to the UN/ECE (2000) the goal of data management is to convert data into information that that meets the specified information needs and associated objectives of the monitoring programme. The essence of good data management is then quality control, appropriate data analysis, and timely and understandable reporting (ibid). Although these requirements seem simple and obvious, they are often not meet, and a considerable investment in personnel and equipment is needed to turn the expensive monitoring data into useful information. Some of the main steps in data management are (UN/ECE, 2000) are:

- **Data validation:** in addition to the quality control measures used in the actual monitoring / measuring and sampling procedures, the data need to be checked and approved before being made accessible. This can include basic things like looking for missing values and outliers to more complex statistical analysis. Although software can help perform these control functions, there is no substitute for human expertise and knowledge.

- **Data storage:** data need to be stored so that they are easily accessible for future use. This is more than just a hardware/software issue, since the data not only need to be accessible, but their context also needs to be appreciated. For example: was the measurement taken in the field and possible less accurate, or was it a more accurate laboratory measurement? Thus factors such as the error margins in the measurements taken, the type of observation point, method of sampling, and other background information also need to be archived.

- **Data interpretation:** Data need to be processed, analyzed and interpreted before they can become useful information. (For example: a single groundwater level has little meaning; but when processed as part of a water level graph, the analysis of trends becomes possible; and when compared with other trends such as groundwater abstraction, an interpretation of the situation can be made.) Organizations should ideally have a "Data Analysis Protocol" (DAP) so that a consistent approach is used for interpretation. The DAP allows for some flexibility in the data analysis procedures applied, but requires that these procedures be documented.

- **Reporting:** This is the final step in data management, and is the link between data management – and all the preceding monitoring activities – and the information users. Reports need to be prepared on a regular basis, possibly annually for policy-makers and more frequently for technical staff. The level of detail should depend on the intended use of the information. Standardisation of reporting formats is encouraged, with the extension of the DAP to include reporting, and the standardisation of software, some of the ways to achieve this. ***Monitoring objectives should always be presented in the reports!***

3.6 Long-term monitoring

The term "long-term monitoring" was encountered so frequently in the literature searches, that it was considered necessary to investigate whether this was a special class of monitoring. According to the American Society of Civil Engineers (ASCE, 2003) long-term monitoring is defined as "the testing of groundwater over an extended period of time in order to document groundwater conditions …" The length of monitoring is not generally defined in terms of time, but by performance objectives – if these objectives are met, the programme can be terminated (ASCE, 2003). However this type of monitoring refers specifically to water quality monitoring in the restoration of contamination sites.

A more general interpretation is given by Taylor and Alley (2001) where long-term waterlevel monitoring usually refers to monitoring of years to decades in length, and is needed for such purposes as:

- Assessing the effects of climate variability and change

- Assessing the effects of regional aquifer development – groundwater availability, water quality changes, land subsidence

- Providing sufficient data for the analysis of waterlevel trends

- Assessing groundwater-surface water interaction

- Calibration and testing of groundwater models

Taylor and Alley (2001) point out that the limitations of existing waterlevel data are often only fully recognized when they are used in modelling, and that insights obtained about groundwater flow via modelling often allow the most critical needs for future groundwater level data to be identified. However this step of using groundwater models to improve future waterlevel monitoring is rarely taken.

It seems clear from this brief introduction to long-term monitoring that it is not fundamentally different in overall context to monitoring of any other length. For example monitoring objectives are still needed, data management is still needed, periodic review of the network are still needed, and so on. However, long-term monitoring is obviously better suited for investigating certain issues, e.g. climate change, than short-term monitoring. Long-term "reference" monitoring will have more value the longer the records are.

3.7 Overall Management of the Monitoring Programme

3.7.1 Efficiency, Effectiveness, and Traceability

The purpose of monitoring is to aid decision-making on water resource management issues. But another aspect or level of management is to review the overall functioning of the monitoring programme itself – to "monitor the monitoring programme." Some of the main monitoring management issues are (UN/ECE 2000):

- **Efficiency** – obtaining the information at as low a financial and personnel cost as possible

- **Effectiveness** – ensuring that the information obtained from the monitoring programme best meets the information needs of decision-makers

- **Traceability** – making sure that the processes and activities that lead to the data and information are properly defined and documented. If the processes and activities are not properly documented, it is difficult to take steps improve them

3.7.2 Institutional Arrangements

Although it might seem like stating the obvious, it needs to be remembered that monitoring doesn't just happen – it needs an institutional framework to make it happen. In other words an institutional framework is needed to drive, oversee, coordinate and steer the processs. The importance of an institutional framework is recognized by the UN/ECE (2000) who state that institutional arrangements are crucial for the successful drawing-up and implementation of monitoring policies, strategies and methodologies.

Loucks and Gladwell (1999) point out that improving sustainability is not just about improving physical and technical matters, but improving the institutions involved, and that understanding of how institutions really work, especially when under stress and/or under pressure from change from within or outside the institution. Although Loucks and Gladwell (1999) are discussing institutions from an overall sustainable water resource management perspective, their comments could just as easily apply to institutions involved with groundwater monitoring.

Another point to bear in mind – with monitoring or any function provided by an institution - is that an institution is comprised of a myriad of individuals with differing levels of experience, differing perceptions as to the institutions's priorities, and differing levels of support for whatever changes or restructuring may be planned at the policy level of the institution (Loucks and Gladwell, 1999). Thus what really happens when an institution is expected to provide support will be an aggregate of the response of numerous individuals, which might well differ from what official mission statements, policy statements, strategic plans, and work plans might indicate (Loucks and Gladwell, 1999).

The impression created from literature searches is that the institutional foundation of groundwater monitoring is one of its least studied aspects. A possible reason for this is that monitoring often gets analyzed (and carried out) by people within an institution, who tend to focus on the nuts and bolts of monitoring, and therefore are likely to be oblivious of the fact that their institution has a certain culture or overall approach to monitoring. It is also possible that people outside (and inside) the institution tend to take it for granted that there is an institution that does monitoring, does it in a certain way, and will carry on doing so.

3.7.3 Integrated Catchment Management

Ultimately, groundwater monitoring should fit in with, and support, Integrated Catchment Management, rather than just looking at groundwater, or water, resources in isolation. According to Hooper (1998), Integrated Catchment Management is characterised by:

- the coordination of land, water resource, and environmental management, often amongst competing jurisdictions
- being known by a variety of alternative names, such as: Total Catchment Management, the Watershed Approach, and Ecosystem Management
- engaging stakeholders through a partnership approach
- systems thinking
- using a balanced approach to weigh concerns for development, versus concerns for sustainability
- directing attention to key variables and issues, and their linkages, rather than being a comprehensive approach which looks at all issues and variables

4. Monitoring and the NWA

4.1 Introduction

The purpose of this chapter is to outline the explicit requirements for monitoring as described in the Act, and some of the implicit and consequential monitoring requirements that flow from the Act and its implementation.

4.2 Monitoring Requirements specified by the NWA

Chapter 14 of the NWA deals specifically with monitoring under the heading: "Monitoring, Assessment and Information." This is what the NWA (Republic of South Africa, 1998) says explicitly about monitoring:

> MONITORING, ASSESSMENT AND INFORMATION
>
> Monitoring, recording, assessing and disseminating information on water resources is critically important for achieving the objects of the Act. Part 1 of this Chapter places a duty on the Minister, as soon as it is practicable to do so, to establish national monitoring systems. The purpose of the systems will be to facilitate the continued and co-ordinated monitoring of various aspects of water resources by collecting relevant information and data, through established procedures and mechanisms, from a variety of sources including organs of state, water management institutions and water users.
>
> Part 1: National monitoring systems
>
> Establishment of national monitoring systems
>
> 137. (1) The Minister must establish national monitoring systems on water resources as soon as reasonably practicable.
> (2) The systems must provide for the collection of appropriate data and information necessary to assess, among other matters -
> (a) the quantity of water in the various water resources;
> (b) the quality of water resources;
> (c) the use of water resources;
> (d) the rehabilitation of water resources;
> (e) compliance with resource quality objectives;
> (f) the health of aquatic ecosystems; and

> (g) atmospheric conditions which may influence water resources.
>
> Establishment of mechanisms to co-ordinate monitoring of water resources
>
> 138. The Minister must, after consultation with relevant -
> (a) organs of state;
> (b) water management institutions; and
> (c) existing and potential users of water, establish mechanisms and procedures to co-ordinate the monitoring of water resources.

Sections 139 to 143 deal with national information systems, and since effective monitoring cannot in practice be separated from effective information systems, the Sections (RSA, 1998) are also quoted in full:

> Part 2: National information systems on water resources
>
> Part 2 requires the Minister, as soon as it is practicable to do so, to establish national information systems, each covering a different aspect of water resources, such as a national register of water use authorisations, or an information system on the quantity and quality of all water resources. The Minister may require any person to provide the Department with information prescribed by the Minister in regulations. In addition to its use by the Department and water management institutions, and subject to any limitations imposed by law, information in the national systems should be generally accessible for use by water users and the general public.
>
> Establishment of national information systems
>
> 139. (1) The Minister must, as soon as reasonably practicable, establish national information systems regarding water resources.
> (2) The information systems may include, among others -
> (a) a hydrological information system;
> (b) a water resource quality information system;
> (c) a groundwater information system; and
> (d) a register of water use authorisations.
>
> Objectives of national information systems
>
> 140. The objectives of national information systems are -
> (a) to store and provide data and information for the protection, sustainable use and management of water resources;
> (b) to provide information for the development and implementation of the national water resource strategy; and
> (c) to provide information to water management institutions, water users and the public -
> (i) for research and development;
> (ii) for planning and environment impact assessments;
> (iii) for public safety and disaster management; and
> (iv) on the status of water resources.

> Provision of information
>
> 141. The Minister may require in writing that any person must, within a reasonable given time or on a regular basis, provide the Department with any data, information, documents, samples or materials reasonably required for -
> (a) the purposes of any national monitoring network or national information system; or
> (b) the management and protection of water resources.
>
> Access to information
>
> 142. Information contained in any national information system established in terms of this Chapter must be made available by the Minister, subject to any limitations imposed by law, and the payment of a reasonable charge determined by the Minister.
>
> Regulations for monitoring, assessment and information
>
> 143. The Minister may make regulations prescribing -
> (a) guidelines, procedures, standards and methods for monitoring; and
> (b) the nature, type, time period and format of data to be submitted in terms of this Chapter.

The Act clearly regards monitoring and information systems as closely related processes – with monitoring seen an integral part of an information system. It is noteworthy that ensuring monitoring standards is not compulsory, but an option the Minster may exercise.

It is interesting that the Act doesn't actually say that DWAF (The Minister) ***has*** to do any physical monitoring itself. Although monitoring data can be collected by DWAF, it can also use Section 141 to compel people to provide monitoring information. Monitoring data can also be obtained via attaching a condition to a license or general authorisation. Thus, provided that national monitoring systems are ***in place,*** DWAF has presumably met its obligations, even if all the physical monitoring is done outside DWAF. On the other hand there is nothing, in ***principle***, that excludes DWAF from doing any or all of the monitoring either. (In ***practice*** resource limitations will dictate how extensive DWAF monitoring can be.)

Besides the leeway in what monitoring activities DWAF actually does itself, there is a lot of leeway for deciding what "national monitoring" actually entails. It could imply:

- Obtaining an overall – national – overview of the resources as a whole
- Background or reference monitoring only

- Any monitoring carried out by DWAF – since DWAF is a national government department
- Any monitoring carried out by DWAF national office, but not by DWAF regional offices

Section 137.(2) of the Act would appear to rule out the approach that national monitoring is a specific subset of monitoring such as background or reference monitoring, since it includes “the quantity of water in the various water resources”, “the quality of the water resources” and “the use of the water resources.” These factors cannot be determined by background/reference monitoring of groundwater in unimpacted areas. In fact the tone of Section 137.(2) in its entirety suggests national monitoring is comprehensive, rather than exclusive. On the other hand, the NWA doesn’t exclude any given type of monitoring either, thus monitoring subsets such as background monitoring could be ***included*** in national monitoring, but do not ***define*** it.

To sum up: it seems clear that “national monitoring” in the NWA means that DWAF has a responsibility for ensuring that the status of the nation’s groundwater resources is monitored, but that the level of direct DWAF involvement in any given monitoring activity can vary as circumstances dictate. It also seems clear that just about any facet of monitoring can be included in national monitoring, but that there id no specific, individual type of monitoring defines national monitoring.

4.3 White Paper on a National Water Policy for South Africa

For the most part the White Paper (DWAF, 1997) contains a concise account of principles and policies that are then expanded on in the detailed regulations of the Water Act. Unusually, the treatment of monitoring in the White Paper is longer and more detailed than its rendition in the Water Act. This would seem to suggest that some of the contents of the White Paper on monitoring were considered too detailed or too explicit, although not necessarily unacceptable, for inclusion in the Water Act.

The details in the White Paper were investigated for insight into what the NWA might **mean** when it refers to “national monitoring.” Section 6.8.2 Policy on Monitoring, Assessment and Auditing, includes the statement that “Monitoring and information management are functions of national Government, specifically of DWAF …..", and goes on to list these responsibilities as:

- National design and coordination of monitoring programmes
- Development of technology and methods to support monitoring, assessment and auditing
- Standardisation of approved methods and techniques for monitoring, analysis and assessment
- Regular review of regulations, standards, methodology and accreditation requirements
- Design, establishment and maintenance of national monitoring networks
- Development and maintenance of information management systems

Thus the White Paper distinguishes between monitoring ***programmes*** that are designed and coordinated – but not necessarily maintained - nationally, and monitoring ***networks*** that are designed, established ***and maintained*** nationally. Thus the White Paper seems to support the argument that there is some monitoring that DWAF should be doing itself. However it is not prescriptive as to what type of monitoring this should be. It could be a special type of monitoring such as background monitoring – although this would contradict Section **137**.(2) which requires national monitoring to provide a comprehensive picture of the nation's groundwater resources. It could equally well be any type of monitoring that regional and local institutions do not have the capacity to do themselves.

It is perhaps unreasonable to look to clarify such detailed issues in either the NWA or the White Paper. Both make the overall objectives of water resource management clear, and many legal tools are provided by the NWA for achieving these objectives. However the practicalities of implementing these objectives require more detailed, lower-level strategies, and these are sought in the following sections.

4.4 National Water Resources Strategy (DWAF, 2004a)

The National Water Resource Strategy (NWRS) is a legal requirement of the National Water Act. Strategies, objectives, plans, guidelines and procedures are set out that – after consultation with society at large – have the purpose of implementing the aims of the NWA and the Water Services Act of 1997. In other words the NWRS provides information and a framework on how to implement the NWA. Any organ of state or water management institution must give effect to the NWRS when exercising any power or performing any duty in terms of the NWA.

Whether DWAF would be sued should it fail to give effect to some aspect of the strategy is an interesting point. Thompson (2006) is of the opinion that if an institution could not give effect to the NWRS because of legal, operational or financial hurdles, then the situation is regarded as *ultra vires* – beyond one's legal power or capacity. This situation could well arise because, according to Thompson (2006), the NWRS in some cases goes further than what the NWA legally requires, and in those situations there is no legal basis in the NWA for giving effect to the NWRS.

Chapter 3, Part 6 of the NWRS deals with monitoring and information. Some of the points and issues mentioned are:

- reliable, relevant, and up-to-date information is fundamental to proper decision-making.
- information should reflect the integrated nature of water resources, in which quantity and quality, surface and groundwater, are all interrelated.
- DWAF is reviewing, and where necessary revising, all data acquisition, monitoring and information arrangements.
- National systems will be developed so that catchment agencies will be able to take an appropriate level of responsibility. Catchment level information will however remain part of the national system so that information is available at the national level.
- A lot of the existing monitoring systems operated by the Department, but these were developed largely in isolation to each other. Spatial coverage

is incomplete, and problems are experienced with the quality and reliability of the information. Access to data collected by other organisations is often problematic.

- DWAF is addressing monitoring shortcomings by amalgamating current and future monitoring and assessment into a coherent structure comprising:
    - data acquisition
    - data storage, maintenance and dissemination
    - data analysis, information generation and reporting.
- An important part of the monitoring and assessment strategy will be to develop cooperation with other organisations that also operate water-related monitoring and information systems.
- The resources available for monitoring are generally inadequate. These include staff, funding, physical infrastructure, instrumentation and information technology equipment. The proposed expansion of monitoring resources will thus require additional resources.

The above components of the NWRS apply equally to groundwater and surface water. There are some issues, however, that pertain only to groundwater. For example, groundwater was regarded as “private” water under the 1956 Water Act, and as a result was not monitored or assessed to the same extent as surface water. Existing monitoring networks will therefore have to be expanded if the potential of groundwater is to be realised, and for it to be properly integrated with surface water use.

The NWRS also reports that some 150 points are currently monitored continuously for groundwater levels and water quality, while some 1000 points are utilised for monitoring at regular intervals. It is stated that about 460 points need to be monitored continuously for an effective national network.

The intention is to refine and develop the existing system so that an effective integrated monitoring network is created at 3 levels:

1. Expansion of the national monitoring by DWAF in relatively unimpacted areas to provide background and baseline information on groundwater levels and quality.
2. Monitoring of major aquifers by catchment management agencies to determine the effects of human activity. DWAF will continue with these networks until the catchment agencies can take over the responsibility.
3. Local impact monitoring, for example information provided by users in terms of the conditions attached to general authorisations and licenses.

A noteworthy contribution of the NWRS is that it ***prioritizes groundwater monitoring***. This has been done according to the perceived need for compulsory licensing. Although compulsory licensing can be initiated for a variety of reasons, the most compelling is that a geographic area is, or soon likely to be, under "water stress" because the demand for water exceeds its availability. Therefore pilot monitoring networks have been established where compulsory licensing is planned in the near future. In the Olifants-Doorn WMA, a pilot monitoring network has been established in the G30 drainage region, commonly known as the "Sandveld."

4.5 Strategic Framework For National Water Resource Quality Monitoring Programmes

4.5.1 Purpose

The purpose of this document by Grobler and Ntsaba (DWAF, 2004b) is to provide an overarching framework for national water resource quality monitoring programmes, so that these monitoring programmes meet the requirements of the NWA, and are effectively implemented. (Monitoring water resource quality is one of the legal requirements of Chapter 14 of the NWA.) The document states that water resource quality refers to "ALL the physical, chemical, biological, and ecological attributes of the resource." It considers the resource as a whole and therefore includes all the attributes associated with it, and not just the water components.

4.5.2 User-centric monitoring

The document's fundamental point of departure is a "user-centric" approach to monitoring, where "all monitoring should be justified by serving specified information users with the resource quality information they need to perform their management functions." The "data-rich but information-poor syndrome" is identified as one of the biggest problems facing long term monitoring. In other words large volumes of data are collected that find little use in water resources management, while at the same time water resource planners and managers complain about the lack of relevant data to support their needs. The user-centric approach is intended to solve this problem, and defines the purpose of monitoring as: "Delivering the management information about water resource quality that is required by water resource managers, planners and other stakeholders."

While this definition might sound like stating the obvious, it represents a profound shift in the approach to monitoring. Previously monitoring revolved around how much data could be collected and stored using available human and infrastructural resources. With the user-centric approach, however, a third component is added, namely the generation and dissemination of information. Thus the three core monitoring functions are, acceding to this document:

- Data acquisition
- Data management and storage
- Information generation and dissemination

The user-centric approach also recognises that users' information needs will change with time and so monitoring programmes must be periodically reviewed and revised to remain relevant. The three core functions all require an Information Technology (IT) support infrastructure.

4.5.3 Monitoring Programmes

A monitoring ***programme*** is defined as a management mechanism that addresses the three core functions of monitoring in order to deliver a coherent set of information products. It is stressed that ***each programme must have a manager*** who is responsible for and "owns" that particular monitoring programme. The manager would be responsible for the design, maintenance and performance of the monitoring programme, and would typically be someone involved in the information generation and dissemination function, since this is the core function that justifies the existence of the other two functions – data collection, and data storage. The manager must have the necessary authority to make sure all three core monitoring functions are performed satisfactorily.

A ***portfolio*** of monitoring ***programmes*** may be grouped according to the institution that is assuming primary responsibility for them, or according to the type of information products generated, e.g. Compliance monitoring programmes or trend monitoring programmes. Three portfolios of monitoring programmes are envisaged according to the tier of water resource governance:

- National (DWAF national office)
- Regional (DWAF regional offices and Catchment Management Agencies (CMAs))
- Local (local institutions and/or water users, e.g. Water Users Associations (WUAs))

A key requirement is that data collected at different institutional tiers should be consistent and comply with minimum quality standards. It is pointed out that there is a huge scope for the sharing of infrastructure and resources between the 3 tiers, and between different programmes in the same tier.

4.5.4 Monitoring definitions

The point is repeatedly made that monitoring includes all 3 of these functions, and if you are only involved in one function, e.g. data acquisition it is incorrect to say you are monitoring. Not everyone agrees with this. The field acquisition of data on a regular basis has been known as monitoring by a lot of people for a long time (E. van Wyk, pers. comm., 5/5/2005).

My personal viewpoint (based on common usage and dictionary definitions) is that data collection ***with a view to making a possible management intervention*** is what defines monitoring. Without the idea of an intervention firmly embedded in the monitoring process, then it is no longer monitoring but simply data collection. For this reason it is suggested that management intervention/decision-making should also be associated with the 3 core functions mentioned above.

The strategic framework, however, acknowledges that issues such as this will arise, and accepts that different terminologies are in use by different groups in the monitoring field. It sees this as a serious stumbling block in integrating monitoring and making it more efficient and effective. For example different sectors might argue they are monitoring different variables and therefore cannot coordinate their activities when in fact they are monitoring the same thing, but using a different name.

The document does not attempt to heavy-handedly define all the monitoring terms in use, but rather argues that the starting point is for different sectors to define what they mean by the monitoring terms they use, so that the different sectors can at least properly communicate with each other. The document therefore defines what it means by certain monitoring terms, with the hope that others will do the same, and that – in the long term – this will lead to standardisation of monitoring terms.

As already noted, the document defines monitoring as the combination of data collection, data storage, and information dissemination. Thus monitoring creates information. ***Assessment*** is seen as totally separate from monitoring, and is defined as the process that converts information into ***knowledge.***

4.5.5 Generic monitoring design guidelines

Generic Water Resource Quality monitoring design guidelines are presented that hinge on the “user-centric” approach. In this approach the design starts with defining who the primary information users are and what there needs are. From these needs the information generation and dissemination function is designed, followed by the data management and storage function, and finally the data acquisition function. *(Comment: this seems somewhat back to front – there seems little point in designing data storage and information dissemination mechanisms, when you don’t even know what data you will be collecting!)* The generic design process, whatever the geographic scale, or monitoring attributes, can be summarized as follows:

1. **Information Generation and Dissemination**
    - 1.1. **Identify the primary users of the information** – this applies whether the programme is being redesigned or designed for the first time
    - 1.2. **Identify the products required** – what is the purpose of monitoring? How will the information generated actually be used to provide the required answers? These questions need to be answered to avoid the “data rich but information poor syndrome.
    - 1.3. **Design the information generation protocols** – now that the designer knows what information products are to be produced by a programme, the generation of these products has to be designed in detail
2. **Design the monitoring network**
    - 2.1. **Select and finalize the water resource quality attributes**
    - 2.2. **Select the sampling sites**
    - 2.3. **Determine sampling frequency**
3. **Design the operational requirements for the programme** – the goal here is to have all the detailed requirements for implementing each of the core functions documented so clearly that a person not involved in designing the monitoring programme could satisfactorily implement that programme
    - 3.1. **Information generation and dissemination** – what needs to be done, by whom, when, using what software, all needs to be clearly documented
    - 3.2. **Data management and storage** – in most cases existing DWAF systems would be used

3.3. **Data acquisition** – procedures, processes and quality controls need to be clearly documented

4.5.6 Capacity Building

The report describes the severe lack of capacity for resource quality monitoring, and suggests a strategy of capacity-building that is an integral part of designing monitoring programmes rather than an add-on to be considered after the programme has been designed. The specific capacity problems identified were:

- a lack of managerial and incentive measures
- a lack of personnel required for operation and maintenance
- a lack of associated research and development activities
- a lack of coordination among water management institutions and agencies
- a shortage of funds

Capacity building requires not just improving skills and knowledge of individuals, groups and organisations, but encompasses a whole range of efficiency mechanisms to ensure the sustainability of monitoring programmes (Figure 13). This requires new approaches and new ways of thinking from DWAF, for example making use of volunteers for (some) data collection – a trend that has been occurring internationally for some time.

The strategy framework advocates the formation of National Monitoring Council – an independent, high-level body charged with overseeing national monitoring interests. Such a Council would, inter alia:

- develop guidelines and tools to provide technical support
- serve as a forum for the viewpoints of various interest groups
- assume a broad responsibility for promoting the implementation of nation-wide monitoring strategies

- coordinate collaboration between the various institutions involved with monitoring
- coordinate nationwide training efforts

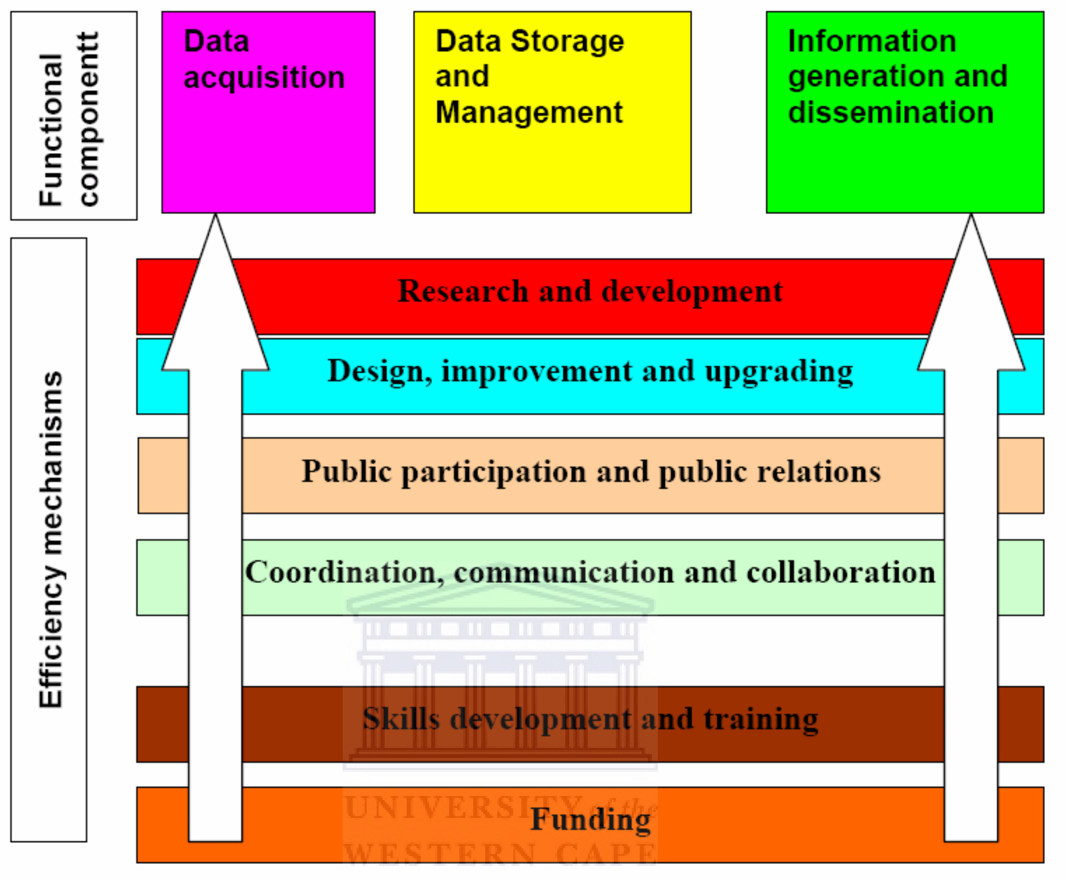


Figure 13: Mechanisms for improving capacity building

4.6 A Five-Year Water Resource Quality Monitoring Plan

This report (DWAF, 2004c) builds on the strategies laid down in the “Strategic Framework for National Water Resource Quality Monitoring Programmes” (DWAF, 2004b). Existing and envisaged monitoring programmes are summarized; objectives to be met within 5 years time are described; and the critical interventions required to meet those objectives are discussed.

