INSTITUTIONAL ARRANGEMENTS FOR GROUNDWATER MANAGEMENT IN DOLOMITIC TERRAINS: SITUATION ANALYSIS

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WRC Report No. KV 140/02

Water Research Commission

INSTITUTIONAL ARRANGEMENTS FOR GROUNDWATER MANAGEMENT IN DOLOMITIC TERRAINS

Comprising three sections

1. Synthesis Report
2. Situation analysis - Social Assessment
3. Situation analysis - Technical Assessment

Report to the

Water Research Commission

by

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INSTITUTIONAL ARRANGEMENTS FOR GROUNDWATER MANAGEMENT IN DOLOMITIC TERRAINS

- PHASE 1 -

EXECUTIVE SUMMARY

The dolomitic groundwater in the North West province is a valuable natural resource, which provides a reliable supply of water to towns, rural settlements, industries, agriculture and other activities in an area where surface water resources are negligible. Groundwater also sustains the flow of several springs, wetlands, and river channels, and is the lifeline of the ecology of these freshwater systems.

Due to the hidden nature of groundwater, the arising management challenges are highly complex. Water Management Areas (WMAs) have been demarcated largely according to surface water systems and seldom coincide with geohydrological boundaries, resulting in complex management problems and institutional arrangements. In the absence of an integrated approach, aquifer management is therefore seldom optimised, leading to neglect and the unsustainable use of groundwater. This is already evident in Dendron in the Northern Province (Masiyandima et al, 2001) and in countries in South and Eastern Asia, where the numbers of people dependent on groundwater are far higher than currently in South Africa (Shah et al, 2000b).

This project therefore seeks to develop institutional arrangements[1] for the sustainable and equitable management of groundwater in the dolomitic terrains of the North West province, South Africa[2]. The dolomitic aquifer is divided between three WMAs, to be managed by three catchment management agencies (CMAs). Institutional arrangements therefore need to be structured to address transboundary management and to realise the principles of equity and sustainability.

Appropriate institutional arrangements need to be informed by a sound understanding of the geohydrology of the aquifer, the ecological context of groundwater and the social, cultural and institutional dynamics of the area. The project has been divided into four phases:

Phase 1: Situation Analysis (desk-top review)

Phase 2: Situation Analysis (field research)

Phase 3: Workshop Management Options and Approaches

Phase 4: Preparation of Management Structure, Institutional Principles, and Information System for Groundwater Management

[1] The term 'institutional arrangements' is discussed and defined for the purposes of this study in Chapter 1.

[2] This project, located in dolomitic terrains of the North West province, is a pilot study to research management options for groundwater management in catchment areas.

This report, which represents the main output of Phase 1, provides an overview of issues related to the use and management of groundwater in the dolomitic terrains of the North West province. Six desktop studies, utilising the existing body of research on groundwater use/management, were undertaken.

Under the technical studies, the role of groundwater in the broader ecological context was analysed at a preliminary level. This was followed by research into the geohydrological properties of the aquifer. Lastly, the nature of impacts on the aquifer, including natural (e.g. droughts) and anthropogenic impacts (e.g. abstraction, pollution), was examined.

From a social/institutional perspective, the opportunities and constraints for groundwater management in terms of the new legal and policy environment were reviewed. Then, the roles and responsibilities of existing institutions involved in groundwater management were analysed. Thereafter the characteristics, needs and concerns of different water users dependent on groundwater were profiled. This was done in order to develop an understanding of water users' needs, concerns and existing capacity, as well as growth in water demands, and where conflicts and opportunities for collaboration between different water users might emerge.

In each study, gaps in knowledge and management challenges related to the groundwater of the study area were sought, in order to define the research priorities for Phase 2 of the project.

Challenges to the sustainable and equitable management of groundwater were identified. These related to aquifer modelling, accuracy of geohydrological information and refinement of estimated variables. Social and institutional constraints included issues of institutional capacity, the representivity of institutions (particularly with respect to small-scale/emerging user groups), and increasing water demands leading to conflict between users. Institutional arrangements need to be developed and equipped with the resources, tools and capacity to address these and other challenges through the management of groundwater.