The report splits the scope of monitoring into: Hydrological Monitoring, Resource Quality Monitoring, and Water Resources monitoring (Figure 14).

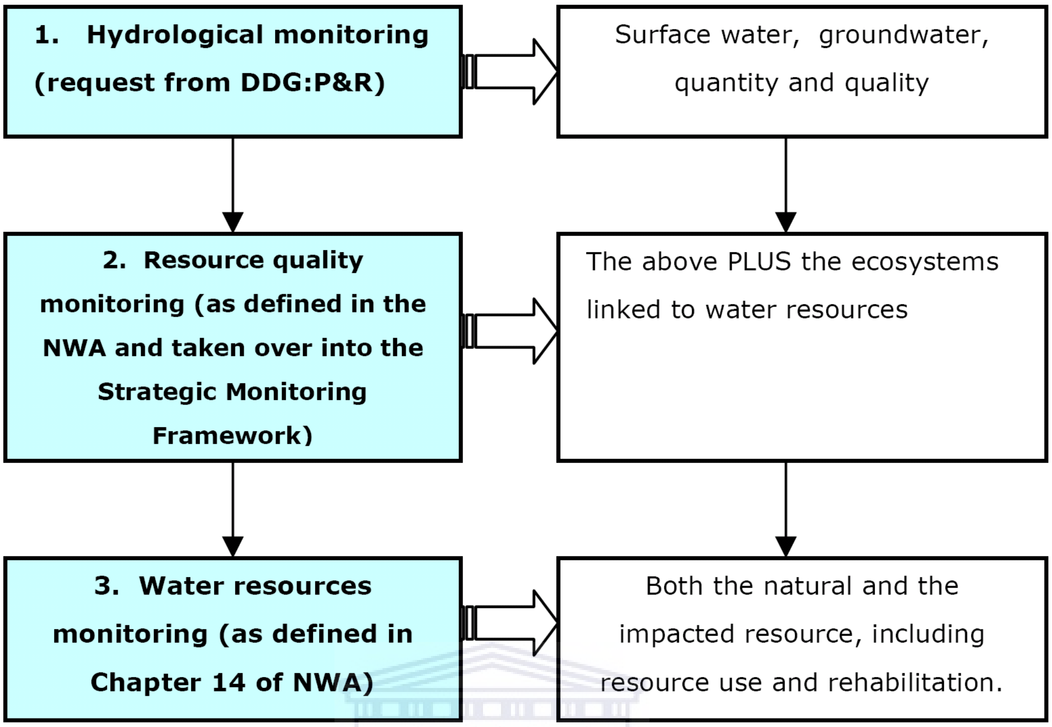


Figure 14: Growth in the scope of monitoring

DWAF currently runs 11 resource quality monitoring programmes, mainly with the objective of establishing status and trends, at an estimated cost of R190 million per annum. These 11 programmes are:

- **National Microbial Monitoring Programme** – Microbes
- **Rivers Health Programme** – Biological Indicators (fish, etc)
- **National Chemical Monitoring Programme** – Water Quality Samples
- **National Eutrophication Monitoring Programme** – Phosphate, Nitrogenous Compounds, Algae, etc
- **National Radioactivity Monitoring Programme** – concentration of radionuclides
- **National Toxicity Monitoring Programme** – toxicants

- **Ecological Reserve Determination and Monitoring** – indices to be developed – programme only exists at a conceptual level
- **Sedimentation** – sedimentation
- **Dam safety** – condition of dam walls
- **Hydrological Monitoring Programme** – surface water levels at gauging stations, flow rates in pipelines, rainfall, evaporations, water quality
- **Geohydrological Monitoring Programme** – mainly water levels, electrical conductivities, chemical character and spring flow

In addition many potential or emerging monitoring programmes have been identified that revolve around assessing and managing impacts to the water resource, many of which will have to be carried out by the users of water themselves. These programmes might include, inter alia, land-use, rural water quality, transboundary programmes, environmental impacts, and ecological changes.

The overall 5-year goal for monitoring is given as "***An effective and efficient national information service***," which entails, amongst other factors:

- User-focus and value for money
- Ease of access for users (one point of entry)
- One version of the truth (no duplication)
- Sharing of data acquisition and management
- Integrated Information systems (as far as realistically possible)
- Appropriate capacity (expanded and multi-skilled capacity)

The document argues that to achieve these objectives in the environment of emerging institutions, growing monitoring needs, and significant bottle-necks, a number of critical interventions are required. The 5-year plan focuses on the interventions required, rather than the implementation of the various monitoring programmes. Thirteen key interventions were identified (Figure 15) with proposed intervention time-scales:

Strategic Intervention	2004/05	2005/06	2006/07	2007/08	2008/09
1. Umbrella programme for monitoring	▨	▨	▨	▨	▨
2. Governance model for monitoring	▨				
3. Integrated monitoring plans for each WMA.	▨	▨	▨	▨	
4. Business plans for individual programmes.	▨	▨			
5. Feasibility study for water use monitoring.	▨				
6. Business plan for Aquatic Ecosystem Health Monitoring.	▨				
7. Guidelines and Standards	▨	▨	▨	▨	▨
8. Development of auditing responsibility.	▨				
9. Scoping of technology for monitoring.		▨	▨		
10. Cost-benefit-analysis for monitoring.		▨			
11. IT systems	▨	▨	▨	▨	▨
12, Capacity-building for integrated monitoring	▨	▨	▨	▨	▨
13. Pilot implementation	▨	▨	▨	▨	

Figure 15: Proposed key monitoring interventions

4.7 Establishment of Departmental Monitor Committees (Groundwater)

4.7.1 Memorandum on groundwater monitoring committees

A memorandum by Van Wyk (2003) builds on the requirements laid down in the NWA, and practices established internationally, to create a framework for the effective and sustainable monitoring of groundwater monitoring.

Four different types of monitoring programmes are outlined using the UN/ECE (2000) approach:

- **Basic/Reference** - to record ambient conditions and long term variations needed for long term water resource management. Trends not (directly) influenced by anthropogenic activities
- **Regulatory -** impacted and/or regional conditions focusing on the management of the functions and uses of that resource. A specific sub-set would be compliance monitoring of authorised water use.
- **Specific Purpose** - this would include monitoring of more research-orientated issues such as the links between surface and groundwater, the role of groundwater in other ecosystems, recharge studies, etc
- **Early Warning and Surveillance** - this type of monitoring addresses point source type impacts such as waste disposal sites

Some of the key points made by the memorandum are:

- The sustainable management of any natural resource requires a reliable set of hydrological data and information
- Groundwater requires a much different approach to monitoring and information generation than surface water disciplines
- Monitoring requires a structured long-term dedicated programme and well managed procedures in order to successfully mange groundwater and the whole of the hydrological cycle
- The NWA makes it very clear that the DWAF Minister has the responsibility to establish and maintain a national monitoring programme to provide the information to achieve the goals of managing a healthy natural water resource in the future.

- Sustainable funding and sustainable institutional commitment to monitoring are key factors in ensuring the long-term success of monitoring
- The need for standardisation
- The need for effective coordination
- The need for a major upgrade and expansion of monitoring

The memorandum identifies the cyclic framework of monitoring with information needs driving the monitoring programme, and funding being the central issue in any monitoring programme or system (Figure 16):

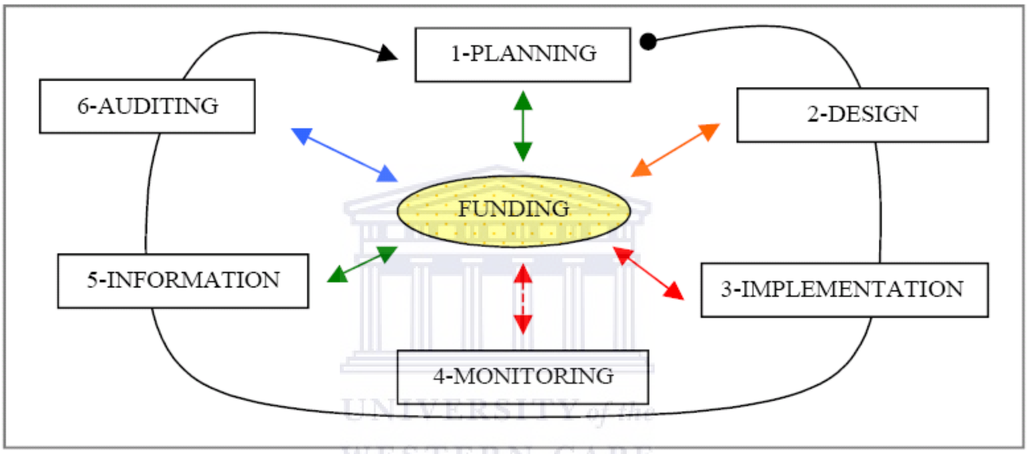


Figure 16: Cyclic framework of monitoring (Van Wyk, 2003)

This memorandum gives a warning that good intentions are not, by themselves, enough because many sophisticated and well-planned monitoring programmes in many countries worldwide have collapsed due to poor support. Problems included:

- Lack of funding
- Lack of clear processes like updating monitoring data on a regular basis
- Lack of continuous interaction between water resource managers and the monitoring groups
- Lack of responsibility for publicising and disseminating the monitoring data

Many of these problems apply to the South African situation as well. To overcome these specific problems, and because of the general issue that all the processes in the monitoring cycle must be properly managed, just as with any other process or procedure, a management structure to achieve these aims, as well as to ensure standardisation and consistency is proposed (Figure 17).

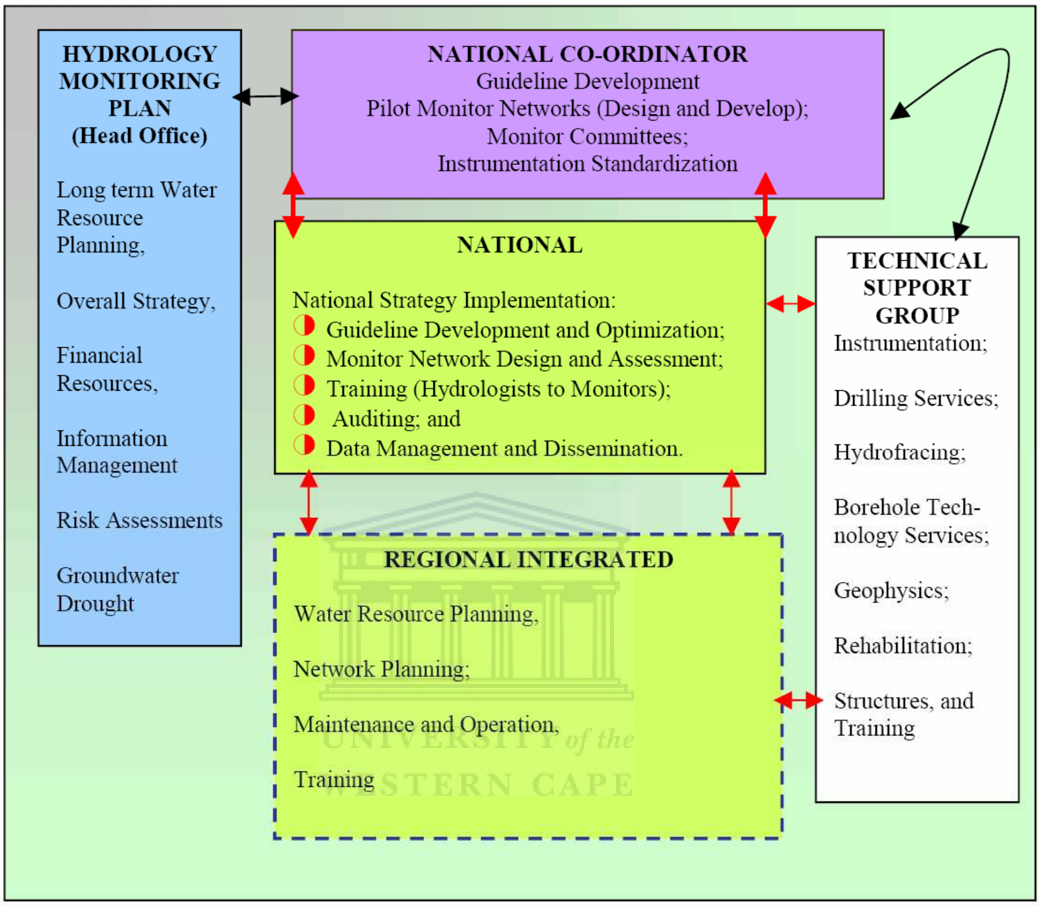


Figure 17: Proposed monitoring management model (Van Wyk, 2003)

This management structure requires three levels of committees with a national co-ordinator providing the link between the national committee and the hydrological committee:

1. **Hydrological Monitoring Committee (HMC)** – this committee is primarily concerned with high level strategies and policies, for example it has objectives to, inter alia, acquire high level championship for monitoring; facilitate the integration of monitoring and regulatory requirements; identify information requirements for sustainable water

development; the creation of a financial support structures that will sustain monitoring.

2. **National Monitoring Committee (NMC)** – the standardisation of monitoring, quality control, and the creation of monitoring guidelines are among the responsibilities of this committee. In other words this committee is tasked with ensuring that the high level polices get implemented in a standardised and coordinated fashion
3. **Regional Integrated Monitoring Committee (RMC)** – while the HMC creates the policies, and the NMC created the standards, the RMC is concerned with the day-to-day practicalities of monitoring, and of making sure that monitoring data is properly archived on DWAF databases.

Thus it can be seen that the National Monitoring Committee forms the link between the strategy formulation of the Hydrological Monitoring Committee, and field operations overseen by the Regional Committees. At present, with so much attention being placed on the internal re-structuring of DWAF, the establishment of monitoring committees is low on momentum (E. van Wyk, pers. comm., 05/05/2005).

4.7.2 Comment on “national” versus “regional” monitoring

The memorandum on groundwater monitoring committees makes a distinction between “national” and “regional” monitoring. In the memorandum national monitoring refers to background or reference monitoring of sites that are not (directly) impacted by human activities, while regional monitoring refers to the monitoring of groundwater systems directly impacted by human activity. The distinction appears to be administrative – national monitoring is seen as the responsibility of the DWAF national (head) office, while regional monitoring is seen as the responsibility of DWAF regional offices.

This distinction does not appear to stem directly from the NWA, which would appear to include both impacted and unimpacted groundwater systems as “national monitoring.” On the other hand, it could be argued that the monitoring of impacted aquifers will devolve to the CMA’s and therefore should be regarded as “regional” monitoring, since this monitoring is the responsibility of DWAF regional offices until CMA’s are formed.

The counter argument is that the monitoring data from CMA's will be forwarded to centralized DWAF databases for national assessments and therefore could also be regarded as national monitoring data. Presumably, a CMA would also require "national" background/reference data in order to discharge its "regional" water management functions effectively.

To further confuse matters, a lot of "national" reference data is in fact collected by DWAF regional offices. And the opposite can also happen – "regional" data of impacted groundwater systems sometimes gets collected by DWAF national/head office staff.

A personal suggestion is that the use of regional versus national is not helpful in this context, and it would be more informative simply to refer to the type of monitoring concerned – i.e. "impacted" and "unimpacted." A further suggestion if that it would be helpful to split monitoring of "impacted" systems into wellfield/site-specific, and aquifer/ general monitoring.

A further suggestion is that "national," "regional" and "local" should refer to the level of management involved rather than a specific type of monitoring. Presumably a broad overview or synthesis of both impacted and unimpacted groundwater systems would be needed for national-scale management of water resources. Whereas local-scale management would require data from individual impacted and unimpacted monitoring points.

It is likely, however, that it will be very difficult to reach consensus on such terminology. Therefore, it probably more important that each worker define what ***they*** mean by national, regional, etc so as to avoid confusion.

5. Recommendations from Previous investigations

5.1 Introduction

The purpose of this section is to review the recommendations, conclusions and general insights regarding groundwater monitoring documented in broad-scale groundwater investigations carried out in the Olifants-Doorn area. Only recent investigations are considered since they are more likely to consider the implications of socio-economic changes in a democratic South Africa.

5.2 Olifants-Doorn Internal Strategic Perspective (DWAF, 2005)

The overall purpose of the Internal Strategic Perspective (ISP) process is to provide DWAF with a framework to manage water resources in a consistent and coherent fashion until this responsibility is developed to Catchment Management Agencies (CMAs). The Olifants-Doorn ISP is a 314-page document that contains a chapter dedicated to monitoring, although many of the groundwater monitoring issues are interwoven with other issues throughout the document. The ISP states that the main objective of regional monitoring is to ***ensure the sustainable use of water resources***. The following is a summary of concerns related to groundwater monitoring that were found at diverse locations in the ISP document:

- Groundwater monitoring is uneven, and inadequate in both frequency and distribution. Monitoring intervals (usually 3 months) are too long and will not capture seasonal events

- Current groundwater monitoring sites are opportunistic rather planned, and there is a very poor coverage according to geological criteria

- Monitoring of springs is inadequate
- Spring-flow data that has been measured by V-notches has not been interpreted
- High altitude precipitation and temperature monitoring is lacking
- Many aquifers supplying towns are stressed, and/or are not properly monitored
- Consultant's data are not routinely integrated with DWAF databases
- The Regional Office does not have adequate capacity to monitor, capture and interpret data
- There is insufficient coordination between groundwater, surface water, and environmental monitoring
- Groundwater quality monitoring to guard against contamination from sea-water intrusion and irrigation return flows is inadequate
- Knowledge of the movement of contaminants through fractured rock is poor

These concerns, along with other issues for all resources – not just groundwater – were the starting point for the following ISP ***monitoring strategy***:

> DWAF must co-ordinate its monitoring efforts with all role-players in the WMA to ensure efficient and effective data collection, capturing and analysis to provide sufficient information for management of the water resource. The WMA strategy must be in line with Regional Office and national strategies which are still being developed.

This ***monitoring strategy*** was then expanded into monitoring ***management actions.*** Again monitoring is treated holistically, although groundwater warrants specific mention in places. The ***management actions*** are best viewed and treated as a complete package and are therefore quoted in full below:

> - Develop a Monitoring and Data Management Plan;
> - Evaluate and interpret groundwater monitoring data and information and integrate the outcome into groundwater management actions;

- Capacity building and development of appropriate monitoring of municipal groundwater and surface water supplies. The water services development plans of local authorities must define their current water requirements and estimates of future water requirements;

- Co-ordinate the groundwater and water quality monitoring and regular information exchange, particularly with respect to the management and monitoring of effluent from wastewater treatment works;

- Initiate a pilot study using advanced technology to measure regional changes in groundwater level rather than borehole-by-borehole measurements based on the principle of appropriate technology in the logistic and social circumstances;

- Select preliminary sites for prioritised groundwater monitoring based on best available information. Integrate the insights and results gained through all relevant studies;

- Establish snow gauges in the high mountains to develop an understanding of the contribution of snowmelt to surface water runoff and groundwater recharge in the Olifants River catchment;

- The National Eutrophication Monitoring Programme should be implemented at Clanwilliam Dam and Bulshoek Weir;

- Clanwilliam Dam water quality information must be communicated to the public during incidents of fish kills.

- Update the priority list of monitoring requirements based on research and the needs assessment;

- Implement improved weather monitoring;

The ISP's first management action is to develop a monitoring and management plan. The ISP provides guidelines on how to compile this plan. Since the guidelines make more sense when viewed in their entirety, they are quoted in full below:

> Guidelines for compiling a WMA Monitoring and Data Management Plan:
>
> - Review or identify all aspects that need to be monitored. Group all monitoring needs into logical systems with common goals according to functional areas, which are then divided further into sub-systems;
>
> - Develop a detailed information requirement and monitoring needs assessment for the various systems, which were grouped by functional areas;
>
> - Identification and motivation of required or additional monitoring points or functions required for the WMA;
>
> - Amalgamation of the identified existing and planned monitoring and assessment systems needs into a coherent and structured monitoring, assessment and information system;
>
> - Review resources required for adequate monitoring of surface and groundwater (and other water-related aspects e.g. rainfall);

- Motivation for the regional share of the national monitoring budget;
- Regularly review and update the WMA monitoring strategy; and feed this back into the regional strategy;
- Initiate and encourage co-operative, collaborative relationships between the Department and other organisations or individuals that have relevant data or operate water-related monitoring, assessment and information systems.
- Development of monitoring programmes in the WMA should take cognisance of existing and developing National Monitoring Programmes e.g. National Eutrophication Monitoring Programme, National Microbiological Monitoring Programme etc.

In addition to these general strategies, management actions, and management plans, the following specific recommendations were also made:

- Consider implementing a system where users are responsible for their own monitoring, and must enter the data on to a database via the Internet. Such self-monitoring programmes will assist in overcoming limited DWAF capacity.
- groundwater modelling of areas under stress is needed, in conjunction with increased monitoring of those areas.
- educate users regarding monitoring methods.
- results of groundwater monitoring need to be disseminated to Water Users. Associations in a comprehensible format. This will encourage cooperation and good water resource management.
- groundwater monitoring in the Lower Olifants River area needs attention.
- an integrated regional monitoring network is needed to increase confidence in water resource understanding, evaluation and regulation.
- groundwater monitoring should focus on waterlevels and electrical conductivity.
- groundwater monitoring must also include abstraction, climate, springs and baseflow.
- dedicated monitoring boreholes are needed away from production wells and wellfields.

- groundwater/surface water interactions and recharge needs to be better understood so that efficient monitoring can be facilitated.

- groundwater monitoring should include interactions with solid waste.

- make all monitoring data available on G.I.S..

- the T.M.G needs to be monitored in its entirety – from mountain recharge to coastal plain discharge.

- it is more important to ensure long monitoring records than increase the number of monitoring sites because many sites will show the same trends.

- monitoring of aquifers and abstraction is needed to improve safe yield estimates. This is the only way safe yield estimates will be improved.

- the hypothesis that recharge to the coastal plain aquifers originates from outside the catchment needs to be investigated by monitoring.

5.3 Other Investigations

5.3.1 Groundwater Resource Directed Measures (GRDM) Assessment of the E10 catchment (Parsons and Wentzel, 2005)

The purpose of this GRDM assessment was basically to test groundwater RDM technologies. RDM is a term used by water resource practicioners to describe the formal setting of management objectives as required by the NWA to protect water and related resources. The management objectives must include setting the Reserve – an amount of water that is required for basic human needs and aquatic ecosystems. Once the RDM management objectives are formally set using the processes described in the NWA they become legally binding on any institution implementing the NWA. Thus a license to abstract water must take into account the RDM management objectives.

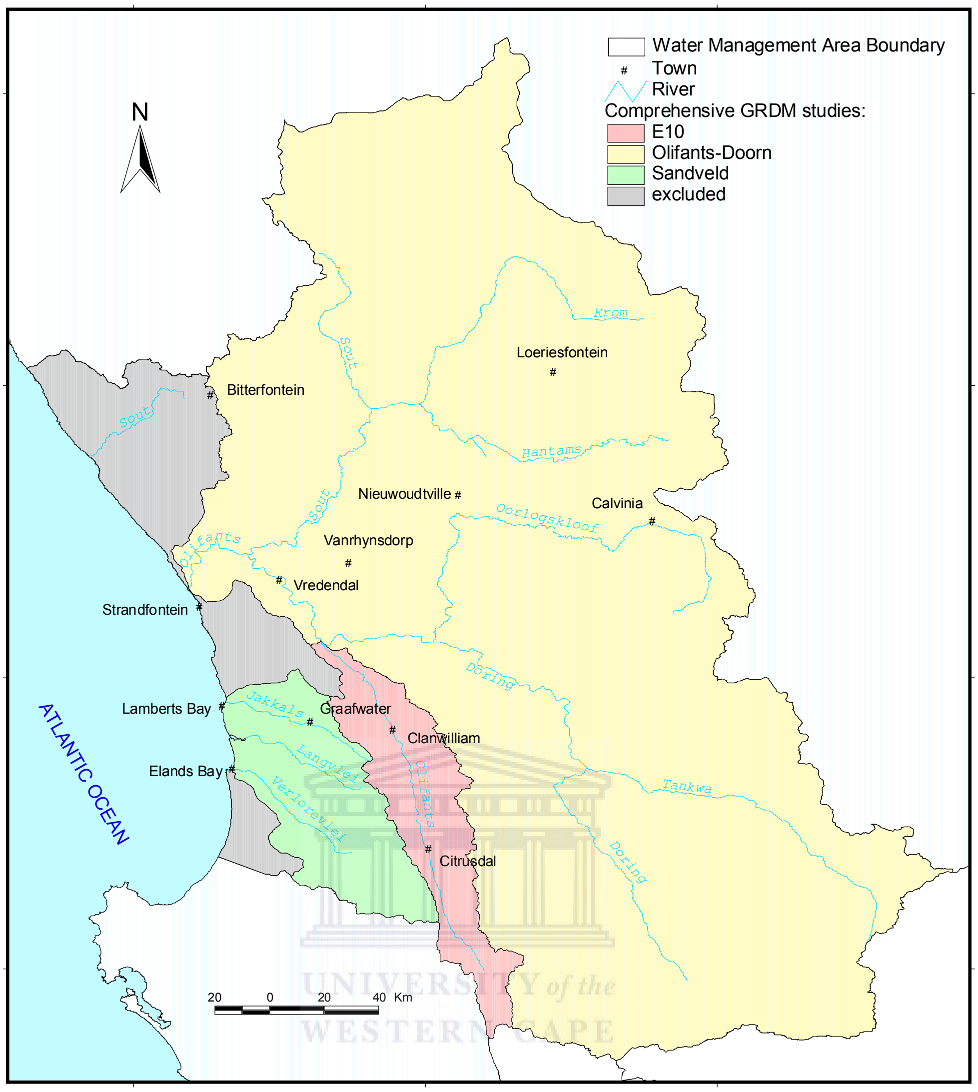


Figure 18: Extent of GRDM study areas

The E10 (tertiary) catchment (Figure 18) was chosen as a pilot study area. The pilot study basically revolved around the determination of a “stress index,” and a consideration of groundwater contribution to baseflow. Stress was equated to estimated groundwater use divided by estimated recharge per quaternary catchment. The E10 area was estimated to be relatively unstressed from a groundwater perspective. The study advocated the use of monitoring when sustainable limits are being approached or exceeded. Useful sustainability indicators were given as:

- abstraction versus recharge or safe yield

- continually declining groundwater levels – sustainable abstraction limits are being exceeded

- deteriorating groundwater quality – suggesting sustainable limits are being exceeded

It was also recommended that the responsible authority establish a groundwater monitoring network in the E10 catchment because of the ever-increasing use of groundwater. Specific monitoring recommendations were that:

- all groundwater users abstracting at more than 1 l/s must monitor waterlevels and abstraction volumes on a weekly basis

- users abstracting at more than 5 l/s must install data loggers set to record waterlevels on a two-hourly basis

Perhaps the most pertinent conclusion reached was that local issues can only really be adequately addressed via local-scale investigations, and that regional-scale investigations are of limited value in this regard, although they do provide a good, introductory overview. This means, for example, that issues such as groundwater-surface water interactions can only sensibly be addressed at the local scale. Although not discussed in the study, the tacit implication would therefore appear to be that such issues, being local of nature, would be difficult to integrate into a regional monitoring programme. In other words a handful of – say – groundwater dependent ecosystem monitoring points, while giving a good indicator of site-specific conditions, could hardly be extrapolated to the region as a whole.