Before entering Phase 2, particular issues require clarification. A key issue is how the various water management initiatives underway in the area (including amongst others, this project and the CMA processes) are integrated to support each other in terms of knowledge, implementation etc. Thereafter, in order to complete the Situation Analysis in Phase 2, in-depth field research is required to address gaps in the existing knowledge base. Investigations need to include both geohydrological and social studies. The formulation of management options through a process that involves multi-stakeholder participation is also essential.

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ABBREVIATIONS

CDM/C	Central District Municipality/Council
CMA	Catchment Management Area/Agency
CMS	Catchment Management Strategy
DoA	Department of Agriculture
DWAF	Department of Water Affairs and Forestry
GGP	Gross Geographic Product
ISARM	Internationally Shared Aquifer Resource Management
IUCN	World Conservation Union
IWMI	International Water Management Institute
NWA	National Water Act (Act 36 of 1998)
NWWSA	North West Water Supply Authority
O&M	Operation and Maintenance
SADC	Southern African Development Community
SDM/C	Southern District Municipality/Council
WMA	Water Management Area
WRC	Water Research Commission
WSA	Water Services Act (Act 108 of 1997)
WSDP	Water Service Development Plan
WUA	Water User Association

1 INTRODUCTION

1.1 *The need for groundwater management in South Africa...*

Groundwater has a history of neglect and unsustainable utilization in South Africa (Braune, 2000b). Despite recent developments in policy, and the importance of groundwater as a strategically important resource on which many rural communities depend, water management in South Africa remains largely determined by surface water systems. Aquifers do not always coincide with the nineteen catchment management areas demarcated for the delegation of water resources management (see Map A.2). In addressing this situation, we need to develop the institutional arrangements for groundwater that protect this important resource, taking into consideration the characteristics and broader role of groundwater, and that address issues of inequity around the access to and use of water resources and services, as provided for in Section 27 of the National Water Act (RSA, Act 36, 1998).

The development of institutional arrangements needs to consider both socio-economic conditions and the status of water resources in the country. South Africa is among the 20 most water stressed countries in the world with water resources unevenly distributed in space and time (Braune, 2000b; DWAF, 1997). This is highlighted in a map of projected global water scarcity, prepared by the International Water Management Institute (IWMI) and presented at the World Water Forum in 2000:

Figure 1.1 Projected Water Scarcity in 2025
(Source: International Water Management Institute (IWMI), http://www.iwmi.org)

In addition, South Africa has a growing population and an urgent need for economic development to address poverty, job creation and inequity. Access to water and water services is vital to health and development opportunities. Poverty alleviation and economic development therefore, have to be one of the focal points of water management. These considerations are built into the new water legislation, with provisions made for consideration of issues related to equity, access, existing use, socio-economic implications, etc. in the issue of general authorisations and licenses (Section 27, RSA, Act 36, 1998).

In laying the foundations for addressing these and other socio-economic issues, the following criteria underpin South Africa's new policy (DWAF, 1997:11):

- meeting the service needs of the unserved
- people must at the centre of the concern for sustainable development
- water management and development should be conducted on a participatory basis
- decision-making must take place at the lowest possible level
- protect and sustain the water resources on which we depend
- manage water sustainably as a limited resource and an economic good to ensure efficient use

In addition, the goals of equity and sustainability are the guiding objectives of the National Water Act (RSA, Act 36, 1998). Equity also needs to address access to water services, water resources and the benefits from water. In a definition that encapsulates both equity and sustainability, Gleick (2000:131) defines sustainable water use as "the use of water that supports the ability of human society to endure and flourish into the indefinite future without undermining the integrity of the hydrological cycle or the ecological systems that depend on it."

With high rates of evaporation and utilisation of surface water resources being pushed to their limits, groundwater is becoming one of the most increasingly important resources to meet the urgent and growing needs for water (Braune, 2000b). Addressing its optimal management in this context is therefore a priority. However, groundwater management is complicated by its unseen and invisible nature. Past and current planning have resulted in a complex situation, where the boundaries of water management areas (WMAs), provinces, local authorities and other initiatives do not coincide - a situation which is further compounded when inserting geohydrological boundaries into the scenario (WISA, 1997). In addition, water management areas (and institutions) are largely defined by surface water patterns, further sidelining the importance of groundwater, and increasing the problems for its management.