5.3.2 Groundwater Reserve Determination required for the Sandveld (Conrad and Munch, 2006)

Although the title of this project mentions only a Reserve Determination, the project actually encompassed the entire Resource Directed Measures process, of which Reserve Determination is just one component. Thus the terms of reference for this project were to develop Resource Directed Measures for the quaternary catchments G30B-G of the Northern Sandveld (Figure 18). A high-confidence Reserve Determination was required by DWAF because groundwater resources in the area are perceived to be highly stressed, principally as a result of groundwater abstraction for irrigating potatoes. In addition sensitive and important ecosystems in the area are showing varying levels of degradation, and so the linkages with groundwater were investigated by a multi-disciplinary team. The study appears reasonably positive about existing groundwater monitoring in the Sandveld:

> Within the Sandveld study area groundwater level and quality monitoring is absolutely essential. The monitoring that has been carried out to date, provides clear data on the status of groundwater within the study area. The areas of concern are clear highlighted and trends with regard to water levels and water quality are also clearly apparent.

A very site-specific approach to setting the management objectives for the RDM process was used, including – for example – specifying desired waterlevels for certain boreholes. Specific monitoring conclusions and recommendations included:

- borehole monitoring of both groundwater levels and groundwater quality must be continued. A central database must be maintained with this groundwater data and easy access to this database by all role players considered.

- All production boreholes should be registered, licensed, correctly equipped for monitoring purposes and monitored.

- Particularly important monitoring parameters are Electrical Conductivity, nitrate concentrations and at certain sites iron and manganese..

- The DWAF Regional Office, the DWAF Head Office, the Cederberg Municipality and GEOSS are currently involved in groundwater monitoring, with differing objectives, and these monitoring activities need to continue being coordinated by the DWAF Regional Office.

- monitoring must align with the purpose of being able to review the Resource Quality Objectives (RQOs) set for the study area, and must enable the level of compliance associated with the RQOs set for the study area to be determined.

- the optimum interval for DWAF monitoring is every 4 months. It is currently being carried out at varying intervals. This monitoring should include water level measurements and a field measurement of groundwater temperature, pH, EC and dissolved oxygen. Annually, groundwater samples should be collected and analysed for major and minor ions.

- the Klaarfontein, Matroosfontein, Oorwinningsfontein and Janse Kraal springs must continue to be monitored, both in terms of water quality and flow. A survey of all springs in the area should be carried out and other possible monitoring sites established.

- On-going public engagement and education is required for the area. Optimally all groundwater users should be monitoring their groundwater use, both in terms of volumes abstracted, groundwater levels and groundwater quality (Electrical Conductivity).

- The comprehensive geodatabase established for the Sandveld must be continued, and all relevant data measured in the field captured. Annual reviews are required of the geohydrological status of the Sandveld.

5.3.3 Groundwater Reserve Determination Study for the Olifants-Doorn Catchment (Fortuin and Woodford, 2006)

As with the Sandveld “Reserve Determination” study, this investigation also looked at the whole RDM process and not just the Reserve Determination. The study (Figure 18) covers the entire Olifants-Doorn WMA, except for the E10, G30, and F60 tertiary drainage regions. The E10 was covered by Parsons and Wentzel (2005), and most of the G30 was covered by Conrad and Munch (2006). This leaves the F60, G30A, and G30H drainage regions not covered by detailed groundwater RDM studies. Presumably this is because there is a lack of surface water features and a lack of groundwater dependent aquatic ecosystems in these drainage regions, and thus the Reserve Determination process was not considered a worthwhile management tool. If this is the case, it seems to show an unhealthy bias towards surface water issues, and lack of appreciation of the groundwater resources in these drainage regions. These resources could well have benefited from the application of the overall RDM process, even though Reserve Determinations would not have been particularly helpful.

The specific tasks of the Olifants-Doorn Reserve Determination study were to:

- classify each groundwater resource unit in terms of Desired Category and Management Class
- determine the Groundwater Reserve
- set the Resource Quality Objectives (RQOs)

As in the Parsons and Wentzel (2005) study it was concluded that specifying regional-level water resource quality objectives will have limited value, and these need to be set on a site-specific basis, possibly as part of the licensing process. Fortuin and Woodford state that little groundwater monitoring has been done in their study area, and that effective monitoring is needed to ensure sustainability. Useful indicators to monitor were given as:

- abstraction versus recharge or safe yield
- continually declining groundwater levels – sustainable abstraction limits are being exceeded
- deteriorating groundwater quality – suggesting sustainable limits are being exceeded
- climatic variables such as rainfall, temperature, evapotranspiration and snowfall
- hydrologic variables such as baseflow in rivers

The first three indicators are identical to those given by Parsons and Wentzel (2005). General recommendations are also identical: "Because of the ever-growing use of groundwater in the Olifants-Doorn WMA, the responsible authority needs to establish a groundwater monitoring system in the catchment." Identical recommendations to those of Parsons and Wentzel (2005) were also made regarding users monitoring their groundwater resource when yields exceeds 1 l/s, and installing data loggers when yields exceed 5 l/s. As with the Olifants-Doorn ISP (DWAF, 2005), Fortuin and Woodford also want monitoring in place so that the relationship between snowfalls and summer river low flows can be assessed.

5.4 Comments

It difficult to disagree with most of the individual points made in DWAF's ISP. Taken in isolation most of them seem accurate and eminently sensible, except for the observations regarding the lack of monitoring of wellfields for town supply. Most of these wellfields are in fact monitored by the applicable District Municipality, with the monitoring data analysed by consultants employed by that District Municipality.

A concern with the ISP is the lack of clarity regarding how exactly all the various ideas will lead to the groundwater resources being used more sustainably. It is not made clear how – for example – snowcover monitoring would lead to the resources being used more sustainably? The linkages between the advocated monitoring and the hoped-for improvements in sustainable use need to be spelled out.

However, the biggest concern with the ISP's strategies, management actions and management plans regarding monitoring, and in general, is that they appear to ***seriously underestimate the human resource capacity of DWAF's regional office to implement these ideas***. The ISP has provided just about every management tool necessary to ensure the equitable and sustainable use of groundwater ***except for the human resources*** to utilize these tools. The current reality is that a solitary official will have to implement all of these ideas, along with all their other duties, when it would seem that managing groundwater monitoring requires a whole team of people, and a vast budget for monitoring equipment as well.

Although this is, perhaps, doing an injustice to the ISP, since it acknowledges that it is "quite impossible to immediately launch into, and achieve, all that is required," and that a phased approach to implementation will be required. The ISP also acknowledges that funds and capacity are real constraints. However it is perhaps instructive to note that of the 14 chapters of the ISP only one chapter – the last – is devoted to implementation strategies, and therefore addresses capacity issues. It would therefore seem that issues such as human capacity are not at the forefront of water resource planners' minds. It could be argued that the capacity to implement the management strategies is as important as the water management strategies themselves. Without the necessary capacity all the resource strategies are no more than wishful thinking. It could further be argued that capacity issues need to be addressed from the outset, and built into the overall planning, instead of being tacked on as an afterthought when all the nice water resource strategies have been formulated.

As far as groundwater monitoring is concerned the ISP wants a lot more groundwater monitoring, yet DWAF struggles to handle its existing monitoring obligations. It would have been helpful for strategies to have been formulated or proposed to resolve the gap between capacity and monitoring requirements. It would have been helpful for some kind of guidance as to prioritisation – what monitoring is the most useful in guiding sustainable groundwater use?

The monitoring recommendations of Parsons and Wentzel (2005) and those of a Fortuin and Woodford (2006) are identical, suggesting liberal use of the word-processing "cut and paste tool." Indeed, there is much duplication in the general studies outlined in this chapter, with hardly any of it properly acknowledged or referenced. There is also much use of data from DWAF's 1:500 000 mapping programme, and from DWAF's Groundwater Resource Assessment 2 (GRA2) programme, with hardly any references to these sources, suggesting that DWAF is being invoiced for the re-hashing of its own data and own work.

The sustainability indicators as used by Parsons and Wentzel (2005) and Fortuin and Woodford (2006) do not appear to be based on sound science. Take declining waterlevels for example – they do not always indicate unsustainability as the authors imply, but could merely indicate water being taken from aquifer storage prior to a new equilibrium being established. Natural recharge has been shown to be a poor sustainability indicator (discussed in detail in chapter 6) so it is debatable whether groundwater use (even it could be accurately determined, which is seldom the case) divided by recharge will be any more reliable.

And while getting the users to do their own monitoring when yields exceed a certain rate sounds fine in principle, in practice this requires someone with a groundwater background to inspect, interpret and generally add meaning to the monitoring data. Especially when data loggers are utilised. It requires specialized knowledge to download the data and do whatever editing is necessary to obtain meaningful information. All of this requires funding. It would have been more helpful if this had been acknowledged and likely sources of funding identified – is the groundwater user expected to pay for these services, or is national government (DWAF) expected to be responsible, or must funding wait until the Olifants-Doorn Catchment Management Agency is formed and funding might be available via water use/management charges?

The monitoring recommendations made by Conrad and Munch seem sensible and practical, possibly because they have plenty of "hands-on" experience of the area, and are already involved in monitoring there.

5.5 Conclusions

Among the various workers doing recent, broad-scale investigations in the Olifants-Doorn WMA, there seems to be consensus that:

- The purpose of DWAF regional-level groundwater monitoring is to ensure sustainability
- Regional-level groundwater monitoring needs to be expanded
- It is the responsibility of groundwater users to do their own monitoring
- More use needs to be made of modern technology – data loggers, the internet, for example

However there appears to be very little consensus on how these goals will be met, and where the human capacity or funding is going to come from. Although, to be fair, these issues were not part of the investigations' terms of reference. There was also little consensus on frequency of monitoring – one study recommended four-monthly for regional monitoring. Other studies were of the opinion that DWAF's existing three-monthly monitoring was completely inadequate, and that monitoring must be done much more frequently, including monitoring by data loggers.

It is disconcerting how much un-acknowledged, un-referenced, non-original material is used in reports prepared by consultants for DWAF.

6. Sustainability

6.1 Introduction

The issue of sustainability has permeated the preceding chapters. In chapter 2 it was noted that a large part of the economy of the Olifants-Doorn WMA is dependant on the sustainability of its water resources. In chapter 3 sustainability was identified as the main objective of groundwater monitoring. In chapter 4 it is described how sustainability and equity are the cornerstones of the NWA. And in chapter 5 various regional monitoring proposals were outlined that all had sustainability as their ultimate objective, even though there were major differences of opinion on what monitoring was needed to achieve that objective.

Sustainability is therefore a key issue in this study, and so it was decided to investigate the concept in more detail. The investigation into sustainability culminated in a paper entitled "Sustainable groundwater use, the capture principle, and adaptive management" (Seward et al., 2006). The rest of this chapter contains a version of that paper with some adaptations so as to better support the aims of this thesis.

6.2 Historical background

The classic definition of sustainable development in general, given by the Brundtland Commission (World Commission on Environment and Development, 1987), is "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs.*"

Similar concerns for the present and the future in the water resources management field are given by Loucks (2000) who states that: "*Water resource systems that are managed to satisfy the changing demands put on them, now and on into the future, without system degradation, can be called "sustainable.""* The demands placed on the resource include the objectives of society, as well as ecological, environmental, and hydrological integrity (Loucks and Gladwell, 1999).

These definitions of environmental sustainability only really began to emerge in the past few decades. However, sustainability's forerunner – safe yield – has been used in groundwater for nearly a century. In the "journey from safe yield to sustainability" Alley and Leake (2004) trace the first definition of safe yield back to Lee (1915) who defines safe yield as the quantity of water that be pumped "regularly and permanently without dangerous depletion of the storage reserve."

In the ensuing decades issues outside the purely hydrological definition of Lee were added, leading to Todd (1959) defining the safe yield of a groundwater basin as "the amount of water that can be withdrawn from it annually without producing an undesired effect." According to Todd (1959) four factors are usually considered when determining safe yield:

1. **Water Supply.** This can either be the recharge to the basin, or the rate of movement of groundwater through the basin, whichever is the lesser

2. **Economics.** Excessive pumping may lower water levels to such an extent that the use of groundwater is no longer economic. In such cases the safe yield hinges on specifying maximum borehole yields or minimum water levels

3. **Water Quality.** The intended use of the water defines the minimum acceptable groundwater quality, which in turn places limits on pumpage that could draw in water of a poorer quality

4. **Water Rights.** Legal restrictions may place a limit on safe yield

The concept of safe yield has been severely criticized, chiefly because of its misinterpretation by people unfamiliar with groundwater that it implies a fixed, underground water supply (Todd, 1959). Sophocleous (1997) criticized ongoing use of safe yield concept in water-management policies, pointing out that safe yield is not a sustainable yield because discharges to streams, springs and seeps are ignored, and because it ignores the sustainability of the system – maximising safe yield by drying up streams, for example, ignores the fact that streams are more than just containers of usable water. Other concerns with safe yield are its vagueness, and it dependence on the particular location of wells (Alley and Leake, 2004).

Lohman (1972) addresses some of these concerns when he defines safe yield as “The amount of ground water one can withdraw without getting into trouble,” with “trouble” meaning “anything under the sun.” Lohman admits that his definition might be regarded as facetious, but argues that it makes more sense than many definitions. To avoid “getting into trouble” Lohman advocates **not putting a number on safe yield before or in the early stages of development**. Even Lohman’s definition of safe yield falls short of the current usage of sustainability, however, because whatever rate of groundwater abstraction is chosen, including zero, it will almost always cause “trouble” with someone, somewhere, across the broad spectrum of users, conservationists, and other concerned parties.

Freeze and Cherry (1979) also tackle the shortcomings of safe yield by arguing there is no single, fixed, safe yield, but rather an optimal or compromise yield. They suggest that, from an optimization viewpoint, “groundwater has value only by virtue of its use, and the *optimal yield* must be determined by the selection of the optimal groundwater management scheme from a set of possible alternatives. The optimal scheme is the one that best meets a set of economic and/or social objectives associated with the uses to which the water is to be put.” This approach of selecting the optimal yield could be of great value in current, more environmentally-aware, stakeholder driven, management approaches, provided use is not limited to consumptive use, but also includes non-consumptive use. Whether this yield should be regarded as an **optimal** yield, though, is open to debate. A **compromise** yield seems a much more accurate definition.

Two opposing chains of thought can be seen to pervade the attempts to define safe yield and sustainability. On the one hand is the body of opinion that recognizes a purely hydrological definition is of little relevance to the real world where subjective, value-laden principles determine sustainability. On the other hand is the body of opinion that is frustrated with all the ambiguities of sustainability, and wants to return to a definition that can be determined solely by science.

With both safe-yield and sustainability being such vague, ambiguous, value-laden concepts, and because both are concerned about avoiding detrimental, long-term effects, it might be inferred that the terms **safe yield** and **sustainability** are interchangeable. However, **safe yield** is generally limited to the factors of supply, economics, water quality, and legal rights, as defined by Todd (1959), while **sustainability** is generally taken as a much broader concept, revolving around the complex interdependence of the resource, the environment, and society (Alley and Leake, 2004). Concerns about the long-term effects of groundwater abstraction on lakes, springs, rivers, wetlands, and estuaries would be seen as sustainability rather than safe yield issues (Alley and Leake, 2004).

6.3 Why recharge does not determine sustainability

In this chapter recharge is defined in the broad sense, following the approach of Beekman and Xu (2003), as an addition of water to a groundwater system. Thus this definition (Beekman and Xu, 2003) includes water reaching the aquifer system via:

- Downward flow through the unsaturated zone
- Lateral and/or vertical flow from other aquifer systems
- Induced flow from nearby surface bodies as a result of groundwater abstraction
- Borehole injection or man-made infiltration points

Discharge is then simply the reverse of recharge, i.e. water leaving an aquifer system, via natural or artificial means. Groundwater abstraction would be one form of discharge.

Todd’s (1959) definition of sustainability clearly indicates that recharge does not equate to recharge, since the amount of water flowing through a basin, economics, water quality issues, and legal rights could all result in a safe/sustainable yield that is less than the recharge.

Seymour and Seward (1996) in their “Harvest Potential” map of South Africa describe three broad scenarios for the interrelationship between recharge, aquifer storage, and “sustainable use”:

- Size of the aquifer considerably exceeds average annual recharge – average annual recharge can be “safely” abstracted
- Size of the aquifer is insufficient to bridge abstraction during droughts – sustainability is therefore limited by storage not recharge

- Size of the aquifer cannot absorb all the recharge in the wet season to bridge abstraction during the dry season – storage not recharge is the limiting factor to sustainability

The term "Harvest Potential" coined by Seymour (Seymour and Seward, 1996) is basically the same as Lee's (1915) definition of safe yield, i.e. it is a purely hydrological concept, does not take socio-economic or environmental issues into account, and thus gives a maximum rather than a sustainable yield. However, even at this level of simplification, the consequence is that in roughly three quarters of South Africa, sustainability is determined by the second two factors listed above, i.e. **storage**, rather than recharge.

Another example of sustainability being less than average annual recharge is given by Freeze and Cherry (1979). Gradual increases in abstraction in a hypothetical groundwater basin were studied using the aid of a complete saturated-unsaturated zone model. The exercise showed that if pumping rates were allowed to increase indefinitely an **unstable** state would eventually be reached. At this point of instability rainfall no longer provides the same percentage of recharge because evapotranspiration from the unsaturated zone now takes more of the infiltrated precipitation before it has chance to percolate down to the aquifer. To prevent the chances of a basin from becoming unstable, production must be limited to significantly less than the average annual recharge.

The above examples have shown that even when using groundwater-basin scale and other "broad-brush" approaches, there are serious problems with simply assuming that sustainability equals recharge. In many cases sustainability will be considerably less than average annual recharge, and so the generalization that sustainability equals recharge is incorrect.

However, when the detailed geohydrological conditions of aquifers and aquifer systems within a given basin are studied, even more serious shortcomings with the "sustainability-equals-recharge" concept emerge because "capture" has to be taken account.

6.4 Capture

Under pre-development conditions, a groundwater system is in long-term equilibrium, and recharge equals discharge (Alley et al., 1999), as shown schematically in Fig. 1:

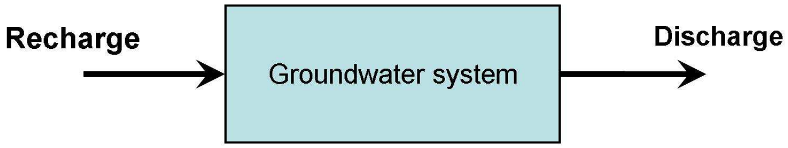


Figure 19: Pre-development Water Budget (Alley et al., 1999)

Discharge could be to streams, lakes, wetlands, saltwater bodies, springs, or via evapotranspiration, while recharge could be from precipitation percolating through the unsaturated to the water table, or from losing streams, lakes and wetlands (Alley et al., 1999).

When groundwater is withdrawn by pumping (Fig. 2), this abstraction must be supplied by (Theis, 1940):

- More water entering the system (increased recharge)
- Less water leaving the system (reduced recharge)
- Removal of water in storage
- Some combination of the above 3 factors

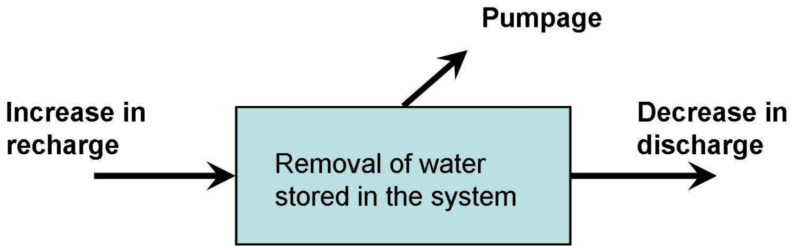


Figure 20: Water Budget showing changes brought about by abstraction (Alley et al., 1999)

The sum of the increase in recharge and decrease in discharge is referred to as **capture** (Lohman et al, 1972). The logical consequences of the principle of capture when an aquifer system is subjected to development are (Alley et al., 1999):

- Some groundwater must be removed from storage before the system can be brought into equilibrium
- The time that is required to bring a hydrological system into equilibrium depends on the rate at which discharge can be captured
- The rate at which discharge can be captured is a function of the characteristics of the aquifer system and the placement of pumping wells – spacing, distance to recharge zones, distance to discharge zones
- Equilibrium is reached only when pumping is balanced by capture. In many circumstances, the dynamics of the ground-water system are such that long periods of time are necessary before even an approximate equilibrium can be reached

Perhaps the most important implication of the capture principle is, however, that **virgin recharge does NOT determine sustainability.** Sustainability is determined by what, if any, induced recharge can be created, and by how much of the existing discharges – natural or otherwise – can be taken up by new abstraction. This is partly a technical problem – positioning boreholes and selecting pumping rates so as to grab as much of the existing losses as possible, and partly a political problem – what reduction in existing discharges is permissible.

Capture – and the implications for sustainability and recharge – can also be described by a simple water balance equation (Lohman, 1972):

$$R + \Delta R = D + \Delta D + Q + S\ \Delta h/\Delta t \qquad (1)$$

where:

R = virgin recharge

ΔR = change in recharge caused by pumping

D = virgin discharge

ΔD = change in discharge caused by pumping

Q = rate of abstraction

$S\ \Delta h/\Delta t$ = rate of change of storage

Devlin and Sophocleous (2005) argue that much of the blame for the misconception that "sustainability = natural recharge" lies in the lack of appreciation of the "capture equation", and the use of a water balance equation that it too simple, i.e.

$$R = D + Q \tag{2}$$

From an examination of the "capture equation" (Eq. (1)) it is clear that in the natural state, the long-term conditions would be: R=D and $S\ \Delta h/\Delta t = 0$. Thus if abstraction is introduced, and if equilibrium conditions are eventually obtained, then it follows that:

$$\Delta R = \Delta D + Q, \text{ or:}$$

$$Q = \Delta R - \Delta D$$

Thus these equations confirm that it is the **change** in recharge, if any, brought about **after** pumping has been initiated that contributes to determining sustainable abstraction. The virgin recharge prior to abstraction does **not** determine sustainable abstraction. The relationship between reduced storage, decreased outflow, and increased inflow, as a result of abstraction is shown graphically in Figure 21:

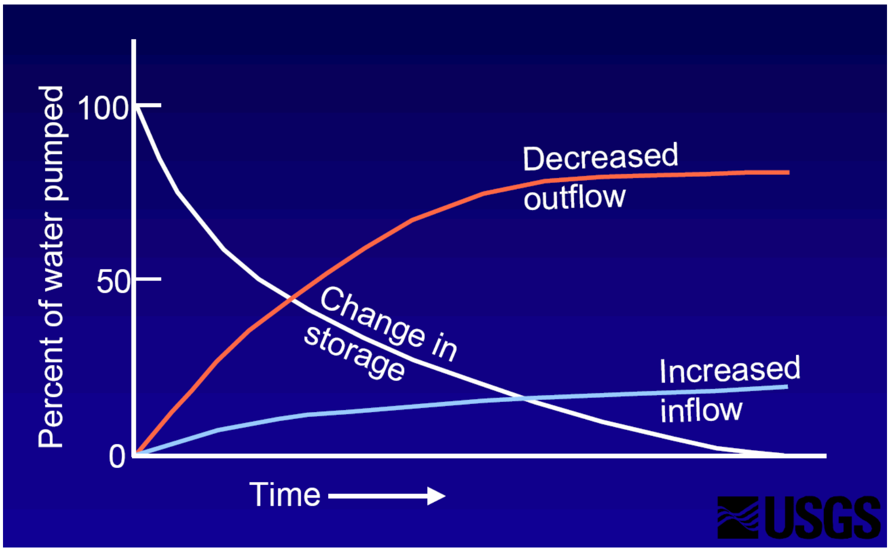


Figure 21: Effects of pumping on inflow, outflow and storage (Leake, 2001)

6.4 Borehole sustainability versus groundwater basin sustainability

Abstraction from a borehole cannot be "sustainable" or "unsustainable" in isolation, but is dependent on other groundwater users, natural discharges, natural and induced recharge, storage and transmissivity, and on what changes to the system are acceptable to the parties concerned. The concept of "sustainable borehole yield" is therefore untenable.

On the other hand, the concept of "sustainable basin yield" is equally untenable if it is made without reference to "production facilities" such as boreholes and springs, since the basin yield can only become a practical reality when accessed via these "production facilities.

Devlin and Sophocleous (2005) use the capture principle to distinguish between borehole and basin sustainability. Boreholes in a basin can be sustainable if their yields do not exceed what can be practically captured. In other words borehole sustainability is dependent on how much throughflow can be intercepted and by how much recharge can be induced by the position, depth, spacing, and yield of boreholes. Thus borehole yield is dependent on what capture of groundwater is **possible**. Basin yield adds to this by including how much capture of groundwater is **permissible.** For example it may be possible to sustain pumping at a given rate, yet the consequences for the environment, or for other water users might not be permissible.

The differences between borehole (or "production facility") sustainability and groundwater basin sustainability lead to important consequences:

- The "true" or "practical" basin yield is actually the sum of all the individual abstraction points where capture is permissible, possible, and sustainable. Doing some form of water balance exercise to arrive at a generalised "basin yield" without taking production facilities into account is virtually meaningless.

- There is no single, fixed "safe" or "sustainable" yield for a groundwater basin, but rather a range of "permissible" yields dependent on how the groundwater is accessed – i.e. well-field properties – and social, economic, and ecological concerns.

This might seem like an irritating and unsatisfactory muddle of basin, well-field, and societal concerns to those who wish to use science to come up with a single “sustainable yield” for a groundwater basin or unit or whatever area is being addressed. For example Kalf and Woolley (2005) state that: “*Aspects of groundwater management factors affecting production facility discharge should be regarded as constraints on the way the physical system is used, and not as part of the physical concept.”* But the realities are that a groundwater basin yield cannot be accessed without abstraction points, just as runoff to a surface basin cannot be accessed without dams and other works. Therefore, in reply to Kalf and Woolley (2005) who insist that “the system” and “human intervention” must be handled separately, it needs to be pointed out that this can’t be done – once human manipulation takes place **it becomes part of the system** and therefore cannot be treated separately! Without a “production facility” yield there is no “sustainable basin yield” – just natural recharge and discharge.

In other words, while it may be possible to determine a single figure for average **natural** recharge and discharge, as soon the system is manipulated, to abstract groundwater for example, a host of factors need to be considered in how the system is manipulated, with the consequence that there is a range of yields describing how much can be got out of the system.

This is not to say science cannot be used in the process – for each option of how to exploit the resource, science can be used to predict, or anticipate the likely outcomes of a given intervention. The mistake is to assume that science only predicts one outcome.

6.5 Sustainable groundwater development and the National Water Act

Sustainability is a key principle in South Africa’s National Water Act (NWA) of 1998: “*Recognising that the ultimate aim of water resource management is to achieve the sustainable use of water for the benefit of all users*” (Republic of South Africa, 1998). The other key principle is equity: *“Sustainability and equity are identified as central guiding principles in the protection, use, development, conservation, management and control of water resources.”* Although sustainability is not defined, it is used in the contexts of sustainable water use, ecological sustainability, and institutional sustainability, which presumably give some clues as to its intended meaning.

One avenue for addressing sustainability in the NWA is by the setting of resource quality objectives (RQOs) as part of an overall classification process. Once the classification process is complete, the RQOs become binding on water-use authorisations. The RQOs can include, inter alia:

- The Reserve
- In-stream flow
- Water levels
- Water quality
- Aquatic biota
- Any other characteristic

The Reserve is defined as the quantity and quality of water required to: (1) satisfy basic human needs, and (2) protect aquatic ecosystems in order to secure **ecologically sustainable <u>development and use</u>** of the relevant water resource (emphasis added – this factor is often overlooked).

RQOs might imply limitations on the use of groundwater so as to avoid undesirable reductions to base flow, reductions in spring flow, damage to aquatic ecosystems, damage to terrestrial ecosystems, ingress of saline groundwater, ingress of sea water, and so on. It seems clear that avoiding or limiting these negative scenarios will be largely determined by the capture principle – limiting the interception of discharges and of non-groundwater bodies, to what is deemed acceptable. A water balance approach – determining recharge minus abstraction – is of little value in unravelling the dynamics of the situation, and thus will give a misleading impression regarding sustainability.

Water use may be regulated by:

- Licensing
- General authorisations
- Permissible continuation of existing lawful use

- Schedule 1 use – this includes reasonable domestic use, non-commercial small gardens, and stock water (excluding feedlots)

The thinking is that Schedule 1 use would have no or minimal impacts, use controlled by general authorisations (Figure 22) would have low risk of impacts, and that a licence is only needed when there is a high risk of impacts. In other words the licensing process is only used when there is a risk that sustainability limits might be exceeded.

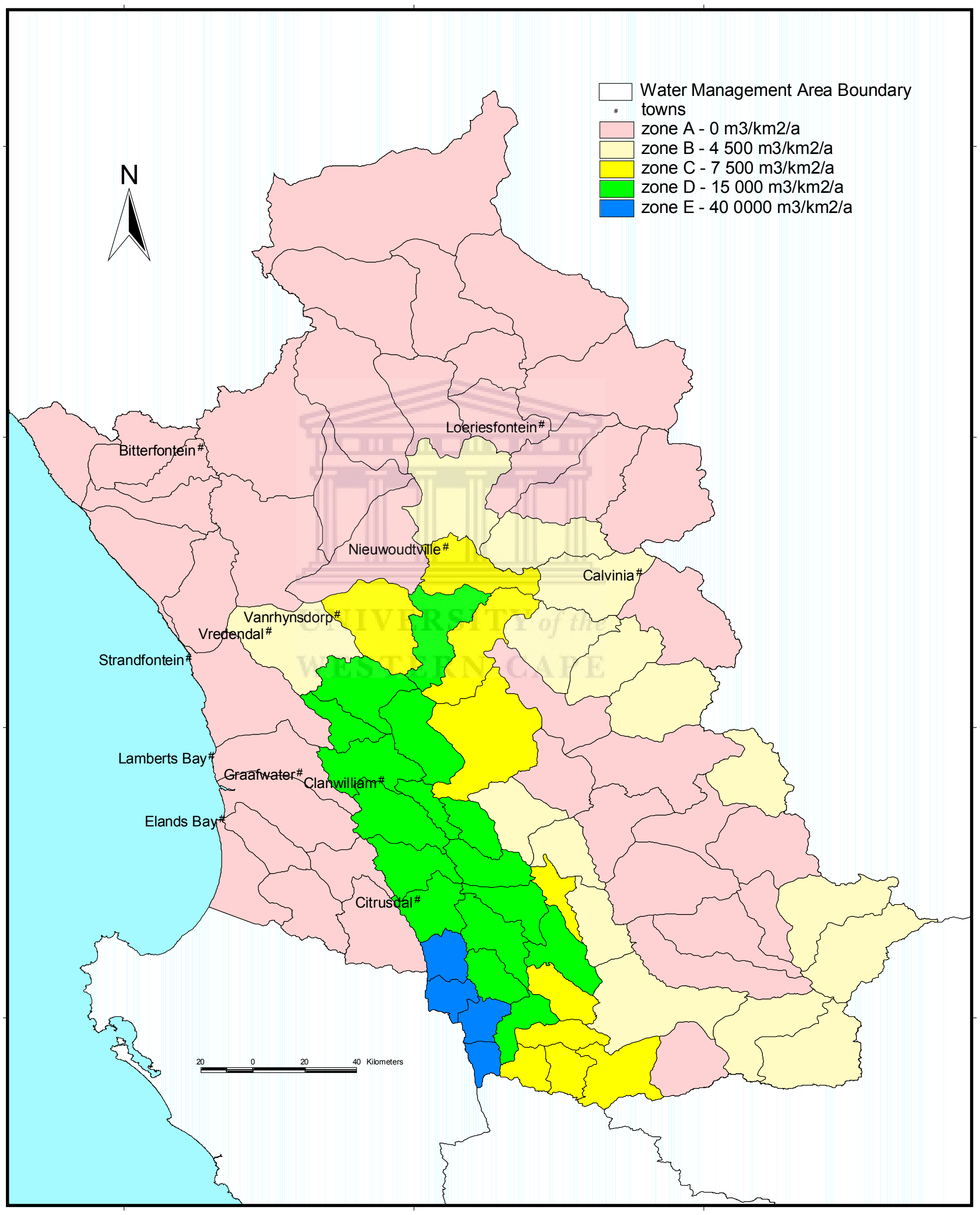


Figure 22: General Authorisation zones for the Olifants-Doorn WMA

Where the General Authorisation zone is set at 0, it means that only "Schedule 1" use is permissible without a license. It can be seen that this zoning condition applies to large parts of the Olifants-Doorn WMA. This includes areas with a low exploitation potential in the north and south-east, as well as the area to the south-west that has a higher exploitation potential but is also deemed to a certain amount of stress because of high groundwater abstraction rates relative to the exploitation potential.

To return to the procedure for the setting of RQOs - if the classification process has been completed, then the RQOs are binding on water use authorisations. However, if the classification is not completed, then the only thing that is required before a licence can be issued is preliminary Reserve determination.

For each licence application, the DWAF national office makes an estimate of the recharge, and the Reserve. The ecological component of the groundwater Reserve is normally based on estimates of in-stream flow requirements (IFR) needed to maintain aquatic ecosystems, using the assumption that maintenance low-flow component of IFR can be met by base flow from groundwater. Thus the amount of groundwater set aside to maintain the ecological Reserve boils down to a certain percentage of base flow. This means that in the parts of the country where there is no base flow, no ecological Reserve based on groundwater can be determined, and the Reserve concept is of little value as a groundwater management tool. It also needs to be pointed out that the Reserve cannot be used to protect terrestrial ecosystems, since it only applies to aquatic ecosystems.

Once the Reserve has been determined, the relevant DWAF regional office then has to decide whether to recommend, or not recommend, the licence application, and what conditions to apply, based on recharge, the Reserve, the quantity required by the licence, existing use, and any other relevant factors. At this stage the normal procedure (Xu et al., 2003) is to "do a water balance." The Reserve, and existing lawful use, are subtracted from recharge. If anything is left over, and this quantity exceeds the licence application, it is assumed there is enough water available, and the licence application is normally recommended.

Conceptually, this approach is wrong. The increased abstraction by the licensee has to be met by the capture of **something.** This could be:

- Reduction in groundwater's contribution to base flow
- Drying-up of springs

- Reduced yields from boreholes on adjacent properties
- Terrestrial vegetation dependent on groundwater dying
- Capture of water from surface bodies such as rivers flowing through the area
- Capture of groundwater from adjacent aquifers and aquifer systems

However, it is exceedingly difficult to predict these effects, and so ongoing monitoring and modelling is advocated (Xu et al., 2003).

6.6 Adaptive management

Predicting the dynamic response of an aquifer system to development, and what can be "captured" will be exceedingly difficult. Aquifer systems are complex, difficult to understand, and the consequences of human intervention are difficult to predict, especially in the case of fractured rock aquifers, which cover 98% of South Africa. It is suggested that the way forward is to accept the complex, difficult-to-predict characteristics of aquifer systems, and build management strategies around those characteristics, rather than deny those characteristics and labour under the misapprehension that just a few more years of research will enable the sustainability of the system to be determined to the nearest decimal place.

Such an approach can be found in adaptive management, which Maimone (2004) considers to be the only viable approach in dealing with the uncertainties in knowledge and the variability of societal attitudes towards groundwater resources. In order to further evaluate the applicability of adaptive management to the sustainable use of groundwater, the key characteristics of adaptive management will be outlined, and then compared with the practicalities of groundwater management.

The basic premise of adaptive management is that "if human understanding of nature is imperfect, then human interactions with nature (e.g. management actions) should be experimental" (Prato, 2003).

Some of the key characteristics of adaptive management are (Rogers et al., 2000):

- An approach to deal with uncertainty from an imperfect knowledge base
- Involves a well planned iterative process of selecting and testing hypotheses of responses to management interventions – scenarios and goals are regarded as hypotheses and estimates to be tested and challenged as the knowledge base grows

Concepts of adaptive management are regarded as a "work in progress" (National Research Council, 2004), but the following elements have been identified in theories and practice:

- Management objectives are regularly revisited and accordingly revised – while differences between and among stakeholders and scientists are unavoidable, there must be some agreement on some objectives to hold the whole process together.
- Models of the systems being managed – an explicit baseline understanding of and assumptions about the system being managed are a necessary foundation for learning. These models can be conceptual and need not necessarily be mathematical.
- A range of management choices – existing data rarely point to a single best management policy and a broad range of alternatives need to be considered.
- Monitoring and evaluation of outcomes – monitoring is needed to evaluate the outcome of the management option chosen, to better understand the system, and to provide a basis for better decision making.
- Mechanisms for incorporating learning into future decisions – there needs to be a formal way for knowledge gained to be integrated into the decision-making framework, and the political will to act upon that knowledge. Management organisations need to be flexible enough to adjust to the new information.

- A collaborative structure for stakeholder participation and learning - *involving* give and take, active learning, involving stakeholders in goal-setting, and some level of agreement among participants.

Some of the elements in adaptive management have been in used in groundwater development in South Africa for decades. It is generally accepted by experienced hydrogeologists that it is virtually impossible to predict the development potential of groundwater with any degree of confidence, and that the best way to understand and quantify groundwater is via using it. In other words the "*Learning by Doing*" approach (Walters and Hollings, 1990). While some have seen this as a negative aspect of groundwater, and have been unwilling to develop it because the uncertainties are too high, others have seen this as a positive aspect, since groundwater can be developed in a phased, incremental manner. Hypotheses about a resource are tested using an exploration programme. If the hypotheses are proved reasonable then pumping tests are done. Pilot-scale abstraction might then be implemented. If this is successful, then larger-scale development might be considered, and so on.

In the past, however, there has usually been little or no stakeholder participation in "adaptive management" of groundwater, and ecological considerations were not normally addressed from the outset. This has now changed, with NWA of 1998 requiring and enabling public participation, and resource quality protection. Ludwig et al. (1993) suggest the following tactics for effective management of natural resources, including an appropriate balance between scientists and stakeholders:

- Include human motivation and responses as part of the system to be studied and managed

- Act before scientific consensus is achieved. Calls for additional research may delay tactics

- Rely on scientists to recognize problems but not to remedy them. Scientists and their judgements are subject to political pressure

- Distrust claims of sustainability. Past resource exploitation has seldom been sustainable, so claims for the future should be viewed with suspicion, especially where sustainability is to be achieved in an unspecified way.

- Hedge - avoid irretrievable commitments, assume that what you're about to do might be a mistake
- Avoid the delusion that more research will, by itself, solve sustainability issues
- Favour actions that are informative, probe and experiment
- Favour actions that are reversible

6.7 The need for adaptive management

Adaptive management is not “trial and error,” but rather a formal, yet flexible, approach for hypothesis testing, with stakeholder participation, when our knowledge base is imperfect and outcomes uncertain. Stakeholder participation is one of the key requirements of the NWA – a requirement that can be met with adaptive management. Therefore, the key tests for deciding whether adaptive management is needed in the groundwater sector are whether the knowledge base is imperfect, and whether the outcomes are uncertain. To assess these issues, some salient factors in the sustainable management of groundwater are discussed:

Our knowledge of groundwater use is imperfect. For example, in the G30 drainage region, where only groundwater is used for irrigation, and where crop circles irrigated by centre pivots are clearly visible by remote sensing, Conrad and Munch (2006) describe estimates of water use that ranged from 9,5 million m^3/year to 53,9 million m^3/year. Where groundwater and surface water are used conjunctively for irrigation, it will be even harder to come up with an exact figure for groundwater use.

Our knowledge of the regional status of groundwater resources is imperfect. For example, in the Olifants-Doorn Water Management Area (WMA) intensive, although far from optimal, regional monitoring only takes place in the G30 drainage region. In the remaining 11 tertiary drainage regions in this WMA, regional monitoring is either very sparse or non-existent.

Our knowledge of groundwater parameters is highly imperfect, especially our ability to up-scale determinations at given point to an entire groundwater basin. This is to be expected given the heterogenetic nature of much of South Africa's aquifers. Zhang et al. (2005) assign an average conductivity of 4,5 – 10 m/day for the Sandveld intergranular aquifers, and describe how calculations of the conductivity of the Table Mountain Group range from 1,99 m/day to 1,99x10^{-3} m/day. With such ranges in input parameters being typical, an output parameter predicting the future with any degree of precision is clearly not feasible. At a more qualitive level, Beekman and Xu (2003) note how the temporal variability of rainfall in semi-arid climates as well as the spatial variability in soil characteristics, topography, vegetation and land use, all add to the variability in recharge estimations. Yearly recharge estimates for the Sandveld have ranged from 12% to less than 1% (Conrad et al., 2004). Such variability in parameters and their estimation does not lend itself to predicting future outcomes with certainty.

Our ability to predict the impacts of groundwater abstraction on surface water and ecological systems are highly imperfect. This compounds the uncertainty of future predictions:

- Large uncertainties exist with respect to the nature of groundwater-surface water interactions (Sophocleous, 2002).

- The link between groundwater and ecology is poorly understood, making it very difficult to make even educated guesses as to the likely impacts of groundwater use (Hunt and Wilcox, 2003; Hancock et al., 2005).

- Our knowledge of the environmental impacts of groundwater use is imperfect. Nation-wide ecological monitoring it is at a very embryonic stage.

Our ability to predict future outcomes is highly imperfect. Some form of groundwater model is usually considered to be the best tool to process all the complex factors involved so that future outcomes can be predicted (Anderson and Woessner, 1991). Yet the post audits discussed by Anderson and Woessner (1991) showed that in all of the cases the model did not accurately predict the future. Bredehoeft (2003) has echoed these thoughts, observing that many models have not provided good predictions. The causes for the poor predictions were identified as: the range of parameters was much larger than included in the model; incorrect choice of conceptual model; and because what took place in the real system was not an anticipated scenario. Anderson and Woessner (1991) advocate that a suite of scenarios should be modelled rather than a single scenario, while Bredehoeft

(2003) states the rule-of-thumb that models can only predict the future with reasonable confidence for a period equal to the period of history match. The practical implications of these observations are that there are very few areas in South Africa with sufficient data to be able to use groundwater models to make reasonable predictions. Lack of medium to long-term monitoring data is the rule, not the exception, and so it can be argued that it will be virtually impossible to make any reasonable future predictions regarding the sustainability of groundwater use in most parts of South Africa.

Monitoring data are often not diagnostic. This compounds our difficulties in assessing current processes and making reasonable prediction. *"Water levels alone are ambiguous and cannot be relied upon to determine whether a system is sustainable or not"* (Kalf and Woolley, 2005). For example declining waterlevels may indicate that a resource is being over-abstracted and will eventually be depleted. Or they may indicate that water is being taken from storage in the short term, as a precursor to equilibrium conditions being established. An example provided by Kalf and Woolley in Figure ? shows that water level trends at short times do NOT allow trends at long times to be predicted – the lower line is virtually stable at short times, but descends dramatically at long times, while the upper line shows the greatest waterlevel drops at short times, but stabilizes at long times.

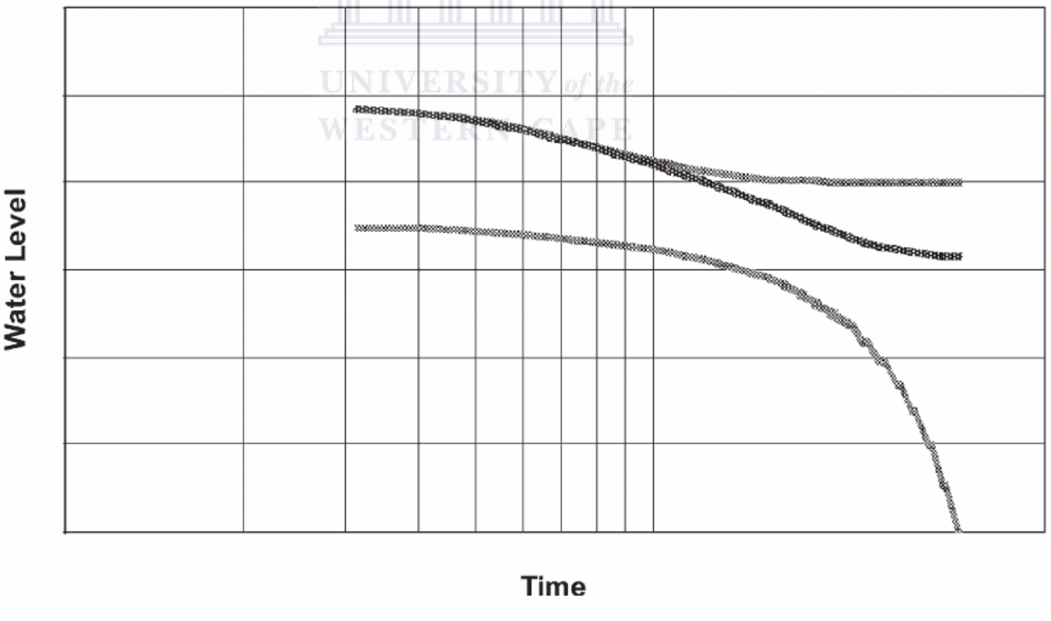


Figure 23: Examples of ambiguous water level responses (Kalf and Woolley, 2005)

This issue of non-uniqueness is also encountered in groundwater modelling, where more than one set of modelled parameters can be used to give an equally good match to the observed data (Bredehoeft, 2003). With more than one set of parameters to predict the future, it is clear that more than one outcome can be predicted.

These examples and issues clearly suggest that our groundwater, and groundwater-related, knowledge base is imperfect, and our ability to predict outcomes is highly uncertain. Thus the conditions have been identified where the application of adaptive management would be either beneficial or even necessary.

6.8 Implications for monitoring

If it is accepted that the capture principle and adaptive management are either useful, or necessary, additions to the methodologies used in ensuring the sustainable use of groundwater, then there are practical implications for monitoring. These implications include:

- In addition to monitoring the status of the groundwater resource (e.g. using groundwater levels and groundwater chemistry) the impacts of using that resource must also be monitored (e.g. springflows, wetland health). Particular emphasis needs to be placed on monitoring potential impacts that are deemed unacceptable.

- A conceptual model, or hypothesis, needs to formulated describing the groundwater system, and the likely impacts of additional abstraction, especially with respect to reduced discharges.

- Monitoring must also be geared to testing the conceptual model.

- Identifying which conceptual model is to be investigated must be done in consultation with all the stakeholders.

- A constant awareness of the potential ambiguity of monitoring data is needed. The same set of observed data can be consistent with several different conceptual or mathematical models. Groundwater scientists therefore need to be especially beware of making bold, unsubstantiated claims that the monitoring data “prove” a particular hypothesis or model is correct.

6.9 Concluding remarks

A range of “sustainable yields” is possible for any given situation, dependent on how intervention takes place, and what is deemed acceptable (or at least permissible). It is therefore open to debate whether “sustainable yield” is the best term to use, since it appears to suggest that there is a single, fixed yield that can be determined. A more accurate and descriptive term is needed. “Optimal yield” or “preferred yield” or “allowed sustainability” are some preliminary suggestions.

The role of scientists should be to identify a range of sustainability options – each with a probable consequence – while it would the managers’ and stakeholders’ role to ***select a preferred option***. Scientists would then monitor the outcomes of that option and revise the sustainability scenarios as needs be.

With large uncertainties in the knowledge of the systems to be developed, large uncertainties in the likely outcomes of development, and a wide spectrum of societal attitudes towards development, an adaptive management or “learning by doing” approach is required. Such an approach need not be at odds with the NWA.

Innovative approaches to monitoring are required that help build a clearer model of the system being developed, and test the model selected under an adaptive management approach.

7. Status of Regional Groundwater Monitoring in the Olifants-Doorn WMA

7.1 Introduction

In this chapter DWAF Regional Monitoring in the Olifants-Doorn WMA is described. The description revolves around data capture, data storage, and information dissemination. These are the three components of monitoring according to Grobler and Ntsaba (DWAF, 2004b). From the literature review it will be recalled that there are other definitions of monitoring – some narrower, such as just the physical collection of data, and some broader, where the evaluation of the information and its use in decision-making are also included. Grobler and Ntsaba's classification of monitoring is used here, not because it is seen as more correct than the others, but simply because the monitoring taking place is largely limited to the monitoring processes as defined by them, namely data capture, data storage, and data dissemination.

7.2 Data collection

7.2.1 Location and type of monitoring points

According to an inventory made of DWAF monitoring in the WMAs overseen by the DWAF Bellville office, there are 282 monitoring points in the Olifants-Doorn WMA (Figure 24). This inventory was made in 2005 and could already be slightly out of data since groundwater monitoring is a dynamic process and subject to ongoing changes. These monitoring points comprise 259 boreholes, 15 springs, 7 rainfall stations, and 1 weather station. The concentration of monitoring boreholes in the south-west quadrant corresponds with an area where groundwater is used intensively for potato irrigation.

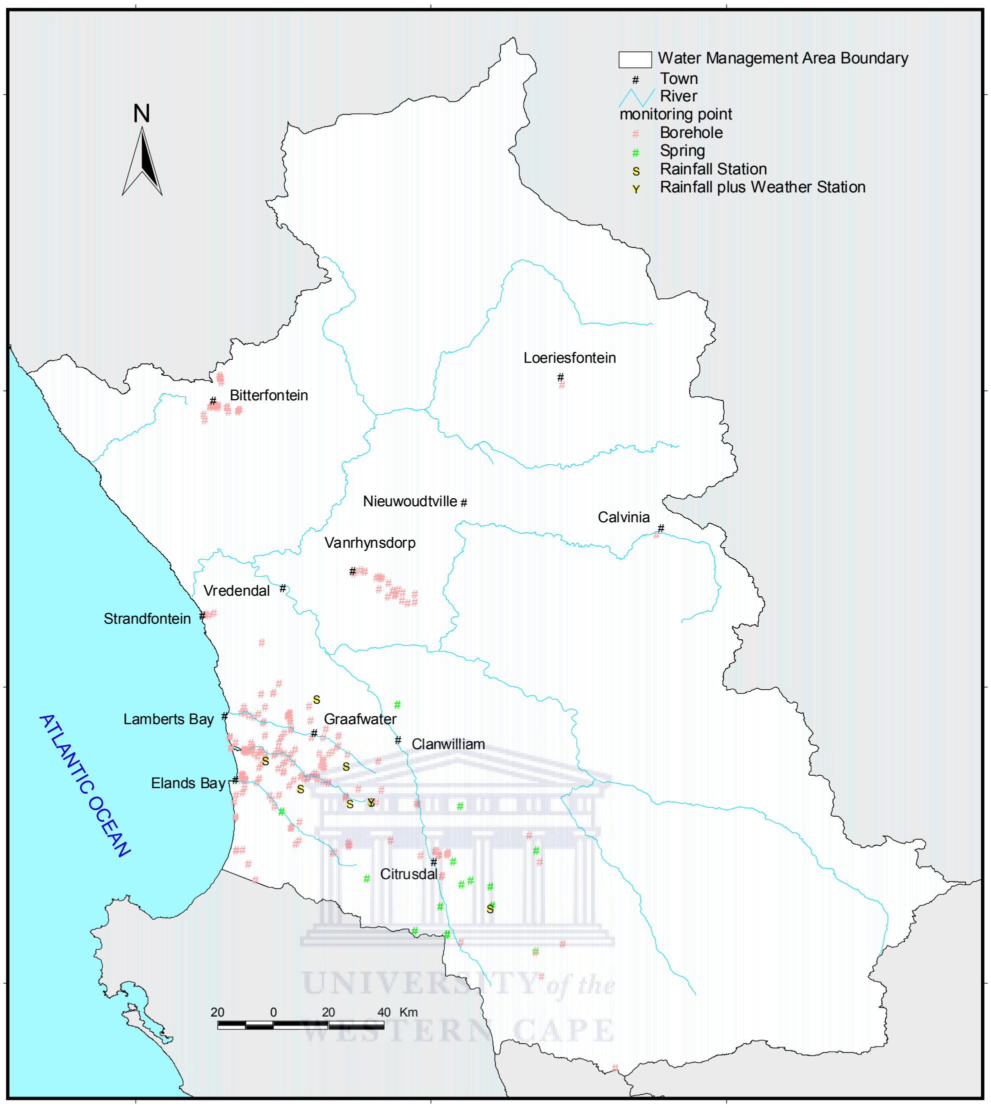


Figure 24: Location of regional monitoring points

7.2.2 Installed Monitoring Equipment

This refers to equipment that is a (semi-)permanent fixture at the monitoring site. It includes equipment specifically installed as a part of the monitoring programme such as data loggers and v-notches. It also includes equipment installed by the owner or user for their purposes – such as a pump for water supply, that is utilised by the monitoring programme to take, for example, water quality samples. Figure 25 gives a breakdown of the installed monitoring fixtures.