This project, a pilot study to explore management options and approaches, including institutional arrangements for the management of groundwater in dolomitic terrains, is located in the North West province in South Africa (see Map A.1). The area consists of a largely flat and featureless terrain with negligible surface water resources, where water users depend on groundwater. The arising management challenges are highly complex, given the cross-cutting geohydrological boundaries, determined by geological features and dolomite flow patterns, and the water management areas demarcated in the region (see Map A.2). The aquifer[3] is divided between three WMAs, to be managed by three catchment management authorities (CMAs). A primary objective of this study is that institutional arrangements therefore need to be structured for optimal management of the groundwater, addressing transboundary management and realising the combined goals of equity and sustainability.

In a semi-arid environment such as South Africa, groundwater plays an important role in the water supply of rural communities, smaller towns, agricultural activities and ecology associated with springs and wetlands. Over 90% of groundwater in South Africa occurs in fractured hard-rock aquifers, which generally have a low storage potential. In contrast, the dolomitic aquifers in the North West province contain large reserves of groundwater and have a good rate of replenishment. Sustainable development is also critically dependent on availability of groundwater and impacts induced by increasing exploitation of the resource and associated problems such as pollution. Effective management of the resource is critically dependent on reliable assessment of the exploitation potential of the resource and all interacting components (e.g. surface water systems, wetlands etc). The more limited the water supplies, the more critical becomes the problem of water quality, pollution and sustainable use of the groundwater resource. The supply and quality of the groundwater are directly related to the average annual rainfall of a region and inversely to the potential evaporation.

1.2 The international context...

Problems resulting from unsustainable groundwater management/use practises in other regions are far more extreme than those we are beginning to experience in South Africa. Problems are magnified in areas such as China, and West and South Asia where population densities and the numbers of people dependent on groundwater are far higher than currently in South Africa. Groundwater problems in these areas include the depletion of groundwater levels due to overdraft, water logging, salinisation and pollution, with a common symptom being the general decline in water tables (Shah, et al, 2000b). Other problems associated with groundwater over-exploitation include the devastation of wetland ecologies (with associated socio-economic impacts such as decline in the tourism industries), the loss of recharge area through the rapid growth of urban areas (e.g. near Beijing in China and Izmir in Turkey), land subsidence due to groundwater depletion, and the risk of saline intrusion into depleted coastal aquifers (Shah, et al, 2000b). Without equitable and sustainable management systems for groundwater, these problems may become a regular occurrence in South Africa.

In addition, the complexity of groundwater management across international borders has not been properly addressed. The uncontrolled drilling of boreholes into aquifers that transcend international boundaries raises complex questions around issues of sustainability and management arrangements at an international level[4]. Groundwater cannot be overlooked in a regional context,

[3] In general, the focal area of this project is defined by the boundary of the resource (the dolomitic aquifer). In the east, the focal area is defined by a dyke, believed to act as a significant barrier to water flow in the aquifer (see Maps A.4 and A.5). This dyke is more or less consistent with the boundary of the Middle Vaal WMA.

[4] Meyer, R. 2001, personal communication, Pretoria, July.

as aquifers, like surface water, do not adhere to international borders. Transboundary aquifer management is, at this stage, relatively unchartered territory, although a need has been identified to address the regional development and protection of this "invisible water" (Molapo, et al, 2000).

Despite these problems, groundwater has a valuable role to play, particularly in poverty alleviation, if integrated management systems are implemented (Braune, 2000b; DWAF, 2000b). In addition, the resilience of groundwater resources during droughts presents an important opportunity for water security in arid and semi-arid countries (Colvin, 2001; Shah, et al, 2000b).

While there are some examples of sustainable management approaches for groundwater resources throughout the world, problems lie in transferring these lessons in water management between countries, taking into consideration very different local conditions within which such systems would be applied (Shah, et al, 2000b). In their paper on "Limits to Leapfrogging", Shah, et al, (2000a) highlight the challenges faced in transposing institutional models for water management from developed countries to the developing world. While institutional models for water management in developed countries may indeed hold some lessons, their application in developing countries has not always been successful, and in some cases has proved counter-productive, due to vastly different local conditions.

Shah, et al (2000a:16) argue the need to take a broader view of institutional development: to look beyond the narrow focus on the role of governments in institutional change, and incorporate all stakeholders (business, civil society, religion, etc.) in the development of institutions, with particular emphasis on the voices from the grassroots. An understanding of the realities within a specific context will best inform the institutional changes necessary for addressing that reality.