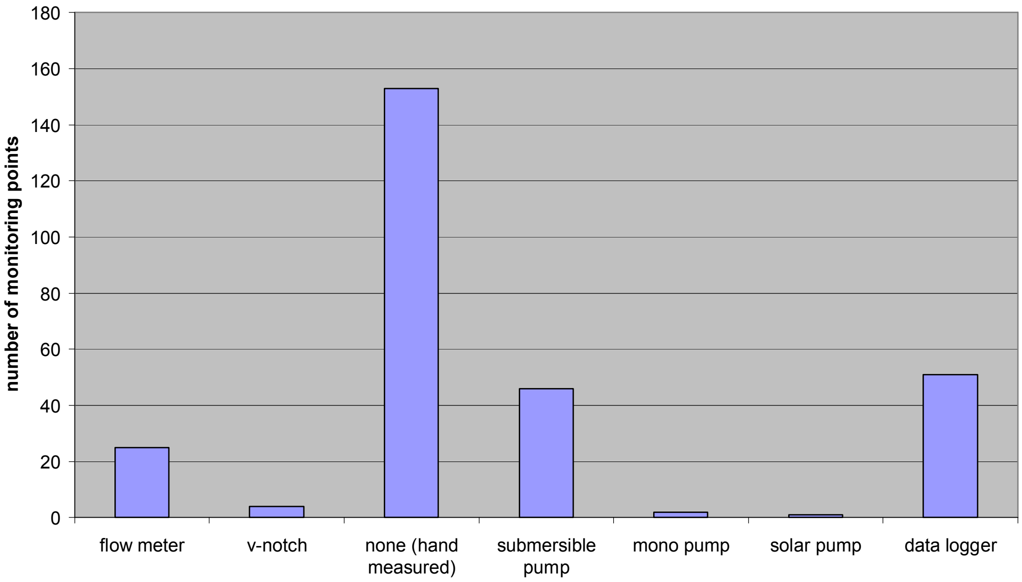


Figure 25: Installed monitoring fixtures

The designation “none (hand measured)” usually refers to an open borehole where waterlevels are measured by hand using a dipmeter, but could also refer to, inter alia, an artesian borehole or spring where the yield is measured by a container and stopwatch. It could also refer to a spring with no installed equipment where a water quality sample is taken.

7.2.3 Monitoring institution

Of the 282 monitoring points, the data are collected by DWAF for 179 of these points, by GEOSS (consultants) for 30 points, and by various municipalities for the remaining 73 points (Figure 26). GEOSS is employed by Potatoes South Africa to collect and analyse monitoring data on their behalf. Figure 27 shows the geographic areas covered by the various data collection agencies.

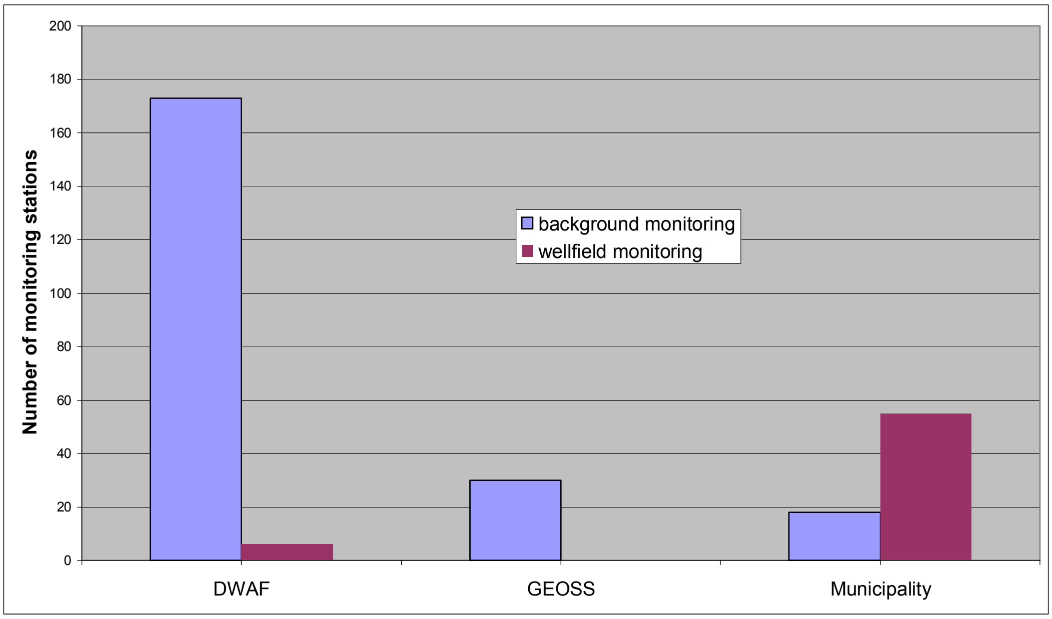


Figure 26: Institution responsible for monitoring data collection

7.2.4 Monitoring Classification

Monitoring, for the purposes of this chapter, has been classified as either “wellfield” or “background.” Background monitoring is here taken to include monitoring of aquifer systems where human influences are potentially discernible, but are outside of the obvious effects of a cone of depression, as well as the monitoring of systems where no direct, local effects are expected. This definition, as with many of the definitions adopted in this thesis, is utilised for pragmatic reasons, rather than out of “correctness” or any desire to see it more universally used. In this instance any further subdivision of “background monitoring” is not attempted for the pragmatic reason that this would be so subjective in most cases as to be virtually meaningless.

From Figure 26 it can be seen that both DWAF and GEOSS are predominately concerned with background monitoring, and – as would be expected – municipal monitoring is mainly concerned with wellfield monitoring.

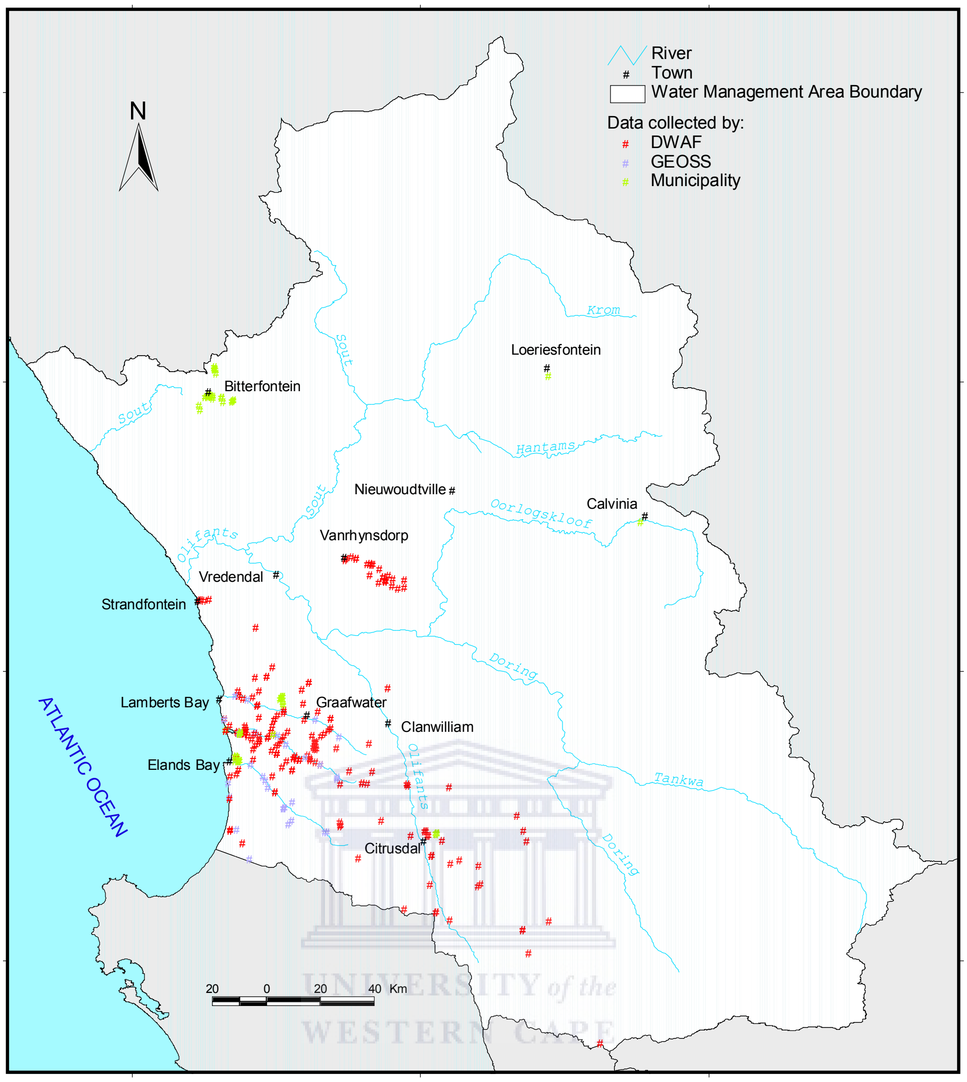


Figure 27: Location of monitoring points versus data collection institution

7.2.5 Monitoring purpose

The overall purpose of the groundwater monitoring programmes in the Olifants-Doorn is not well documented, especially in the case of the monitoring physically performed by DWAF itself. It seems fair to summarize the purpose of Municipal wellfield management as the sustainable and/or optimal use of the wellfields concerned. The GEOSS monitoring programme collects data that can be used to establish the status of the groundwater resources that are used for irrigating potatoes and hence be used to guide the sustainable use of those resources.

A lot of the monitoring physically carried out by DWAF is opportunistic (DWAF, 2005), and appears to be an add-on to various investigations. Many investigations have been carried out to learn more about the intergranular aquifers in the area and to learn more about recharge to, storage in, and movement through, various aquifer systems (Umvoto, 2000);(Nel, 2005). Some exploration and hydrocensus boreholes were then adopted as monitoring boreholes, presumably to further the objectives of the investigation in question, but these monitoring objectives have generally not been formally documented, and each subsequent researcher or worker is left to unearth or guess the monitoring objectives as best they can.

For example monitoring in the mountainous areas in the vicinity of Citrusdal is presumably in response to the recommendations of Umvoto (2000) for a spring-flow monitoring network to assist in the modelling of seasonal recharge in that area, although this is not explicitly documented.

While Nel (2005) clearly states that: “Water level monitoring in the rivers and wetlands should be used to indicate the sustainability of the current and future abstraction” in the investigation of the Langvlei catchment, these objectives are not formally documented in any monitoring programme, making it far from clear which points are being monitored to support this objective.

However, taken from a broad perspective, it is possibly fair to summarize DWAF monitoring, as being concerned with the sustainable use of groundwater resources. But the specific linkages as to how DWAF monitoring at any given point will facilitate sustainable use are far from clear.

7.2.6 Monitoring measurements

Figure 28 shows the types of measurements made by the various institutions involved. (In some cases more than one type of measurement is made at a monitoring point, and so the monitoring point will be plotted more than once). It can be seen that waterlevels are by far the dominant monitoring attribute, with waterlevels and ECs monitored by all institutions. The Municipalities also monitor volumes of groundwater abstracted, while DWAF also does some monitoring of spring and borehole discharge yields as well as some rainfall and weather monitoring.

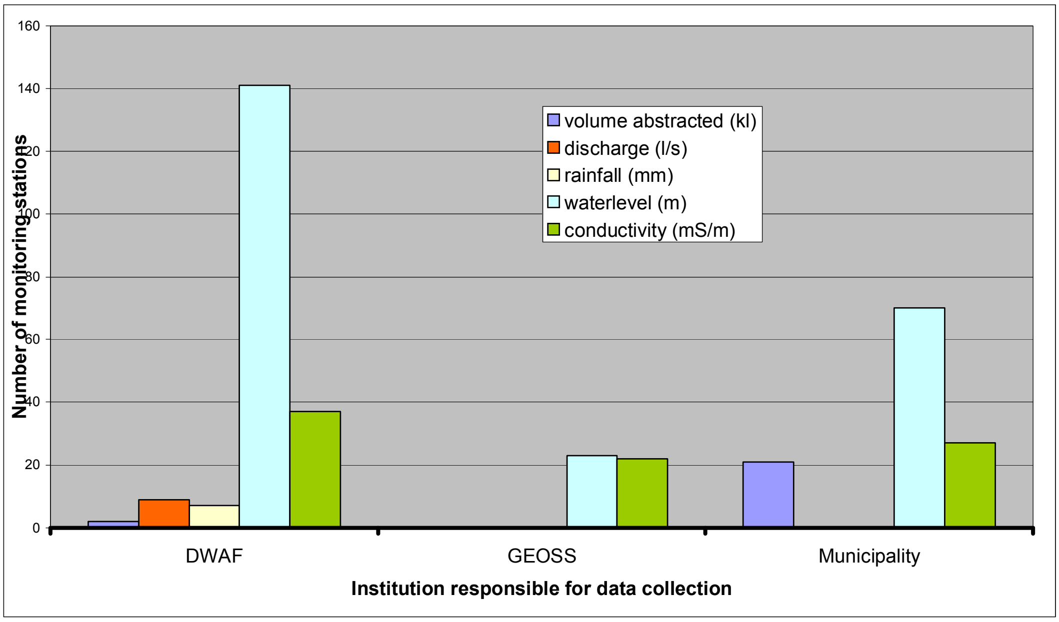


Figure 28: Parameters monitored

7.2.7 Monitoring Frequency

The data collection that DWAF is responsible for carrying out is scheduled to occur at intervals of three months, except for national water quality sampling points that are sampled every six months. The GEOSS monitoring round is normally carried out annually. Monitoring by the municipalities is typically carried out every 1-4 weeks.

Table 3 shows the actual monitoring rounds completed by DWAF. It can be seen regular monitoring at three-monthly intervals was achieved in 2003, but thereafter monitoring has become more erratic. At the beginning of 2003 the number of DWAF points was slightly more than 50. It is currently 179. It would therefore appear that DWAF has the resources to monitor 50 or so monitoring points every 3 months, but that it struggles with the current numbers. It is therefore suggested that DWAF monitoring of 100 monitoring points or less might be a reasonable target to be monitored regularly within its resource capability.

Table 3: DWAF monitoring rounds completed in 2003-2006

	2003	2004	2005	2006
January				
February	√	√	√	√
March				
April				
May	√	√		
June				
July				√
August	√			
September				
October				
November	√	√	√	?
December				

√ = DWAF monitoring round completed

7.2.8 Quality Control

Quality control, including the verification of data is not a formal part of the data collection process. Some informal quality control does take place however, most commonly as the data-collector taking data from the previous monitoring round with him, so that current measurements can be cross-checked. Measurements that seem inconsistent with the previous round are repeated.

7.3 Data Storage

7.3.1 Data Entry

Several databases are involved in the storage of monitoring data. Up until the end of 2004 the broad pattern of monitoring data storage was for data from data loggers to be captured on Hydstra by the DWAF national office in Pretoria, and measurements made by hand (waterlevels, ECs, etc) to be stored on the National Groundwater Database (NGDB). The NGDB data were entered on to the database in either Pretoria or Bellville. The exception was water quality samples that were analysed by DWAF's labs at Roodeplaat near Pretoria, and then entered on the Water Management System (WMS) database.

At this time much of the data physically collected by DWAF was forwarded to GEOSS who collated the data with their monitoring data and data collected by the Cederberg Municipality, and then forwarded the collated data to DWAF, Pretoria, for entry on to the NGDB.

For most of 2005 the above system broke down and very little Olifants-Doorn monitoring data was stored on DWAF centralized databases. The exception was water quality analyses, which were still entered on the WMS. The reason for the breakdown appears to have been confusion regarding DWAF's phased changeover from the NGDB to the National Groundwater Archive. From the beginning of 2005 no monitoring data was accepted for entry on to the NGDB and all monitoring data was supposed to be entered on Hydstra. Data were dutifully processed and sent to DWAF, Pretoria by DWAF, Bellville personnel and GEOSS for entry on to Hydstra. However, no Olifants-Doorn data actually got entered on to Hydstra because of bottlenecks in entering the entire country's groundwater monitoring data on to Hydstra in Pretoria.

The confusion appears to have arisen out of the fact that Bellville data-typists were unaware that the monitoring data had not been entered on to Hydstra in Pretoria, and because the other staff involved with the Olifants-Doorn monitoring data were - in addition to being unaware that the data had not yet reached Hydstra – were even unaware that there had been any changes in the data entry process.

As from 2006, an attempt has been made to rectify this situation by entering all Olifants-Doorn monitoring data locally (DWAF, Bellville) when it has to be entered on to Hydstra. (Water quality samples are still analysed, and the data entered on to WMS, in Pretoria.)

7.3.2 Quality Control

There is no formal quality control of the monitoring data entered onto central databases. Actually this is not quite correct – the database will not accept data if it is not in the correct format, but this is not quality control in the sense of picking up erroneous data.

Some form of informal quality does take place, however, either in the form of spot-checks, or by information users querying information that does not appear to make sense. Below are some examples of quality control problems that I stumbled over while trying to get hold of data to assess the groundwater situation in the Olifants-Doorn:

Figure 29 shows how data from an Ott data logger looked before it was entered into Hydstra, while Figure 30 shows the same data after it was entered into Hydstra.

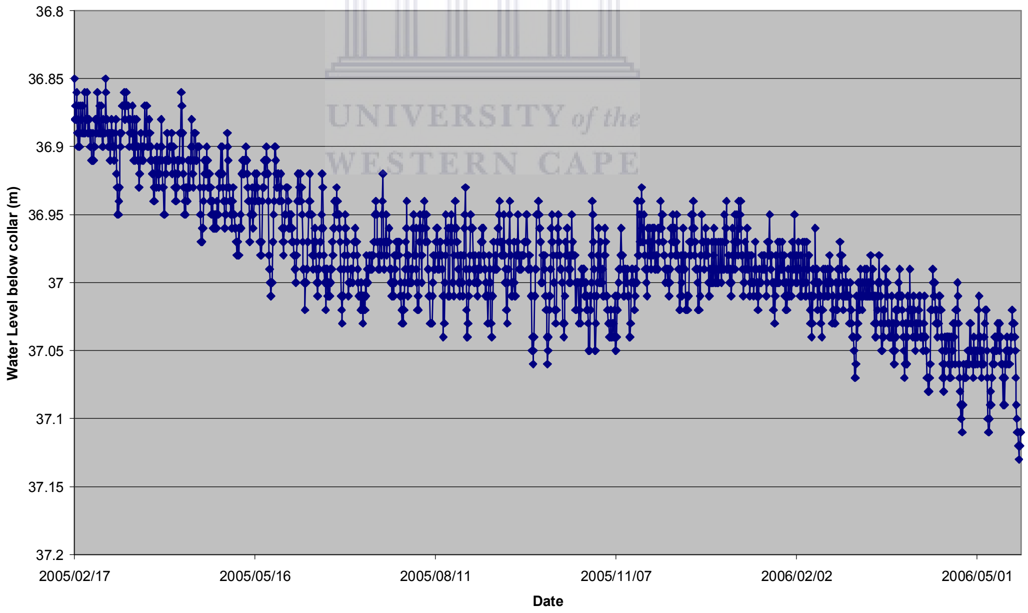
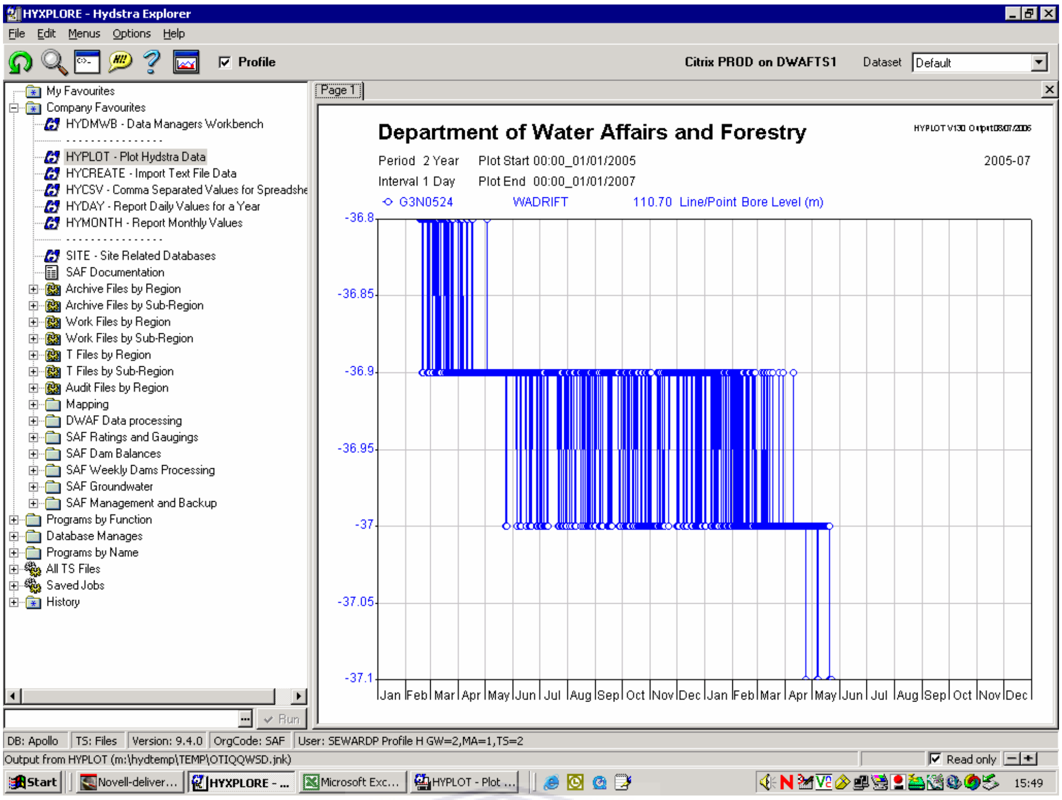


Figure 29: Example of Ott logger data BEFORE being entered into Hydstra



Department of Water Affairs and Forestry

HYPLOT V130 Output 03/07/2006

Period 2 Year Plot Start 00:00_01/01/2005

Interval 1 Day Plot End 00:00_01/01/2007

2005-07

G3N0524 WADRIFT 110.70 Line/Point Bore Level (m)

DB: Apollo | TS: Files | Version: 9.4.0 | OrgCode: SAF | User: SEWARDP Profile H GW=2,MA=1,TS=2

Output from HYPLOT (m:\hydtemp\TEMP\OTIQQWSD.jnk)

Figure 30: Example of Ott logger data AFTER entered into Hydstra

The reason for the errors in the Hydstra graph is probably very simple. In this case it appears that an inappropriate decimal formatting was used, and that Hydstra was told the logger data should be stored to one decimal place, when actually it should be three, or two at least. The data typist, having successfully entered the data, clearly thought the job was done. But without some form of checking of the entered data, errors will proliferate, making it close to useless, or such an unreliable source of data that people requiring monitoring information will go to other sources, such as the data collector's data sitting on an Excel spreadsheet on their personal pc. This might seem a very trivial issue, and it is easily rectifiable, but it needs some form of monitoring information manager to ensure proper quality control is taking place.

Another problem is that a large number of monitoring boreholes have been plotted in the sea (Figure 31).

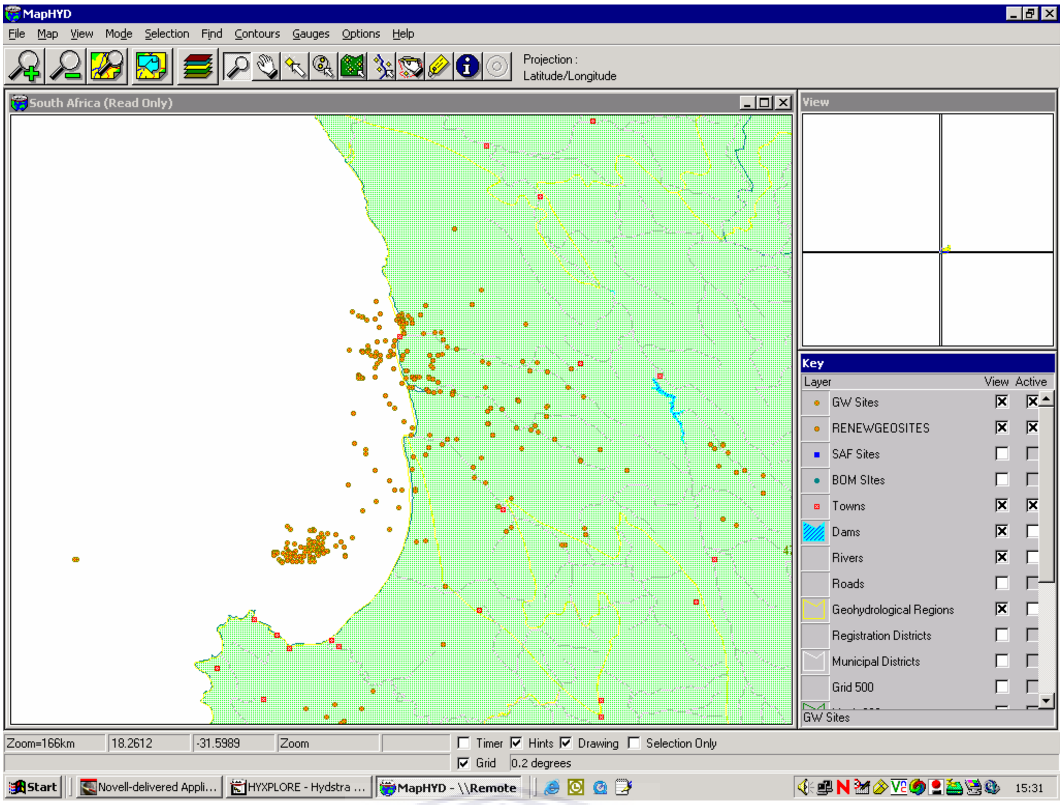
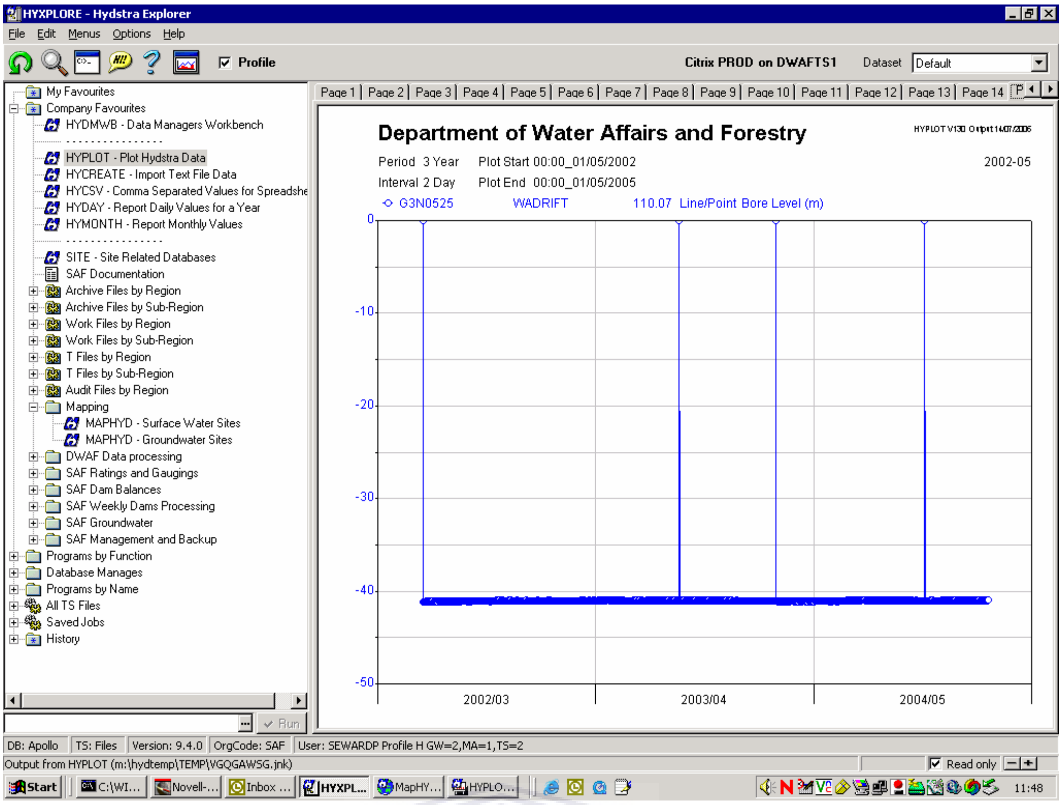


Figure 31: Monitoring points plotted in the sea by Hydstra

In this case the errors crept in at higher level than that of data typist. A large number of monitoring sites had to be created in Hydstra to accommodate data that used to go the NGDB, but now can only be entered into Hydstra. Apparently the errors crept in because of a fault in the programme used to convert the coordinate format. Apparently this will be sorted out.

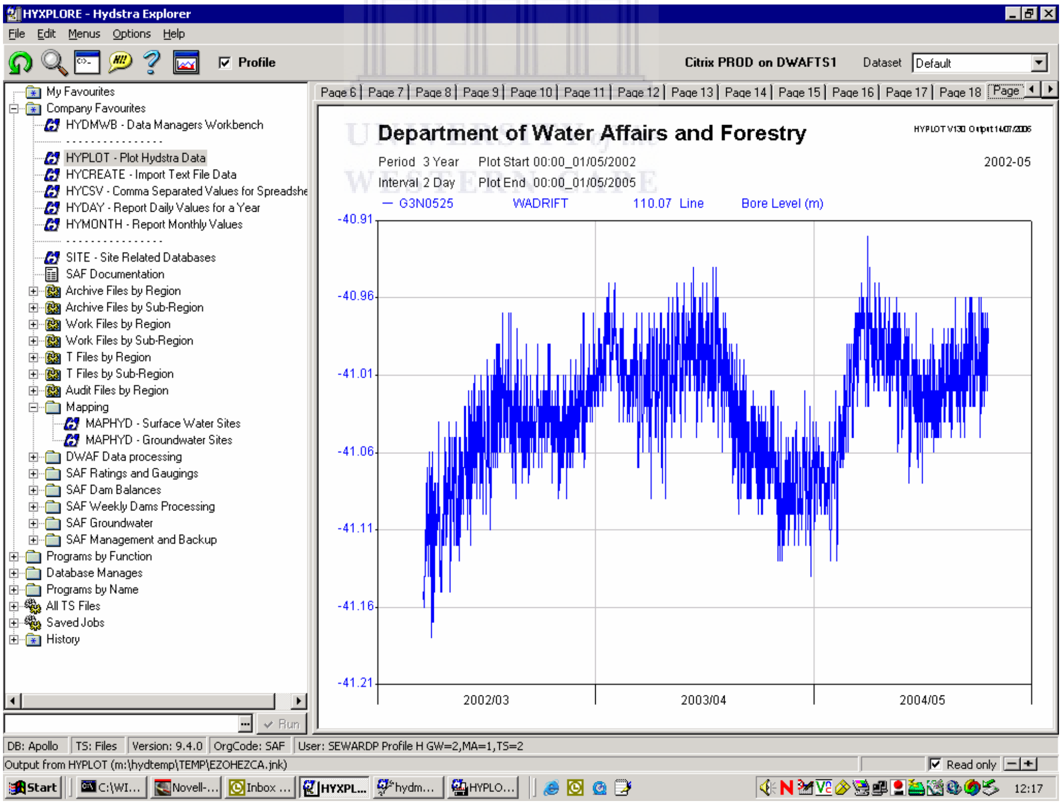
At the risk of labouring the point of data storage quality control issues, a third example is given below. Figure 32 shows how Hydstra depicted data from an Ott data logger. According to the Hydstra graph, waterlevels with a “0” value are periodically encountered. However these null values are actually how Hydstra interprets a “no reading” from the Ott logger at the prescribed interval, rather than a “waterlevel = 0.” After the noughts were manually deleted, the graph as in Figure 33 was obtained.



DB: Apollo | TS: Files | Version: 9.4.0 | OrgCode: SAF | User: SEWARDP Profile H GW=2,MA=1,TS=2

Output from HYPLOT (m:\hydtemp\TEMP\VGQGAWSG.jnk)

Figure 32: How Hydstra reads a data logger null value



DB: Apollo | TS: Files | Version: 9.4.0 | OrgCode: SAF | User: SEWARDP Profile H GW=2,MA=1,TS=2

Output from HYPLOT (m:\hydtemp\TEMP\EZOHEZCA.jnk)

Figure 33: Effect on Hydstra graph of deleting data logger null values

Errors like this can seem very trivial, and they are very easy to avoid, and they are reasonably easy to correct. However they are very prevalent in the Olifants-Doorn data (and in the data for the country as a whole.) And left uncorrected they can give a very misleading impression. For example a quick glance at the waterlevels in Figure 32 would suggest they are static, although the corrected plot shows this impression is incorrect, with distinct, albeit small, changes in waterlevels.

These problems cannot really be attributed to Hydstra itself - any graphical programme can be made to generate garbage graphs, especially by novice users. Nor can they be attributed to staff incompetence, since they are not incompetent. These problems are actually caused by a lack of over-arching quality control. The monitoring information system consists of a number of fragmented activities, analogous to links in a chain. Each person – each link in the chain – may have performed their work admirably, but be unaware that they have introduced errors in the system. For example the person editing Ott data logger data using Ott software will be completely oblivious that leaving in the “no values” will create problems in Hydstra because the graph looks fine when viewed with the Ott software. Similarly, a data-typist when entering the data, will feel they have done the job correctly when they have met all the formatting requirements of Hydstra, yet be oblivious that they may well have entered garbage data.

The obvious solution is some kind of data manager who oversees all aspects of the monitoring process, and ensures quality control. This is hardly managerial rocket science - yet the absence of this person (who is, presumably, analogous to the “programme manager” of Grobler and Ntsaba (DWAF, 2004b)) appears to be the cause of so many problems and frustrations.

7.4 Information Provision

7.4.1 REGIS

Having all the data in one place would seem to be a necessary first step in converting data into information. And with monitoring data scattered around in various databases, it would seem both logical and necessary to have a single database or information system that pulls all the monitoring data back together again. This is what REGIS (Regional

Geohydrological Information System) aims to do. Data from the NGDB, WMS, and Hydstra are – or can be – updated to REGIS regularly so that monitoring data can be downloaded from a single access point (Figure 34).

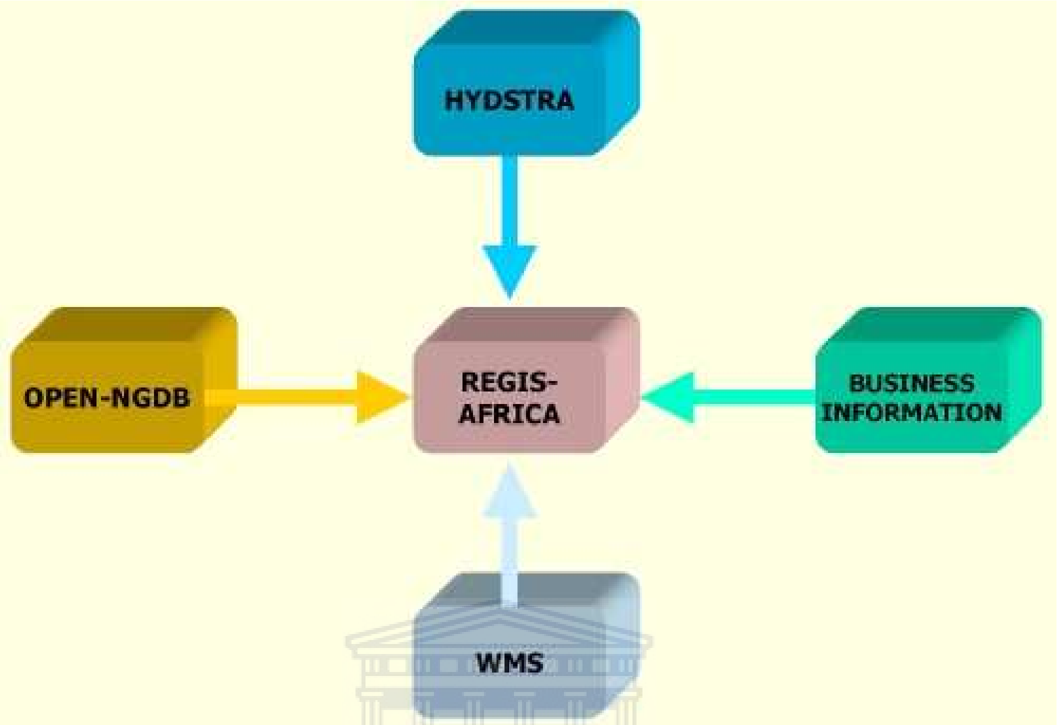


Figure 34: Regis data sources

REGIS is a Dutch system that was adopted by DWAF to provide a more user-friendly, GIS-based, interface with groundwater data. Its essential components are an ArcView GIS bolted to an Oracle database, with numerous add-ons to make extracting and summarizing data (e.g. graphs) a simple process for someone with no GIS or database knowledge.

However, it is not widely used, with GIS experts feeling it adds nothing to what they can already do using their GIS, and preferring to do things their own way, and non-GIS experts preferring to ask data-typists to provide them with monitoring data so that they can process it in more familiar software such as Microsoft Excel.

7.4.2 Available monitoring information versus monitoring data collected

The purpose of this section is to give an indication of what percentage of the field data collected actually ends up on DWAF databases as accessible information. The situation in 2005 and 2006 is atypical because of the confusion caused by the phased, ongoing transition from the National Groundwater Database (NGDB) to the National Groundwater Archive (NGA). Thus the situation in 2004 is described because this is the most recent "normal" year.

Figure 35 compares the number of waterlevel graphs located on REGIS versus the number of waterlevel monitoring stations for the various institutions involved. According to this analysis approximately 50% of the waterlevel measurements either never reached DWAF databases, or were never measured. Based on monitoring data available on local pcs in the DWAF Bellville Office, it would appear that missing DWAF and GEOSS waterlevel data were in fact collected, but were never entered on a national database. The most common reason or excuse for the data not being entered was because the monitoring station had not yet been allocated a Hydstra and/or NDGB site reference number, and therefore – as for as those databases were concerned – the monitoring station did not exist.

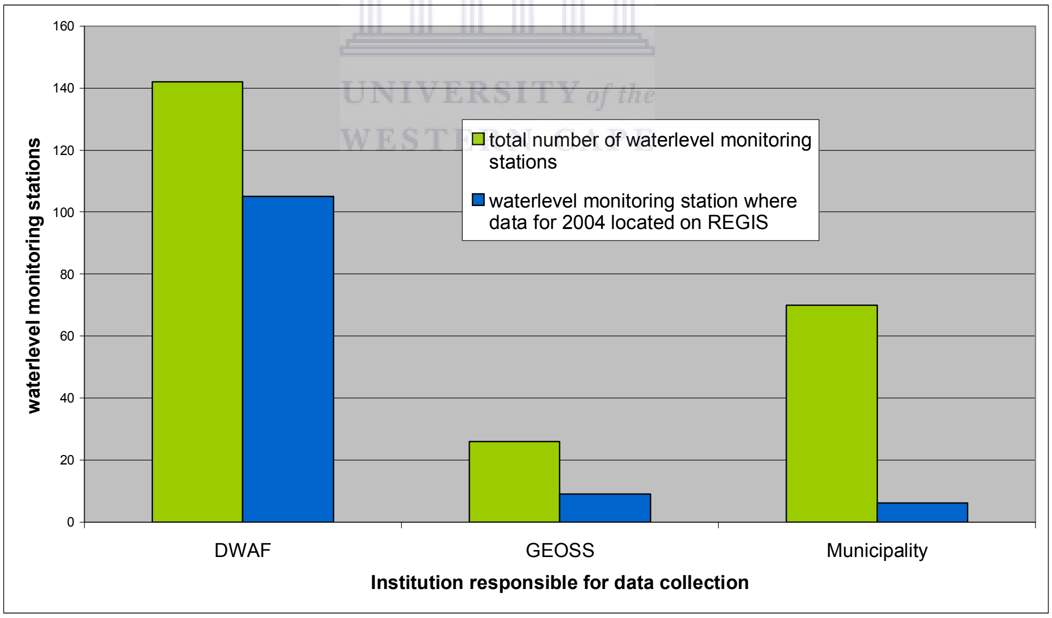


Figure 35: Waterlevel data located on Regis versus number of monitoring stations

Very little Municipality waterlevel data could be located in the DWAF Bellville office for the year 2004, although it is known that consultants regularly provide reports to most of the Municipalities involved based on monitoring data collected by the Municipalities. The implication is, therefore, that the Municipalities are – by and large – carrying out waterlevel monitoring, but are not forwarding the data to DWAF.

Water quality measurements (Figure 36) present a somewhat different picture than waterlevels with more than two thirds of the EC monitoring stations having EC information on REGIS. These EC measurements are primarily laboratory measurements.

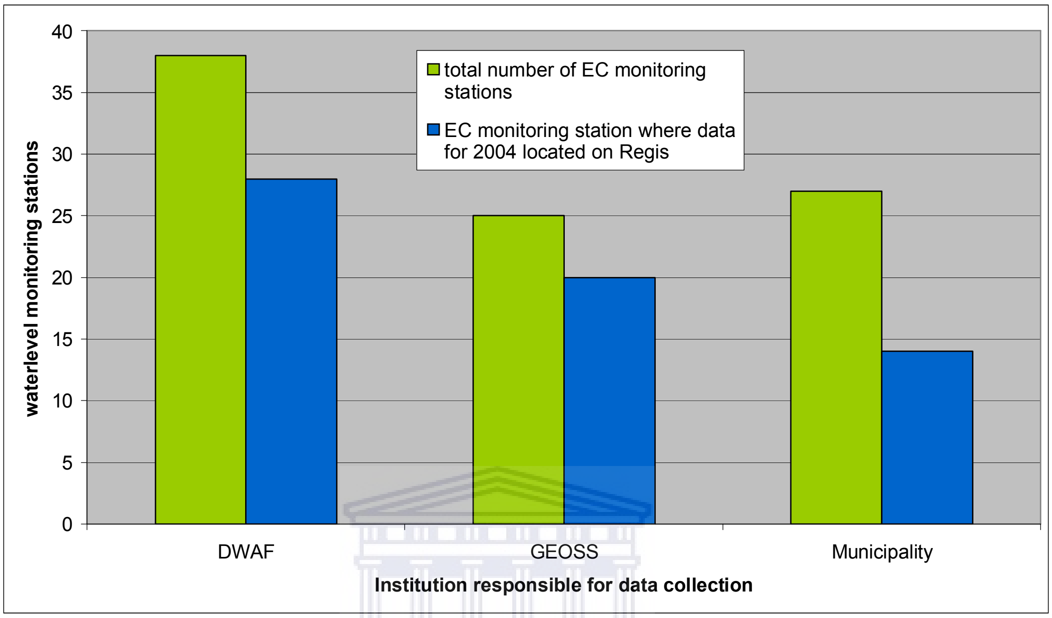


Figure 36: EC data located on Regis versus number of monitoring points

One possible reason for the increased availability of these data – as compared to waterlevels - is that the process of converting water samples to water quality information is largely "self-driven" or "automatic" and has to follow a formal sequence. Once a sample has been collected it has to be analysed with a certain date. An office full of water samples is an extra motivation to the official concerned to pass the samples on to the next link in the chain. Samples to be analysed by DWAF labs have to have the necessary documentation. Once analysed the data have to be entered on the WMS database. Thus EC, and Ph, major ions, and whatever other quality parameters are analysed will tend to become available "automatically" if a water quality sample is taken. It is possible that the remaining absent information could represent either incorrect accounting of what constitutes a water quality sampling point, or that no sampling was done if the owner's pump was not running.

When it comes to attributes other than waterlevels and water quality, a very different picture emerges regarding information availability on REGIS. Nothing regarding discharge rates, volumes abstracted, or rainfall could be located on REGIS for the Olifants-Doorn WMA. In some cases this is because the monitoring point has not been registered as a site with the appropriate database. In other cases this is because the data were never forwarded to DWAF for entry onto the appropriate DWAF database.

7.4.3 Information Accessibility

Monitoring information is by-and-large only directly accessible by DWAF officials that have the necessary authorisations and have required hardware and software installed. In some instances consultants working for DWAF will also have direct access.

For other information users, a request has to be submitted to a data-typist, who will then download the required information and forward it, usually in a Microsoft Excel format.

If the locations of the monitoring points are not known in advance, REGIS is a poor tool for locating them because it does not distinguish between monitoring points and hydrocensus points. In the REGIS system, if a waterlevel is measured at a point, even if only once, it is classified as an “observation well” and is lumped with monitoring wells where records may have been kept for decades. Figure 37 shows the location of these monitoring points against a backdrop of all observation wells located on Regis. Unless the coordinates of the monitoring points for which data are required are known, it can be a very time-consuming process to locate monitoring data on REGIS. Hydstra, at least, manages to avoid this problem since it only stores time-series data.

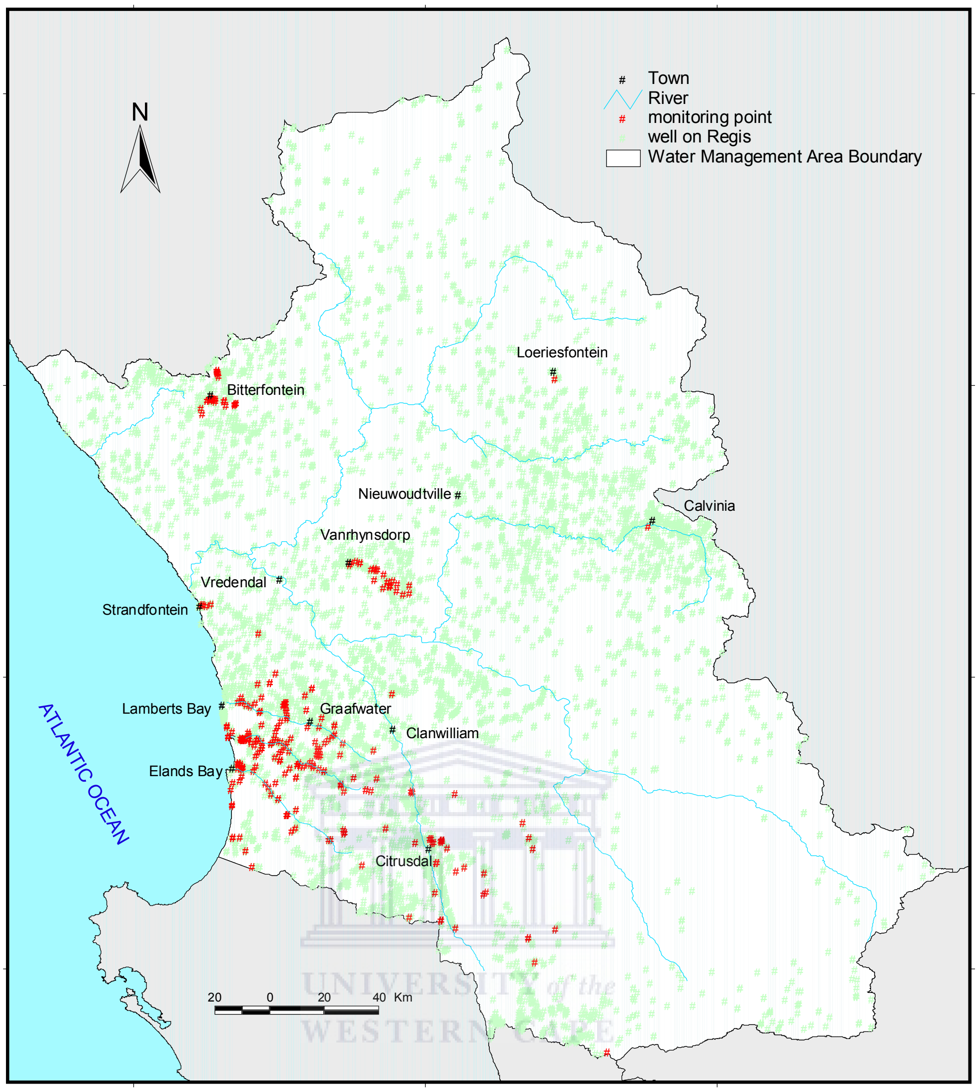


Figure 37: Monitoring points versus Regis observation wells

8. Effectiveness of groundwater monitoring in the Olifants-Doorn WMA

8.1 Introduction

It is very easy to get caught up in the detailed intricacies of management and monitoring and lose sight of the fact that, at their core, these are part of a very simple process. This process (Finlay, 1985) can be viewed as three key steps:

- formulate a plan
- implement the plan
- control the plan

Controlling the plan means deciding on an appropriate response to the success, or otherwise, of the plan. In order to control the plan, the implementation of the plan has to be ***monitored***. Whether the business activity is the selling of widgets, or the management of natural resources such as groundwater, these core principles still apply. Management and monitoring are interwoven processes.

The aim of this chapter is to provide some form of evaluation or "control" of the monitoring process. In other words the focus is on "monitoring" the monitoring process itself rather than the monitoring of the groundwater – and connected – resources.

The approach used in this chapter is to look at the outputs of the monitoring process, rather the details of the process itself, since – as noted in the previous chapter – it is possible for individual links in the process to be functioning very well, but the overall functioning to be poor. The issue of sustainability has been shown to be a key aspect groundwater monitoring and so the aim in this chapter is to assess how effective the regional groundwater monitoring being carried out in the Olifants-Doorn WMA is as a tool to help determine sustainable groundwater use. Therefore the two outputs considered are:

1. How well does the monitoring reflect the status of the groundwater resources? Does monitoring accurately depict sustainable and unsustainable use?
2. How well is monitoring information being used in the decision-making process? Is the monitoring information being used to ensure sustainability?

8.2 Groundwater monitoring versus groundwater resource status

8.2.1 Regional coverage of groundwater monitoring

The Olifants-Doorn WMA consists of 88 quaternary drainage regions. Regional groundwater monitoring is being carried out in only 25 of these catchments (Figure 38). At face value this would suggest that regional groundwater monitoring is failing to address sustainability in 63 (72%) of the quaternary drainage regions. This situation could – perhaps – be justified if it was known that very little groundwater was being used in the un-monitored quaternary drainage regions, and/or abstraction was well within sustainability limits.

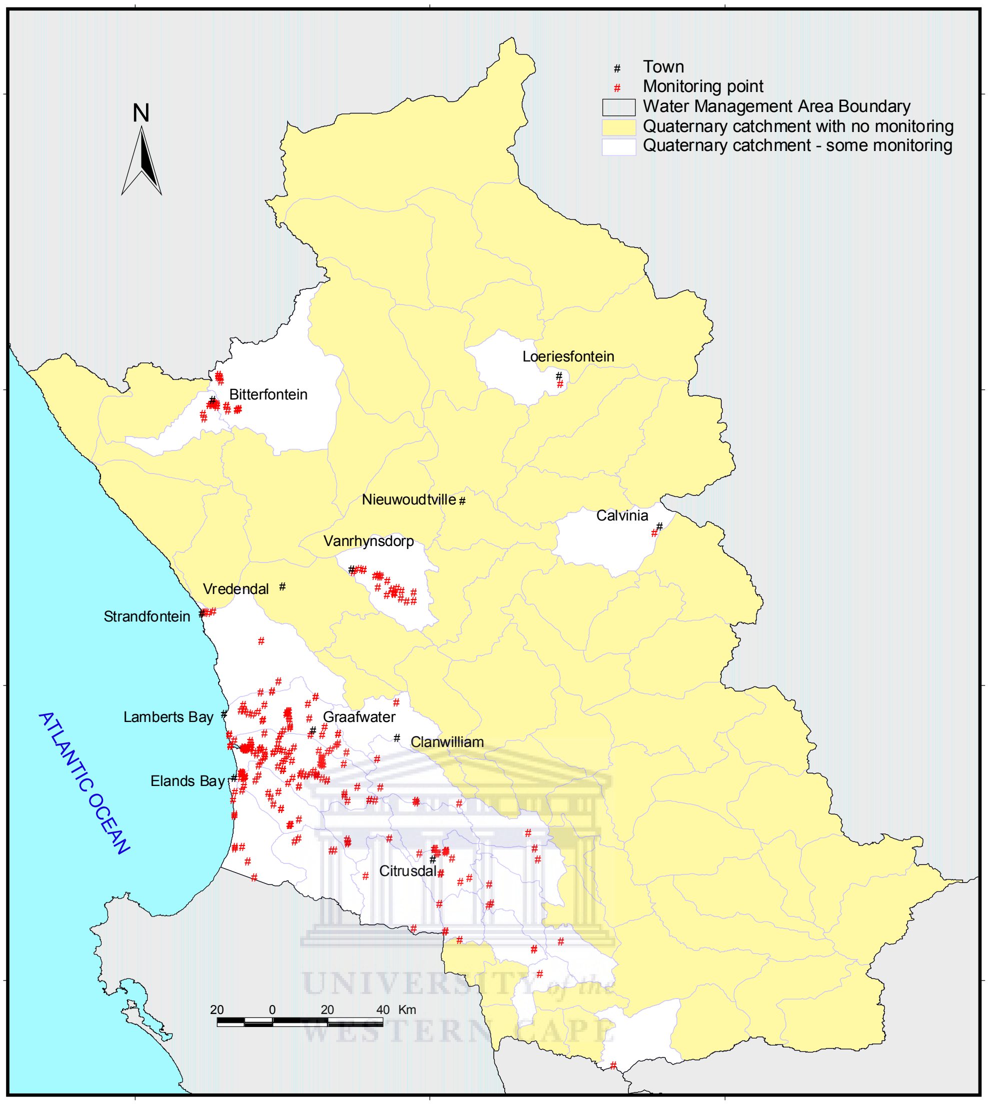


Figure 38: Quaternary catchments with no groundwater monitoring

8.2.2 Monitoring versus groundwater use

Figure 39 compares groundwater monitoring versus groundwater use. The groundwater use data were taken from the Groundwater Resources Assessment phase 2 (DWAF, 2006a) project. Although there are more detailed studies, some of which may contain more accurate groundwater use estimates, differing methodologies have been used for different parts of the WMA. The GRA2 data are therefore used here to ensure a consistent use estimate methodology for the entire WMA.

The use data were taken from the GRA2 Planning Potential project (DWAF, 2006a) since they appeared more realistic than the use data contained in the GRA2 Groundwater Use project (DWAF, 2004d). *(In the GRA2 datasets provided, the Planning Potential project uses the term "A_T" or "Total Abstraction" for groundwater use, while the Groundwater Use project uses the term "TOTGWUSE".)* This situation – with different use values from different GRA2 projects - is somewhat disconcerting since the use data in the Planning Potential and Groundwater Use projects are supposed to be the same! This issue was taken up with the GRA2 project managers and workers but they were either unwilling or unable to provide an explanation.