1.3 "Institutional Arrangements"

Institutional arrangements depend on a country's prevailing cultural, social, economic and political conditions, and as these conditions change, the institutional arrangements need to adapt accordingly (UNEP/GPA, 2000). South Africa's political transition, and the recent process of water law reform, has resulted in the need for new institutional arrangements to organise water management in line with these changes. Before addressing this issue, is it necessary to clarify the concepts of institutions and institutional arrangements for the purposes of this study.

"An institution is a set of norms or effective rules used by a group of people in order to organise a certain sphere of their collective activities" (Aylward and González, 1998:60). In the context of this project, we are therefore addressing the rules and norms used to organise the collective activities related groundwater management. This is further defined by the rules and norms specific to a particular geographic area and a particular resource, namely groundwater in the dolomitic terrains of the North West Province. Although this is a pilot study and the institutional arrangements should be generic, there are nevertheless specific institutions at the local level that need to be considered.

In South Africa, rules and norms are informed by the Constitution and by the legislation enacted under the Constitution. These institutions lay out the principles, objectives, and institutional approach and structure to be adopted in relation to, for example, water management. It remains to define the specific institutional arrangements for the resource, according to both the requirements set out at a national level and according to local needs. In this case, the institutions provided at a national level do not cater for a critical aspect of the specific resource, namely that it transcends the management boundaries defined by the State for water resources. Institutional arrangements need to make provision for this characteristic, which is typical of groundwater. Then, the roles, responsibilities and functions of institutions within this structure need to be defined, and finally, the requirements, such as information or capacity building, needed to manage the resource effectively need to be identified.

Institutional arrangements therefore including the following:

- principles, objectives and institutional approach for groundwater management
- overall institutional structure and implementing agencies
- roles, responsibilities and functions of implementing agencies
- requirements and support needed to ensure functioning institutions

1.4 Objectives of Phase 1

Some background was provided in the previous section on the context of this project, and its overall objective: the development of institutional arrangements for the sustainable and equitable management of groundwater in dolomitic terrains. In developing this framework, the project has been divided into four phases:

Phase 1: situation analysis - desk-top review
Phase 2: situation analysis - field research
Phase 3: workshop management options and approaches
Phase 4: preparation of management structure, institutional principles, and information system for groundwater management

The core of Phase 1 comprises the first part of a situational analysis drawing on existing information. Several areas of study were isolated for the purposes of this study, which have been integrated in this synthesis report. The study components and the structure of the reports for Phase 1 is illustrated in *Figure 1.2*:

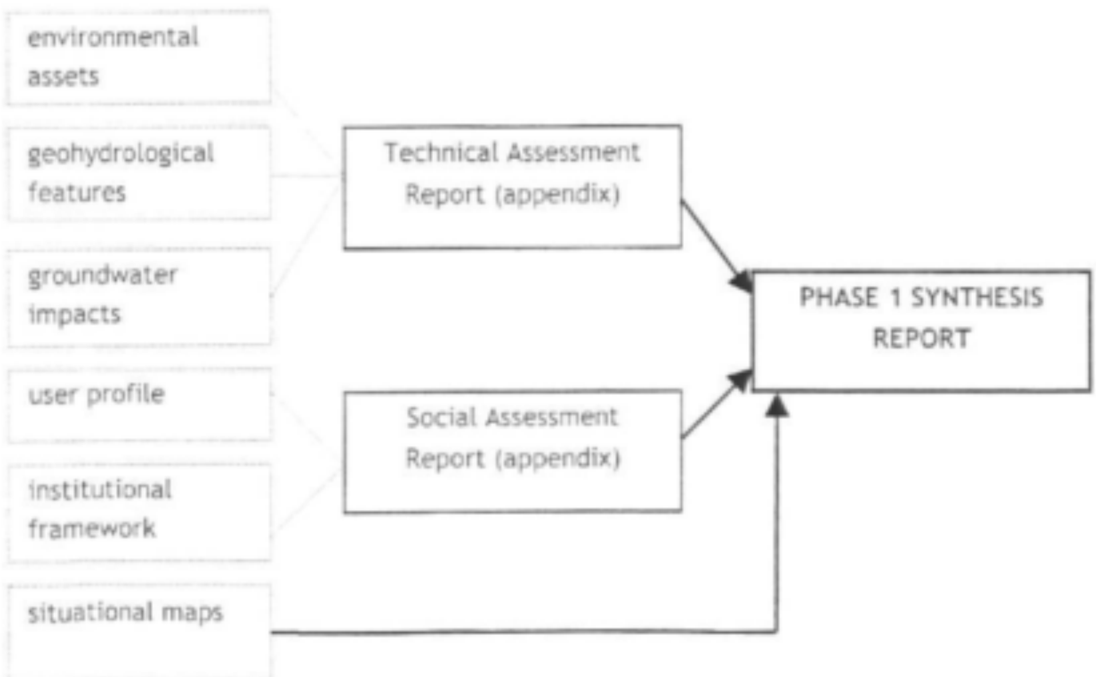

Figure 1.2 Study Components and Report Structure of Phase 1

In line with the Terms of Reference for Phase 1 of the project, this phase will assist in highlighting gaps in knowledge as well as begin the identification of management challenges that may arise as a result of managing a resource that transcends WMAs.

This report, which represents the main output of Phase 1, provides an overview of issues related to groundwater use and management in the dolomitic terrains of the North West province. The outputs of Phase 1 that are being addressed through the Phase 1 Synthesis Report[5] are:

- desk-top studies as well as situational maps
- gaps in knowledge identified and synthesized
- preliminary identification of management challenges, inputs for information system and options for institutional arrangements

1.5 Methodology

The purpose of this phase of the project is to examine and synthesise existing research and other documented information related to groundwater management in dolomitic terrains, to identify gaps in the existing knowledge base, and to highlight issues for further investigation in later phases on the project.

Document analysis has therefore guided most of the research in this component of the project. This has included a review of relevant legislation and policy documents, past research and reports on groundwater and water management, papers and publications addressing groundwater/water management, as well as a review of information available on the internet. In addition, the use of socio-economic statistical census data from the municipal demarcation process in 2000 has provided an important socio-economic background to the study.

In addition, two field visits were conducted - the first as an introduction to the study area, to gain an awareness of the geohydrological and environmental issues, and the second, as part of a stakeholder analysis, to conduct semi-structured/informal interviews, particularly amongst groups who were not accessible telephonically. This provided valuable insights into some of the social and institutional issues in the study area that need to be addressed. A series of telephonic interviews with key informants was also undertaken to gauge a conceptual understanding of the views and perceptions of stakeholders across the area, particularly those involved in the use and/or management of water, as well as experts.

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[5] Two detailed reports (included as appendixes) were compiled as a result of these studies of which this report provides a summary and an overview:

Stephens, A. 2001. Social Assessment: Institutional Arrangements for the Management of Groundwater in Dolomitic Terrains (Phase 1: Situation Analysis). IUCN South Africa.

Bredenkamp, D. 2001. Technical Assessment: Institutional Arrangements for the Management of Groundwater in Dolomitic Terrains (Phase 1: Situation Analysis). IUCN South Africa.

As much of the information presented in the institutional and social components of this report is gained from interviews, it is important to realise that the information presented is, in many cases, opinions and perceptions, and not necessarily fact. However, as perceptions (or misperceptions) held by stakeholders, this information is valuable and important to consider in developing institutional structures for groundwater management that suits the social dynamics of the study area.

1.6 Other water management studies

In pursuing an integrated approach to planning and management, it is important that this project take into account other studies currently underway in the project area, particularly in the case of water management projects, the outcomes of which will have significant implications for each other. This also provides an opportunity to share knowledge and resources where necessary/possible.

The number of long-term projects not only creates confusion, but also fatigue amongst stakeholders, affecting their level of interest, willingness to cooperate and to participate in the process and its outcomes. Promoting an understanding of the benefits (or prevention of negative impacts) by participating in these processes might go some way to alleviate this problem. Participation is a key component of this project, particularly considering the array of stakeholders involved, and will significantly influence the results of the research. In addition, participation of stakeholders is an important element of water resource management, and is strongly emphasised in water law and policy. It is therefore essential that participation inform the development of a management framework in which stakeholders will ultimately play a key role. As a result, it is necessary to approach the public participation process of this study sensitively, with awareness of, and possibly in conjunction with similar processes in the area.

The establishment of the catchment management agencies (CMAs) are processes currently underway in the study area. However, the establishment of the CMAs are at different stages in their development and following different approaches[6]. It is nonetheless important that there is integration between these processes and this groundwater project as the outcomes of these projects have the potential to significantly affect each other. In addition, this project has the potential to support the implementation of the CMA processes (and other water management initiatives in the area) through enhancing the knowledge base on groundwater and addressing the challenges of groundwater management.