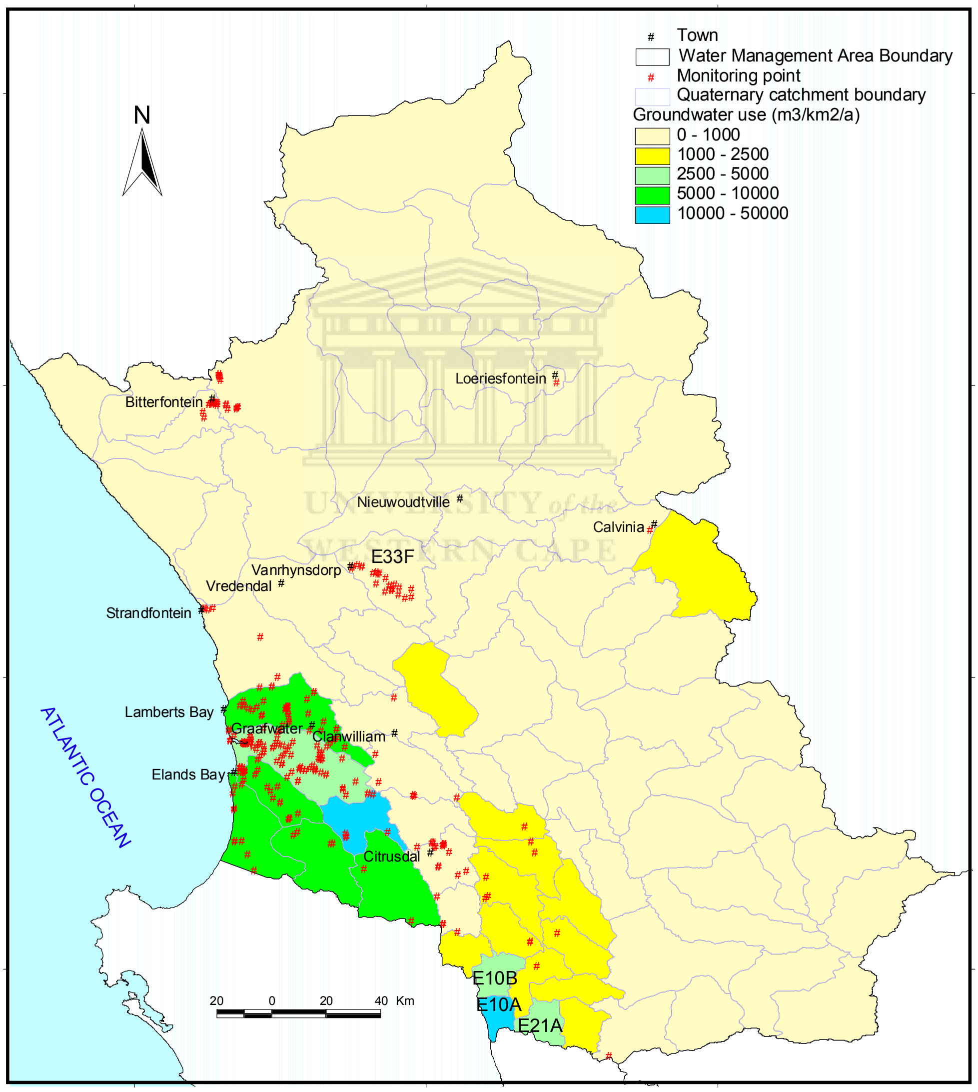


Figure 39: Groundwater use versus monitoring points

Figure 39 shows that most of the quaternary catchments with (assessed) high groundwater use do indeed have some form of regional groundwater monitoring taking place within them. The only exceptions are, according to the GRA2 data, the E10A, E10B and E21A quaternary catchments in the south of the study area. However the limitations of the GRA2 project are shown up in the E33F drainage region. According to GRA2 there is no groundwater use there, although the Calvinia 1:500 000 Hydrogeological Map (Zenzile, 2002) indicates irrigation from groundwater to be in the 2-5 million m^3/year. A DWAF official is currently involved in a project to assist the Vanrhynsdorp WUA establish and maintain their own groundwater monitoring network in this catchment.

8.2.3 Monitoring versus groundwater exploitation potential

Exploitation potential data are taken from the GRA2 Planning Potential project (DWAF, 2006a). The Planning Potential project calculated many different "groundwater potentials." In this section, the GRA2 "average groundwater exploitation potential" is used since the authors of the Planning Potential report recommend it as being the most likely indicator of what can realistically by abstracted on a long-term, sustainable basis.

Figure 40 shows there is a broad correlation between regional monitoring intensity and exploitation potential. However, if one wanted to be consistent, and to focus on the high exploitation potential areas, there are several quaternary catchments where monitoring would have to be initiated.

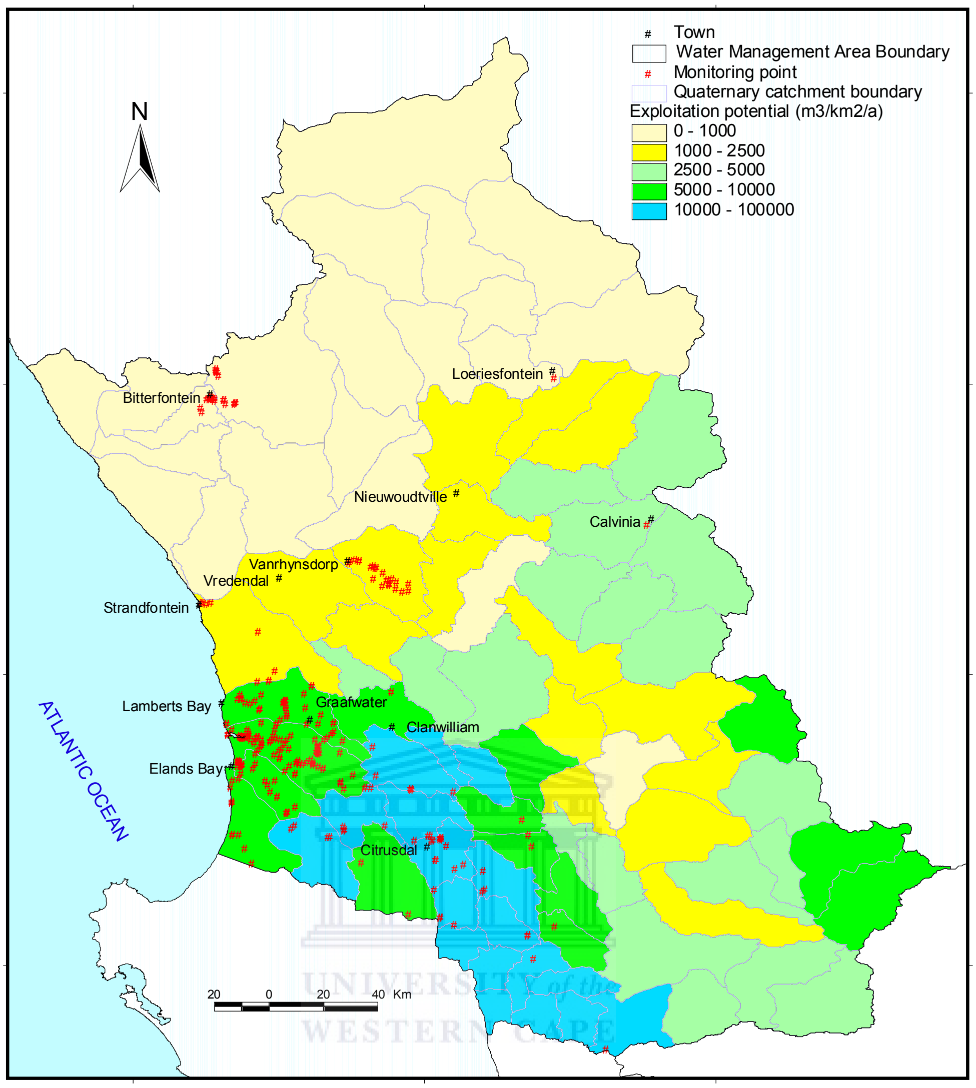


Figure 40: Groundwater exploitation potential versus monitoring points

8.2.4 Monitoring versus groundwater stress

In this chapter groundwater stress is defined as groundwater use divided by exploitation potential. This can be used as a rudimentary and preliminary indicator of groundwater sustainability. Other workers such as Parsons and Wentzel (2005) have defined groundwater stress as groundwater use divided by recharge. The use of exploitation potential rather than recharge is preferred here because it accommodates such factors as base flow, acceptable levels of drawdown, and groundwater storage and is therefore closer to the concept of sustainability than recharge alone. Groundwater use and exploitation potential data are taken from the GRA2 Planning Potential project (DWAF, 2006a).

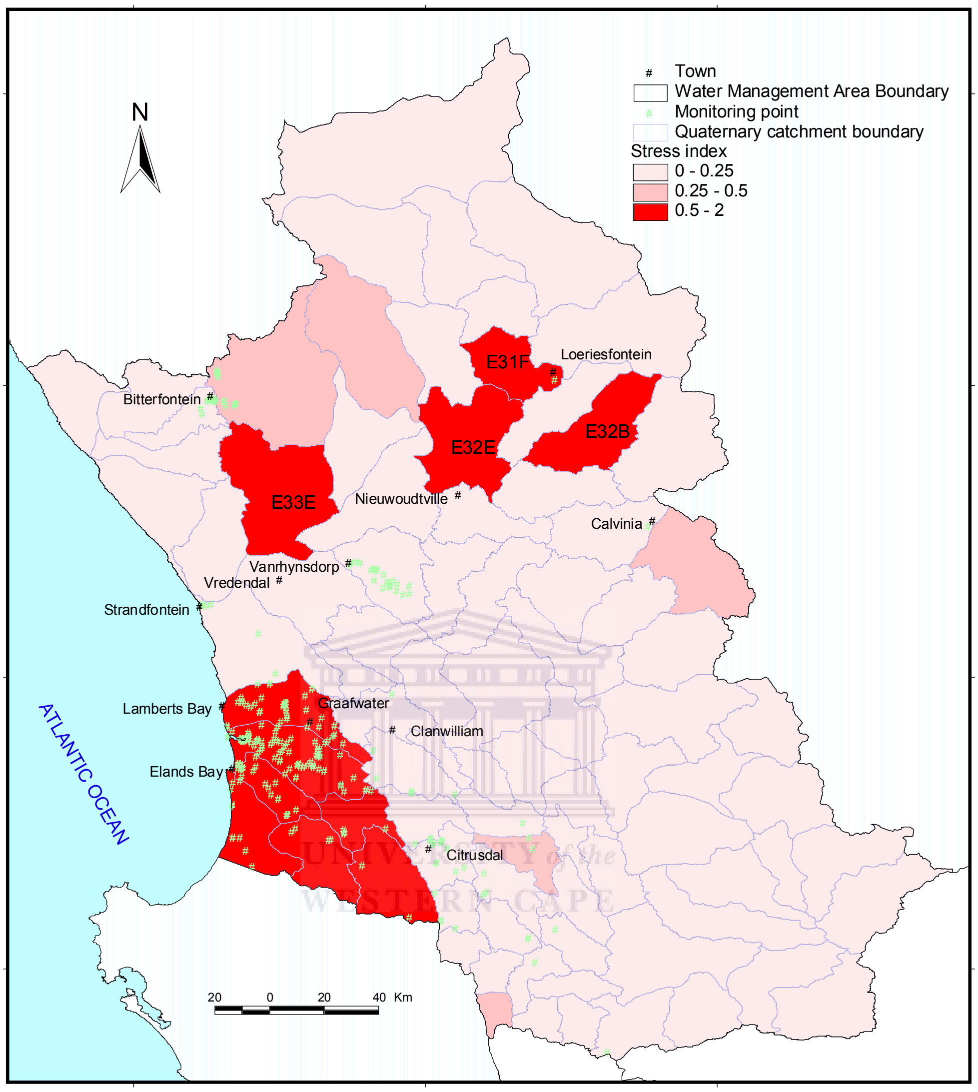


Figure 41: Groundwater stress(i) versus monitoring points

The groundwater stress map (Figure 41) reveals the following broad patterns:

- A correlation between monitoring and stress in the south-west of the area – the potato farming area.

- An area to the south-east of Citrusdal that is monitored but not (according to these data) stressed. From previous maps it can be seen that this is classified as a high groundwater use area. This area is apparently not stressed because this area also has a high groundwater exploitation potential.

- An ***apparently*** unstressed area that is intensively monitored at Vanrhynsdorp. However if the GRA data (zero irrigation) are replaced with data from the 1:500 000 Calvinia Hydrogeological Map, this catchment would fall into the 0.5-2 stress index category, and would therefore be deemed to be stressed.

- Intensive monitoring at Bitterfontein, but with limited regional stress. This would suggest that whatever problems are being experienced with the boreholes supplying water for Bitterfontein via desalinisation, these are local wellfield, rather than regional sustainability issues.

- Some apparently highly stressed areas in the north of the area where no monitoring is being carried out – the E33E, E32E, E31F and E32B quaternary catchments These 4 catchments have a relatively low groundwater use (according to GRA2), but have been deemed stressed because the exploitation potential is also relatively low. Just a small change in either the use or exploitation potential estimates could cause the catchments to be re-classified with a much lower stress. It is therefore possible that these 4 catchments have been assigned an erroneously high stress category. It is also possible that opportunistic surface water use has been incorrectly interpreted as groundwater use. Further studies, including possible field investigations would be needed to resolve these issues.

However, perhaps the most noteworthy conclusion from this analysis, it that monitoring is focused on the area ***that has BOTH high use AND high stress levels*** – the potato farming area in the south-west.

As noted in section 8.2.2 it is possible to obtain two different groundwater use figures from the GRA2 project. The map in Figure 41 was obtained by using the term “annual abstraction.” When stress is determined from “total groundwater use” rather than “annual abstraction” a groundwater stress map as shown in Figure 42 is obtained.

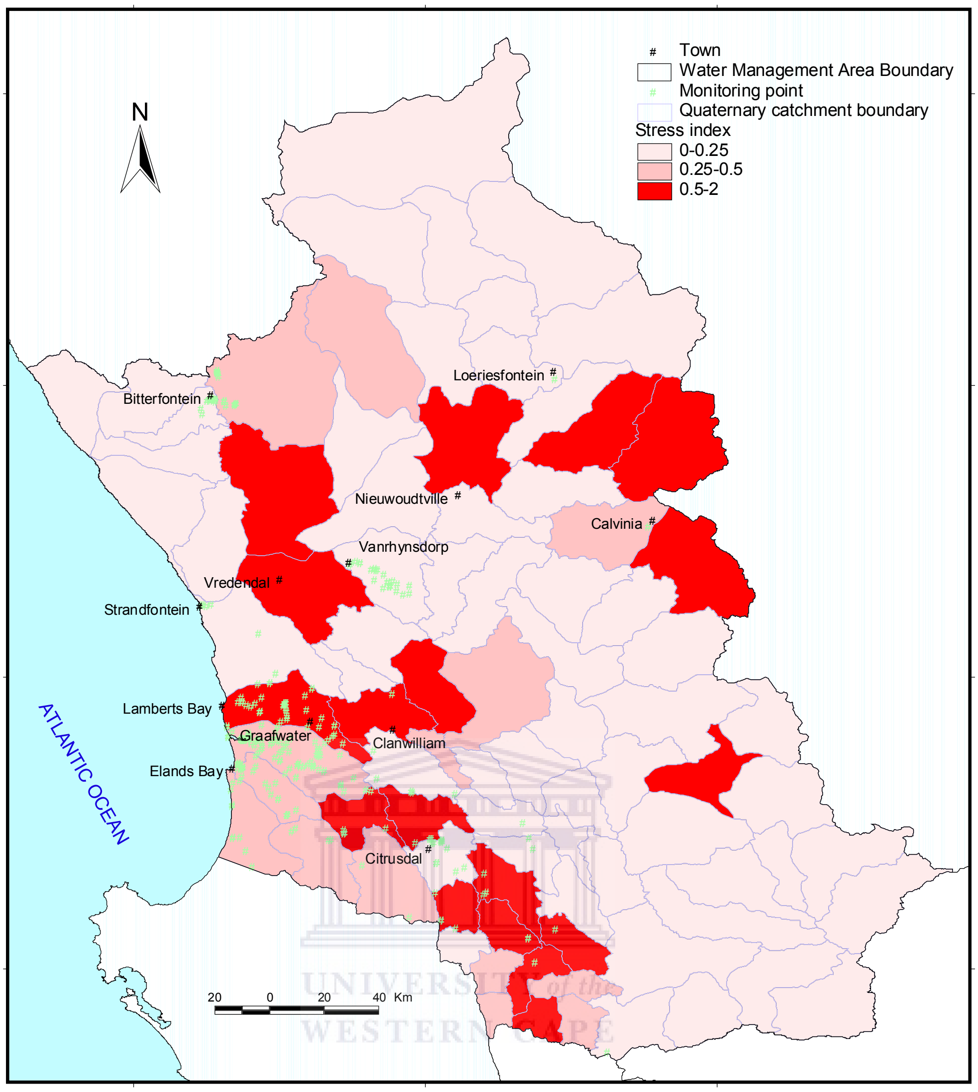


Figure 42: Groundwater stress(ii) versus monitoring points

This map is significantly different from the stress map shown in Figure 41. It can be speculated that the "total groundwater use" term is biased towards registered, rather than actual, use and is clouded by uncertainty regarding the groundwater component of conjunctive use.

Possibly the main points to be learned from the "stress" maps is that the synthetically derived data show great variability, so groundwater use needs to based on physical monitoring and not projections, and a stress index cannot realistically be used as an alternative to physical monitoring of waterlevels and water quality.

8.2.5 Waterlevel and EC changes versus groundwater stress

The preceding section compared areas where groundwater monitoring is taking place with areas where groundwater resources are estimated to be stressed. This section goes one step further and investigates what the actual monitoring parameters reveal regarding stressed and unstressed catchments. Waterlevel and ECs were selected because these parameters are the most prevalent in the monitoring data. A map showing significant changes in waterlevels and ECs (Figure 43) was compiled. A waterlevel or EC graph was categorised as showing a “significant change” based on a visual inspection. Although a more statistical approach could have been used, it was felt that scientific judgement rather than statistics was better suited to extracting geohydrological meaning from the large number of disparate datasets – different lengths of records, different aquifer types, different distance from abstraction points, and so on. For example, a waterlevel decline of 2m was regarded as insignificant if it occurred over a period of less than a year, next to a pumped hole, in a fractured-rock aquifer, but significant if it occurred over a period of several years in an intergranular aquifer away from abstraction points.

An inspection of Figure 43 reveals that:

- There are a large number of monitoring points showing waterlevel declines in the G30F catchment, thus supporting the perception that this catchment is stressed.
- For the high-use, high-stress south-western area, monitoring points do NOT show deteriorating trends throughout the area as a whole. This could be because the monitoring stations are unevenly spread and therefore unrepresentative. It could also be because over-abstraction does only occur locally throughout the area, and that – taking the region as a whole - over-abstraction is possibly not taking place.
- The GRA2-based classification of the area to the south-east of Citrusdal as high-use, but low stress appears to be supported by monitoring data, although there are insufficient monitoring points to be certain about this.
- The E33F catchment to the east of Vanrhynsdorp, where it is (locally) known that significant amounts of groundwater are abstracted for irrigation, shows signs of falling waterlevels and increasing ECs. The

GRA2 classification of this as an un-stressed area would therefore appear to be incorrect.

- Some waterlevels are declining at the boreholes used for town supply for Bitterfontein. This is presumed to be a well-field management rather than a regional issue.

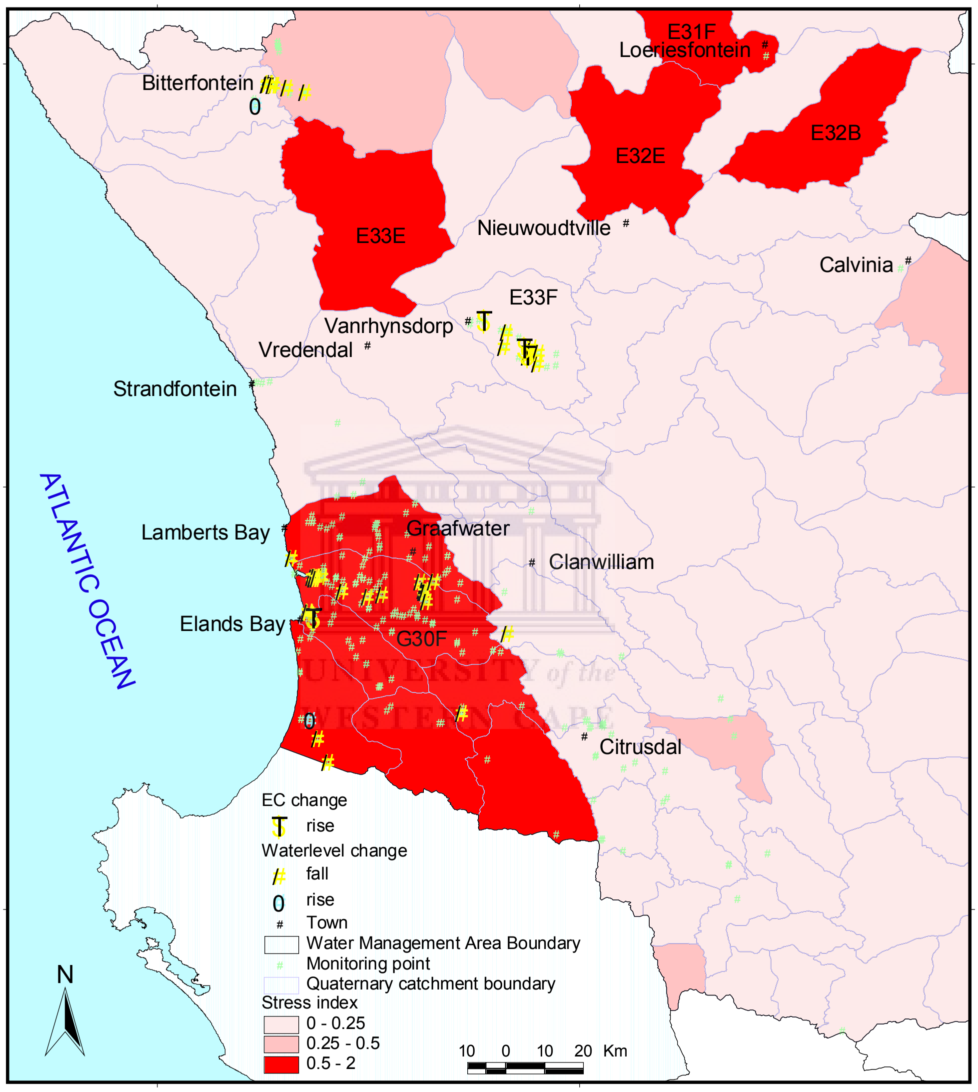


Figure 43: Waterlevel and EC changes versus groundwater stress

It would be unwise, however, to attach too much meaning to the above analysis. For example, it would be very rash to say that because the stress index is greater than 1, the resource is being used unsustainably. Seward et al. (2006) have shown that estimates of parameters such as groundwater use and recharge can easily be an order of magnitude out, and therefore so can derived parameters such as a stress index. Seward et al. (2006) also show that waterlevels are not diagnostic – falling waterlevels can eventually stabilize as a new equilibrium situation is reached; and apparently stable waterlevel can start to decline dramatically as a resource being tapped via a recharge boundary is depleted.

It would, therefore, be sensible NOT to make bold statements about the status of the groundwater resources in the Olifants-Doorn WMA solely on the strength of stress indices, and waterlevel and EC trends. It would be more sensible, rather, to use this sort of information to plan and prioritize future work – to do field surveys to investigate if monitoring is needed in a certain area, to rationalize monitoring networks in other areas, and so on.

8.3 Monitoring data and decision making

As far as is known, the Olifants-Doorn regional groundwater monitoring data has scarcely been used for decision-making to facilitate sustainability. This perception is based on the following observations:

- The Olifants-Doorn ISP (DWAF, 2005) pay little attention to the existing monitoring data, but instead focuses on where it thinks additional monitoring should be carried out, and what type of monitoring.

- The various Groundwater Resource Directed Measures (RDM) reports compiled for the Olifants-Doorn pay little attention to monitoring data, and instead prefer to use a stress index to assess the status of the groundwater resources. The stress index is usually groundwater use divided by recharge or exploitation potential. Like the ISP report, the groundwater RDM reports prefer to focus on monitoring that needs to be done, rather than what the existing data show.

- I am aware of only one user requesting copies of the monitoring data collected on their property.

- At a Public Participation Meeting held at Elands Bay on 22 November 2005, convened by DWAF to address water resource management in the

Sandveld, the monitoring data used to depict the groundwater situation was based on data collected by consultants and did not include the much larger set of data collected by DWAF.

- DWAF does not create reports that synthesize the Olifants-Doorn monitoring data and make it of value to decision-makers.

- No complaints have been received regarding the quality of monitoring data on DWAF's databases. Based on my own experiences, there is a lot of editing that still needs to be done on a lot of the data, and if anybody had received data in such unsatisfactory condition, they would – at least – have enquired as to how they can make sense of it.

- For large parts of 2005 no groundwater monitoring from the Olifants-Doorn data were entered onto any DWAF central database. Although a major irritation to managers of the process, there did not appear to be any data users who were inconvenienced by the unavailability of data, thus implying there were no (prospective) users of the data.

It is granted, that this is hardly a scientific survey into the use of Olifants-Doorn monitoring data for decision-making. However it is difficult to find evidence that would suggest that the monitoring data are key elements in important decision-making. It is therefore concluded that monitoring data do not currently play a major role in decision-making.

What are the reasons for the (perceived) lack of use of the monitoring data? One possible explanation is that looking at monitoring data was not part of the terms of reference in the many Olifants-Doorn studies commissioned by DWAF. Another explanation is that DWAF is not doing enough to synthesize and disseminate the data. Few would argue with that. Yet another explanation is that the monitoring data fall into the "data rich but information poor" syndrome as described by Grobler and Ntsaba (DWAF, 2004b). Whatever the cause of the problem, it would appear that there is a problem, and that it needs to be addressed.

9. A Groundwater Monitoring Strategy for the Olifants-Doorn WMA

9.1 The importance of strategy

In the long run success in an organisation is not determined by the energy, efficiency or productivity of individual components within that organisation, nor by good personnel relations, but by the strategies adopted by the organisation (Johnson, 1985). According to Johnson (1985) some of the key characteristics of strategic decisions are that they:

- are concerned with the scope of an organisation's activities
- match (or attempt to match) the activities of an organisation to the environment in which it operates
- match (or attempt to match) the activities of an organisation to its resource capability
- are complex in nature and have many, interwoven, ramifications

Strategies can exist at many different levels in an organisation, from an individual's career strategy to the overall strategy of the organisation. Groundwater monitoring in the Olifants-Doorn requires an operational or functional strategy, which is clearly at a lower level in the hierarchy than the overall corporate or departmental strategy, yet the same strategic principles apply, and the operational strategy should contribute optimally to the overall, higher level, departmental strategy.

Strategic management is often thought of as a highly formalized process, involving, for example, the establishment of a mission statement, the establishment of strategic objectives, strategy implementation, resource planning, revising the organisational structure, and so on. In practice, however, many successful organisations employ a much more intuitive and iterative approach to strategic management where "the organisation probes the future, experiments, and learns from a series of partial (incremental) commitments rather than through global formulations of total strategies" (Quinn, 1980). This incremental approach is considered appropriate where the environment is continually changing (Johnson, 1985).