A further DWAF project is underway in the study area, investigating the augmentation of primary water supplies to Zeerust, Mafikeng and Swartruggens. Contact has been made with this project team, and the need for integration and coordination identified, particularly during the later stages of the projects. Local planning processes, which should also be considered where necessary, include the preparation of integrated development plans for the district councils in the area, as well as the preparation of water service development plans.

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[6] For example, the Board of Crocodile West-Mariko CMA would be established during 2002 and the CMA would be phased in over the next five years, while the CMA process in the Middle Vaal CMA was still in the early stages of establishment.

1.7 Structure of this report

This report is structured to present a clear and integrated overview of the key issues emerging out of Phase 1 of the situation assessment of this project.

Section two outlines the legislative and policy environment affecting the management of groundwater in South Africa, as well as an analysis of the opportunities and constraints for groundwater management under the new water legislation.

Section three provides a brief overview of the study area, outlining the social, institutional and geohydrological context of the project, within which institutions need to operate.

The existing institutional arrangements are presented in section four, looking at the roles and responsibilities (related to groundwater management) of institutions currently in existence in the study area. Thereafter, in section five, the main categories of water users are profiled, in order to provide an understanding of the characteristics of different user groups dependent on groundwater, which groups' water needs are increasing or decreasing, where competition or conflict might lie, and how the needs of different groups are represented in terms of water management structures/institutions in the area.

Sections six to nine address the technical issues of the study, looking at the broader ecological role of groundwater in the environment and groundwater-dependent ecosystems in the area (section six), the status of groundwater quality (section seven) in the study area and the main factors impacting on groundwater (section eight), which those ultimately responsible for groundwater management need to understand.

Finally, the challenges to sustainable and equitable management of groundwater that have emerged through these specific study components are discussed in section nine, and preliminary management options introduced, based on a review of the existing body of research.

2 LEGISLATIVE FRAMEWORK FOR GROUNDWATER

South Africa has gone through an extensive review of water legislation since 1994, resulting in the promulgation of the Water Services Act (RSA, Act 108, 1997) and the National Water Act (RSA, Act 36, 1998). These Acts provide a combination of legal obligations, rights, responsibilities and constraints for the sustainable development and management of water resources in South Africa. This section looks at the opportunities and constraints for the groundwater management in the new water legislation.

2.1 Development of water policy in South Africa

Prior to 1994, water law in South Africa was based on the development needs (domestic, agricultural and industrial) of white settlers and was shaped by Roman law, Roman Dutch law and later English and American law (Kavin, 2000). The results of these influences were the distinction made between public and private water (riparian principle), which entitled landholders unlimited use of private streams and groundwater resources found on their land. In 1912 the Irrigation and Conservation of Waters Act was introduced, dealing mainly with irrigation and giving agriculture priority use of water. Due to conflicting demands emerging with the rapid growth of mining and industry, this legislation was repealed in 1956 through the introduction of the Water Act (RSA, Act 54, 1956). However, the Act entrenched the concept of private water and there was no obligation to share resources equitably.

The 1956 Water Act made the following distinction between different categories of groundwater (Lazarus, 1998; Kavin, 2000):

- *Subterranean water:* Subterranean water includes, 'water naturally occurring underground or obtained from underground in an area declared...as a subterranean Government water control area'. Subterranean water is not defined as either public or private water in the Act but is a category of water distinct from underground water and subject to different allocation rules.
- *'Public' Surplus water:* Surface water (streams) qualified as public water and was further categorized as either normal flow or surplus water. Because underground water cannot qualify as normal flow since this must visibly flow, it qualifies as surplus water, which is any public water other than normal flow.
- *'Deemed' Private water* is water that is pumped from underground (e.g. borehole water). Provided this water is not derived from a public stream, the Act deems this water to be private water. It is this category of groundwater that has created the greatest obstacles to those managers concerned with managing water resources in the national interest as the sole rights to use and enjoy private water vest in the owner of the land on which it is found.