Besides being more intuitive and iterative than often recognised, strategic management – in practice – will reflect the values of those concerned, whether those values are of the organisation as a whole, a particular component within that organisation, or of an individual. Thus strategic management involves more than reconciling organisational resources with the environment it finds itself in, since organisational values must also be reconciled with the first two factors (Johnson, 1985). This point is of more than academic interest for departmental strategy, since individual's whose values are not aligned with overall departmental values may not be the most reliable people to implement departmental strategies.

9.2 Key issues that must be addressed in the Olifants-Doorn WMA

From the previous section, it can be seen that strategic planning can be simplified to an attempt to reconcile the resources of an organisation to the requirements of the environment in which it operates, while simultaneously taking cognizance of the values of the organisation. This process can be formal, intuitive or both. From a synthesis of the preceding chapters, it is suggested that the key issues that have to be considered in a regional monitoring strategy for the Olifants-Doorn WMA are:

- an avalanche of ideas, opinions, advice and requests regarding what regional monitoring should be done

- sustainability - most calls for regional monitoring have the issue of sustainability at their root, although the link between the monitoring activity and how it will ensure sustainability is usually far from clear

- lack of consensus and lack of clarity as to what sustainability actually means - sustainability may be the ultimate goal of monitoring, but what is meant by sustainability has often not been clearly thought through

- limited capacity within DWAF to do the field data collection component of monitoring

- human resource capacity issues have been neglected - most calls for monitoring are based on water resource management issues, and human resource requirements get scant or no attention in formulating the monitoring requirements

- there is little evidence that data collected by DWAF is used for decision-making to ensure sustainability

- there is little or no dissemination of synthesized regional monitoring data

To sum up: there is a mass of monitoring activities that DWAF ***could*** be involved in, but limited resources to carry out these activities. A strategy for the Olifants-Doorn must therefore attempt to reconcile the imbalance between requirements and resources. One approach would be a vast increase in resources. It is suggested that this is not practical in the short-term, and that it probably not feasible in the long-term – a vastly expanded Public Service is not current policy, and is difficult to see where sufficient trained staff would come from even it was.

A more realistic strategy would, therefore, be based on reconciling monitoring activities with the available resources, rather than on increasing resources. This does not mean attempts to increase resources must be excluded from the strategy, it just means that working with existing resources must be the first step.

While water management charges for bulk water supply in the Olifants-Doorn are a potential source of funding to expand monitoring, it is unlikely that they will permit a dramatic expansion of monitoring. The current resource management tariff for irrigation from groundwater in the Olifants-Doorn WMA is 0.7 c/m^3, while current groundwater irrigation use is estimated as 42 million m^3/year. If registered use corresponds to estimated use, and if all charges are collected for registered use, then approximately R300 00 per annum will be generated. If all these funds were applied to monitoring, or at least data collection in the field, they would not enable a substantial increase in monitoring activities using current monitoring procedures. It is therefore suggested that any monitoring plans or strategies should be based on a conservative estimate of the availability of funding, and that this should be more-or-less what DWAF currently spends on monitoring in this area.

If funds are limited, the most viable route would be most of the monitoring done by users themselves with DWAF providing assistance and guidance where necessary. And since fieldwork is much more expensive that office work, primarily because of transport/travelling costs, one option would be to use the funds primarily for office-based data-capture.

Also, if only limited funding is available, and those funds are generated primarily by high-use irrigators, it would be difficult not to justify using those funds for high use and/or high stress areas. Whatever the deployment, it is clear that prioritisation will be necessary.

While donor – and other – sources of funding may from time to time become available, it is difficult to plan a monitoring programme on such funding. For monitoring to ensure sustainability, the monitoring itself must be sustainable. This requires stability of funding, which is, possibly, most likely to be achieved via some form of government, or government agency (e.g. CMA), support. Opportunistic funding would be better used in once-off projects, rather than on-going monitoring.

If working (broadly) within existing resources is accepted as the basis of the strategy, then two general tactics can be considered:

1. **Prioritisation** – clarifying what are the priorities and focusing on them
2. **Innovation** – looking for alternative monitoring approaches so that more monitoring can be done with the same resource capacity

The next section, attempts to identify the key components of a regional groundwater monitoring strategy for the Olifants-Doorn by addressing the issues of ***prioritisation*** (or focus) and ***innovation***.

9.3 Key components of an Olifants-Doorn groundwater monitoring strategy

9.3.1 Focus on “groundwater resource status” monitoring

The priority for groundwater monitoring should be the quality and quantity of water in the groundwater system, and the use of that water, as required in **137.** (2) of the National

Water Act (RSA, 1998). This could be achieved by monitoring ECs, waterlevels, and volumes abstracted. While the NWA requires other aspects of resource status to be monitored, for example the health of aquatic ecosystems, it is argued that it is beyond the scope of an already stretched groundwater section to expand its activities to other forms of monitoring.

Resource status monitoring could imply an expansion or a contraction of activities, depending on one's point of view. It could be regarded ad an expansion of monitoring activities if all that has been done in the past is measure waterlevels ("hydrological monitoring") without attempting to use them to assess the quantity of groundwater in the resource. It could be regarded as a contraction of activities if past monitoring has included a lot of data collection for research and other "special purposes."

In this strategy a focus on "groundwater resource status" monitoring is proposed so that monitoring can be reduced. The thinking here is that a lot of Olifants-Doorn monitoring was initiated, and is still being carried, as part of intensive research studies. A lot of this monitoring does not contribute directly to assessing the status of the groundwater resources and would therefore fall away if (basic) resource quality monitoring were implemented. Even if it failed to significantly reduce the amount of monitoring done, by focusing on resource status monitoring, it would at least ensure a more uniform approach to regional monitoring throughout the WMA.

9.3.2 Address the need for water use monitoring

Although water use monitoring forms part of resources status monitoring, it is repeated and highlighted here because of the difficulties involved and because it has not been routinely monitored in the past in the same way that waterlevels and water chemistry has. Besides the statutory obligation to ensure that water use is monitored, there is also the practical issue that you "can't manage what you don't measure." It will be exceedingly difficult to call for, and enforce say a 10% reduction in abstraction so that groundwater is used more sustainably if it is not known what that abstraction rate is.

9.3.3 Non-regional monitoring should be non-regionally funded

This is simply the reverse side of the previous argument that the DWAF regional office should focus on resource status monitoring. In other words monitoring required by a research project should be funded by the researchers, whether the researchers are from an academic institution, another DWAF component, or some other institution. Disputes between neighbours over groundwater use requires them to do the monitoring, not the DWAF regional office. Wellfield monitoring is the responsibility of the groundwater users, and so on. While the DWAF regional office must play a coordinating role in these monitoring activities, including the sharing of data across different monitoring programmes, it should refrain from being drawn into doing monitoring that it not primarily concerned with resource status monitoring

9.3.4 Improved Monitoring Information Dissemination

Very little of the data collected by DWAF is synthesised and made available in a user-friendly format to potential decision-makers. This needs to change if monitoring is going to effectively contribute to sustainability.

9.3.5 Compulsory or voluntary monitoring by groundwater users

Monitoring conditions are routinely attached to groundwater licensing conditions. The usual stipulation is that monitoring records must be kept and made available to DWAF for inspection when required. Monitoring in these cases usually refers to the abstraction or an adjacent borehole. It should not be too difficult to add a monitoring borehole that is away from the pumped borehole to the licensing condition, and require that the data be forwarded regularly. This would require a small increase in data-typist work to enter the data onto a database, but the cost would be negligible compared with DWAF having to collect the field data itself. This proposal has been made in the Olifants-Doorn ISP (DWAF, 2005), where a web-based data entry by the users themselves is also discussed.

Where licenses are not required, and abstraction is permitted under a General Authorisation, monitoring could still be stipulated as an attached condition to the General

Authorisation. It is also possible that some monitoring could be purely voluntary, and help to create awareness of, and a commitment to, groundwater management and monitoring issues, possibly within the framework of a community-based organisation such as a Water Users Association.

9.3.6 Focus on areas where groundwater stress and borehole yields are highest

Groundwater stress: The argument here is that only when aquifers are subject to moderate or high levels of stress do they need to be managed (and hence monitored) by human intervention. In other words, the lack of interest in fully developing certain aquifers, and their resultant low levels of stress, is essentially doing the job of managing these aquifers.

Borehole yields: This utilizes the same principle that Haupt (Water Systems Management, 2001) uses when he reduces exploitation potential by a factor (exploitability factor) to take into account borehole yields. The basic principle is that low borehole yields make it uneconomical and/or impractical to access all the water that is being transmitted through an aquifer. Thus in this case it is low borehole yields that "manage" the aquifer and prevent it being used unsustainably – at a regional level, at least. Table 4 is based on Haupt's work, but with an extra category added, following the approach used in the GRA2 Planning Potential project, (DWAF, 2006a).

Table 4: Exploitation factor versus average borehole yield

Average Borehole Yield (l/s)	Exploitation Factor (EF)
<0.3	0.3
0.3-0.7	0.4
0.7-1.5	0.5
1.5-3.0	0.6
3.0-5.0	0.7
>5.0	0.8

The exploitability and stress factors were then combined on the map shown in Figure 43. It is suggested that the highest priority for monitoring is the high stress areas, while the second priority is the high exploitability areas, even though they might be classified as low stress at the moment, since the potential for over-exploitation is high. It can be seen that the bulk of the area is classified as low stress and low exploitability, and regional monitoring could either be a low priority or even omitted from that area. There are also some anomalous areas such as the E31F, E32B, E32E, and E33E quaternary catchments that have been assigned a high stress, but low exploitability, that appear to warrant further investigation.

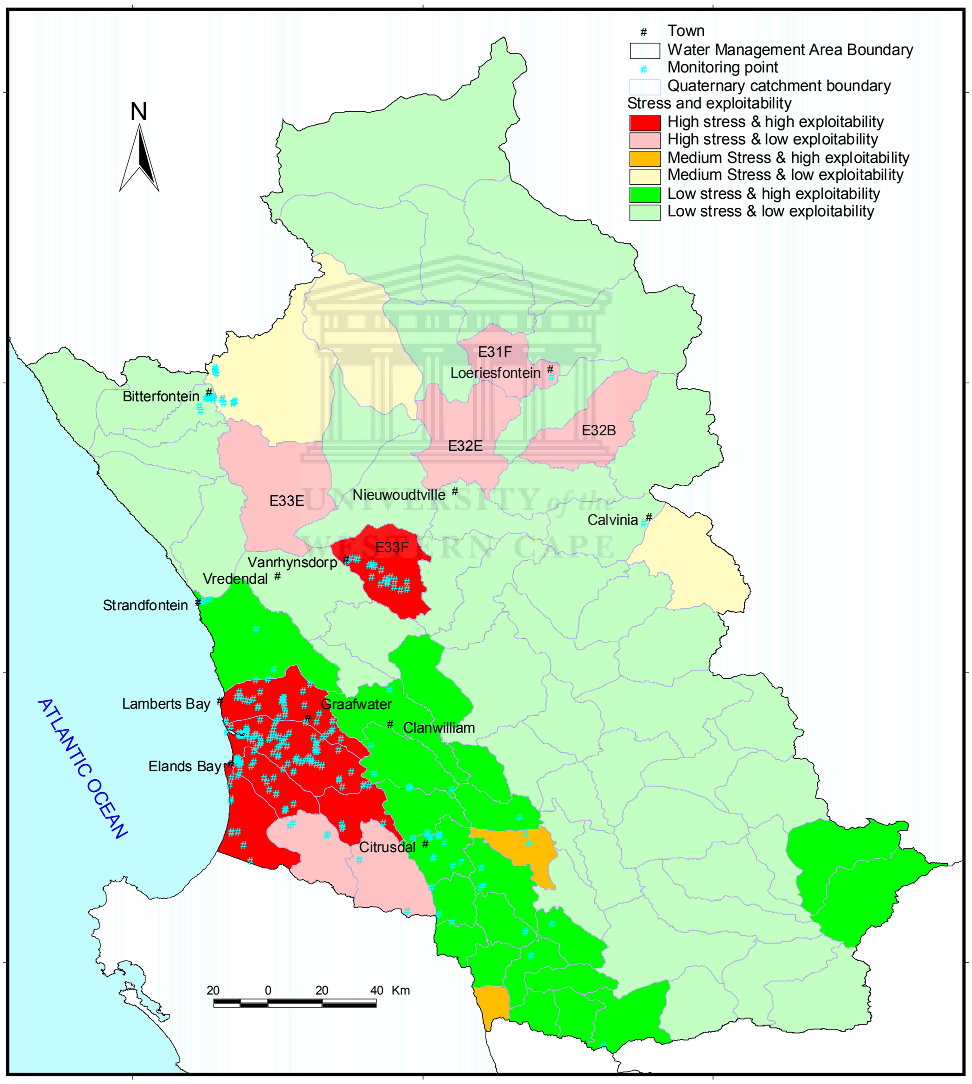


Figure 43: Groundwater stress and groundwater exploitability

9.3.7 Optimize monitoring frequency and density

Generally, the longest (planned) monitoring interval by DWAF in the Olifants-Doorn is 3 months, and there are often concerns that this monitoring interval is too long, and should be either monthly or “continuous” (i.e. via a data logger taking several readings per day.) However in other countries, e.g. Pakistan, monitoring is often carried out at only 6-monthly intervals without any serious shortcomings, and optimisation using statistical techniques focuses on spatial density rather than monitoring intervals (Gangopadhay et al., 2001). Using a detailed statistical analysis Rosario et al., (2005) showed that many monitoring points in the Limpopo region could actually monitored quarterly rather than monthly. The use of statistics to optimize monitoring ***frequency*** is therefore recommended.

The benefits of using a statistical approach to optimize monitoring ***density*** might not be so useful, though, since the aquifers in the study area are generally of a local and discontinuous nature, and it is usually not feasible to extrapolate monitoring levels over any significant distance. (One particular groundwater compartment could show significant drops in waterlevels, while a compartment a kilometre or so away, might show no declines in waterlevel.) If statistical techniques are to be considered, they should at the very least take the local and discontinuous nature of the aquifers into account.

9.3.8 A programme manager to oversee the monitoring

It has been noted earlier that there is a lot of fragmentation in monitoring activities, with many different individuals involved in different activities in the monitoring cycle “chain.” In such a system there is a high risk of garbage information entering the system, not necessarily because an individual has done anything wrong in their link of the chain, but because something innocuous and seemingly correct in their “link” can cause a serious mess further down the chain. A programme manager to oversee the monitoring process is therefore clearly needed. The manager would be involved in planning and implementing the monitoring networks and information dissemination, and therefore would do much more than ensuring quality control.

This requirement for a monitoring programme manager is discussed in detail by DWAF (2004b), where it is stated that one monitoring programme should only have one programme manager, but a given programme manager might be capable of overseeing more than one monitoring programme. In the Western Cape setup one possible scenario would that monitoring in all 4 WMAs in the region, and not just the Olifants-Doorn, be managed by one person.

9.3.9 Compile a monitoring management plan

A big short-coming with the current groundwater monitoring is the lack of a monitoring management plan, or indeed the lack of ***any*** useful documentation. Any new worker confronted with the monitoring network has to figure out for themselves the best they can what exactly the overall aims of the monitoring network is. The same applies to individual monitoring points – while the person who decided to make it a monitoring point, presumably had a clear idea of its purpose was, this was hardly ever formally documented, and later workers have to totally immerse themselves in the regional geohydrology before they can then start making educated guesses about the aims of individual monitoring points.

A management plan is therefore needed to rectify this situation. Such a management plan needs to be explicit regarding:

- the overall strategies of how monitoring will help resource management
- where the funds and personnel to do the monitoring will come from
- the overall scientific aims of the monitoring
- the purpose of each and every monitoring point

In short, the documentation should be so clear – as explained by DWAF (2004b) - that an outsider could use it to take over the monitoring activities with any other instruction. The Olifants-Doorn ISP (DWAF, 2005) gives further details and advice on how to draw up a monitoring management plan.

9.3.10 Monitoring committees at the Water Users Association level

It is suggested that a WMA is too large an area to be represented by a single forum for the practical, operational-level implementation and coordination of monitoring. For example, it would be difficult for groundwater users in Calvinia to have a role to play in groundwater monitoring at Elands Bay, and vice versa. The WUA level seems much more practical for a forum for people with a common interest to discuss common issues. A WUA would also seem the ideal group to receive report-backs and information dissemination on monitoring, and be the ideal group to steer or generally provide inputs to monitoring activities. Such a forum would also be a good place to test innovative ideas for monitoring, such as volunteer monitoring.

9.3.11 Take cognizance of the likely impacts of climate change

The latest thinking (Midegely et al., 2005) is that the Western Cape, which includes the Olifants-Doorn WMA, will be warmer and drier in the future. The availability of water is likely to diminish, yet important ecosystems may require more water reserved for them in order to survive. To reconcile water availability with demand will require considerable skill, especially since demand reduction to the agricultural sector is seen as a key part of the process. In such a difficult situation it seems obvious that the status of groundwater resources will be needed to be known with more accuracy, so that groundwater requirements and cut-backs can be established with increased precision and fairness, and therefore – hopefully – with less conflict.

9.4 Implementation strategies

9.4.1 Approach used to select priorities

Clearly not all the components of a strategy outlined in section 9.3 can be implemented overnight. Some form of prioritisation is needed so that these components can be implemented in a step-by-step manner. In other words some kind of implementation strategy to "prioritise the priorities" is needed.

Neither the National Water Resource Strategy (DWAF, 2004a) nor DWAF's corporate strategy (DWAF, 2006b) provides sufficient detail to prioritise operational, day-to-day, activities in a WMA since both these documents deal with higher level strategies.

Instead the basic management principle of ***effectiveness*** was used. An attempt was made to prioritise the key interventions listed in section 9.3. according to their likely effectiveness in improving the sustainable use of groundwater. Although this prioritisation was made after considerable research and is based on considerable experience, it still depends heavily on one person's judgement, and therefore needs to be tested in discussion both inside and outside DWAF.

9.4.2 Proposed Monitoring Intervention Priorities

The interventions, in order of proposed priority are:

1. ***Address the need for groundwater use monitoring*** – to ensure sustainable use, that use must be known. This is a difficult and daunting challenge, and needs coordination with all regional and national initiatives to achieve use monitoring.
2. ***Establish monitoring committees at the WUA level*** – this has been proposed as the most appropriate level for a forum that deals with the day-to-day practicalities of regional, resource status monitoring. Obviously higher level committees and coordination will also be needed.
3. ***Improve monitoring information dissemination*** – monitoring data will have limited value if they are not reaching key decision-makers. Information dissemination is currently a weakness in the Olifants-Doorn monitoring activities.
4. ***Establish/support self-monitoring by groundwater users*** – with limited resources at its disposal, and a large need for monitoring, this is seen as a key strategy for ensuring representative monitoring. DWAF is in a (slightly) better position to absorb increased data entry than it is to do increased data collection.

5. ***Compile a monitoring management plan*** – there is an urgent need for the overall WMA monitoring strategy to be clearly documented, along with operational guidelines, and the monitoring objective of each monitoring point in the network.

6. ***Establish a programme manager to oversee monitoring*** – all the key interventions listed here need a programme manager to drive them, otherwise they will be diluted and eventually neglected by people with more "urgent" activities.

7. ***Focus on "groundwater resource status" monitoring - non-regional monitoring should be non-regionally funded*** – with limited resources at its disposal, the state's first obligation should be to see that its statutory obligations are met (the resource status monitoring in chapter 14 of the NWA (RSA, 1998), and refrain from seeing itself as a "one-stop-monitoring-shop" to everybody that has a need for monitoring.

8. ***Revise networks*** – this lumps together several key interventions from section 9.3: *focus on areas where borehole yields are highest, focus on areas where aquifer stress is highest,* and *optimize monitoring frequency and density.* The reasons for this being given such a low priority are: (a) significant – although probably not optimal – monitoring is already taking place in areas where both use and stress are high; and (b) all the other factors need to be addressed before network revision will be ***effective*** in ensuring the sustainability of groundwater use.

9. ***Take cognizance of the likely impacts of climate change*** – despite being placed last, this is possibly one the most important issues. It ended up being placed last because it was very difficult to know where to place it in the list of priorities. It is very difficult to highlight specific interventions that must be prioritised so as to deal with the effects of climate change. ALL aspects of groundwater monitoring and management need to be addressed with more precision so that an increasingly scarce water resource can be more equitably and efficiently utilised. Therefore the implications of climate change are that ALL the monitoring priorities listed above must be highlighted.

9.5 Implementation tactics

9.5.1 Utilize Adaptive Management

Some of the key aspects of adaptive management are stakeholder participation, hypothesis testing, learning by doing (Walters and Hollings, 1990), and a formal structure within which this experimentation can take place. Adaptive management needs to be applied to both the management of the water resources themselves, AND the management of monitoring interventions. For example the priority list of monitoring interventions described in section 9.4 should itself be regarded as a hypothesis to be tested by stakeholder discussions and implementation. Some of the hypothesis could well turn out to be incorrect.

An example: one might form the hypothesis that sustainability could be better managed by requiring everyone that uses more than a certain volume of groundwater to have flowmeters installed. However if a massive commitment to this intervention only achieved a 1% compliance rate, one might have to re-think the hypothesis.

Similarly hypotheses need to be developed of how the groundwater resources function – how water recharged, stored, transmitted through the system, and discharged, and so on. From such knowledge, however imperfect, the likely consequences of groundwater use can be predicted, albeit with considerable uncertainty. A preferred groundwater use scenario needs to be selected by all the stakeholders and monitoring implemented so that various hypothesis on which the scenario is built can be tested.

The adaptive approach does not need to be at odds with formal systems (bureaucracies). In fact the two approaches complement each other. Without the discipline of formal institutional structures, adaptive management could degenerate into chaos.

9.5.2 Accept that sustainability is “in the eye of the beholder”

Sustainability is not a fixed number, like “average annual recharge,” but a compromise between all stakeholders on what it is deemed acceptable, and on what can be continued into the future (Seward et al., 2006). What is acceptable, or at least tolerated by the wide spectrum of interest groups, in one area may well be unacceptable in another. Groundwater monitoring therefore needs to be flexible and be capable of responding to the subjectivity of sustainability, and not become too fixated on standards and uniformity.

Science should concern itself with identifying the “sustainability scenarios” or options, rather than trying to pin sustainability down to a number, and then let the stakeholders select an option.

9.5.3 Work within limits of exiting human resources

It is very tempting to list all the monitoring activities that one would like to have done, and only afterwards start to think about the resources needed to implement those ideas. It has been suggested in this thesis that working within existing resources is a more realistic approach for the Olifants-Doorn WMA. The monitoring interventions prioritised in section 9.4 are all intended to be implemented with existing resources, and could be achieved by re-prioritising, or even just raising the status of these activities. For example it should not be too unreasonable to expect DWAF officials to give short presentations on regional monitoring activities at, say, WUA meetings since they will be usually expected to attend those meetings anyway. And it should not be too unreasonable to expect DWAF to be able to synthesize its monitoring data and make it available for information dissemination since it has already invested in the tools to do this – e.g. Regis. The activities of a monitoring Programme Manager might well only require formal, documented changes to certain official’s work programmes. And so on.

However, it is accepted that attempting to implement this monitoring strategy solely by re-prioritising and re-focusing might not be totally successful, and that – modest – increases in staff levels might be required. This might be an extra data typist, as well as dedicated Programme Manager.

9.5.4 Use characterisation and modelling to give “meaning” to monitoring data

It has been pointed out (Kalf and Woolley, 2005) that monitoring data are usually not diagnostic. Declining waterlevels, for example, could mean that a resource is being pumped to depletion. On the other hand they could also indicate water being taken from storage as a precursor to new equilibrium conditions being established. It is important NOT to make bold, unsubstantiated claims that monitoring data "prove" one or other particular scenario (Seward et al., 2006) because the same data can fit many different scenarios.

Therefore monitoring data should not be used in isolation. A rudimentary form of characterisation of yields and ECs, as used in the 1:500 000 hydrogeological map series can be a good starting point. For example, simply by knowing whether a borehole is in a high-yielding area or not can help give "meaning" to waterlevels – significant drops in a low-yielding area would probably be due to local over-exploitation, while in high-yielding areas significant water level drops could mean the resource as a whole is being depleted.

If the geohydrology is not known, a monitoring borehole may be located on a tiny, disconnected aquifer, whose water levels and water qualities show trends that are completely unrelated to the major aquifers under consideration.

Characterisation, conceptual models, flow models, and chemical models can all facilitate the understanding of a resource so that the "meaning" of monitoring data can be interpreted with more confidence.

While the Programme Manager must clearly have the best available model (conceptual or otherwise) at hand when designing or revising a monitoring network, it is suggested that fully developing these models is beyond the Programme Manager's scope, and beyond the current capacity of DWAF. It is further suggested that this is the optimal place to draw consultants and research institutions into the monitoring process – in the development of conceptual and mathematical models to guide and give meaning to monitoring data, rather than directly in physical data collection and storage.

10. Conclusions

1. The overall purpose of regional monitoring was identified as ensuring sustainability – specifically ensuring sustainable use.

2. Sustainability involves addressing many subjective issues. It is more appropriate for science to help clarify the sustainability options, and to monitor the option choose, rather that labour under the misapprehension that sustainability can be defined in terms of a single, fixed number.

3. A monitoring strategy or the Olifants-Doorn WMA was formulated. The strategy is based on an attempt to reconcile monitoring activities with existing resources. The essence of this proposed strategy is contained in the following prioritised interventions:

   (i) Address the need for groundwater use monitoring

   (ii) Establish monitoring committees at the WUA level

   (iii) Improve monitoring information dissemination

   (iv) Encourage/support self-monitoring by groundwater users

   (v) Compile a monitoring management plan

   (vi) Establish a programme manager to oversee monitoring

   (vii) Focus on groundwater resource status monitoring – non-regional monitoring should be non-regionally funded

   (viii) Revise networks

   (ix) Take cognizance of the likely impacts of climate change.

4. The monitoring strategy, while based on considerable research, is heavily dependent on the judgement of the compiler of the strategy. It needs to be tested by discussion within and outside of DWAF.

5. The Olifants-Doorn WMA is probably not the best choice for a typical South African WMA to use as case study for the building of a national monitoring strategy. Its combination of winter rainfall, lack of major urban centres, lack of industries, and almost total dependence on agriculture, makes it essentially unique in South Africa. However, the proposed monitoring strategy is sufficiently generic, that it should be applicable to most WMAs with no, or minor modification. For example, the need for groundwater use monitoring is a national, and not just an Olifants-Doorn issue. However, it would be prudent to test the Olifants-Doorn strategy in other WMAs before using it as the basis for a national strategy.

6. The hypothesis that regional monitoring should focus on resource status monitoring could neither be proved nor disproved in the scientific sense. The hypothesis is, however, supported by legal, policy, and practical considerations.

7. Monitoring data are less diagnostic than is often realised. Ongoing characterisation and modelling is needed in order to improve our interpretation of monitoring data.

8. An adaptive management approach needs to be used, for both the management of the resources, and the management of the monitoring.

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