The lack of accountability to government for proper groundwater use and management has frequently resulted in the over-exploitation of groundwater resources (Lazarus, 1998). A period of extensive review and reform of water legislation followed 1994, resulting in the publication of several policy documents and legislation related to water:

- The *Water Supply and Sanitation Policy* (1994), motivated by approximately 10 million people without access to basic water supplies and a further 22 million without access to basic sanitation. The WSSP outlines policy principles for the delivery of water and sanitation services.
- The *Constitution* (1996) and the Bill of Rights ensures access to potable water and an environment that is not harmful to the well being of the people of South Africa.
- The *National Water Policy* (1997) establishes the principles for resource sustainability and security of water supplies, and translated into the following legislation.
- *Water Services Act, No 108 of 1997 (WSA)* aims to create a developmental regulatory framework within which water services can be provided. The Act establishes water services institutions and defines their roles and responsibilities. The WSA gives substance to constitutional requirements and provisions, whilst acknowledging the authority of local government in respect of water services.
- *National Water Act, No 36 of 1998 (NWA)* aims to ensure that South Africa's water resources are protected, used, developed, conserved, managed and controlled in a sustainable manner for the benefit of all persons. The Act places National Government, through the Minister of Water Affairs and Forestry, as the public trustee of the nation's water resources.

The National Water Act and Water Services Act have important implications for groundwater, providing a framework for sustainable use of the resource. However, while all water in the hydrological cycle, including groundwater now has equal status under the NWA, groundwater remains the most prone to poor management, due to a lack of understanding of its occurrence, attributes and dynamics.

2.2 *National Water Act (Act 36 of 1998)*

The lack of explicit recognition of the unity of the hydrological cycle in the 1956 Water Act was an inexplicable anomaly, however the National Water Act of 1998 rectified this by recognising groundwater as public water, as reflected in the Water Law Principles (DWAF, 1997). Because groundwater has the same status as surface water, the sustainable use of groundwater will be achieved through the same three policy goals which have been formulated for surface water resources (DWAF, 2000b). These as stated for groundwater resources are:

- To implement *source-directed controls* to prevent and minimise, at source, the impact of development on groundwater by imposing regulatory controls and by providing incentives;
- To implement *resource directed measures* (RDM) in order to manage such impacts to protect the reserve and ensure sustainability;
- To *remedy groundwater quality* where practicable to protect the reserve and ensure at least fitness for the purpose served by the remediation.

Source directed controls are the "traditional" measures used to protect water resources, and aim to minimise the over-exploitation and degradation of groundwater (DWAF, 2000b). They consist of:

- Establishing an understanding of the vulnerability of groundwater resources to pollution;
- Establishing an understanding of the relationship between polluting activities (sources) and groundwater quality;

- The regulation and prohibition of land-based activities which may affect the quantity and quality of water;
- Control of practices and use of measures to reduce the polluting effects of activities which threaten groundwater quality; and
- Controlling the aggregate impact of certain prescribed activities.

Resource directed measures[7] are measures to protect water resources and consists of three core concepts (DWAF, 1999):

a) *Classification:* Under a national protection-based classification system, water resources can be grouped into classes representing different levels of protection. The risk, which can be accepted in each class, is related to the level of protection required for that class. This provides a nationally consistent basis and context for deciding on an acceptable level of short-term risk, against the requirements for long-term protection of a water resource. For water resources which are especially important, sensitive, or of high value, little or no risk would be acceptable, and they would be assigned a high protection class.

b) *The Reserve.* This is defined by the Act as "the quantity and quality of water required:

   - To satisfy basic human needs by securing a basic water supply for people who are or who will in the reasonably near future be relying upon, taking water from, or being supplied from the relevant water resource; and
   - To protect aquatic ecosystems in order to secure ecologically sustainable development and use of water resources" (RSA, Act 36, 1998).

c) *Resource Quality Objectives (RQOs).* The RQOs for a water resource are a numerical or descriptive statement of the conditions based on scientifically derived criteria, which should be met in the receiving water resource, in terms of resource quality, to ensure that the water resource is protected.

Implementing the requirements of the legislation will require the resolution of the following issues, without which there will be limited integration of groundwater in the broader water resource management framework (after Xu *et al*, 2000):

- Integrated classification to link delineated hydrogeological systems with eco-region classification systems (RSA, Act 36, 1998);
- Approaches to establish reference conditions (conditions prior to impact)
- Approaches to identify and map groundwater dependent ecosystems;
- Understanding groundwater / surface water linkages
- Appropriate RQOs and monitoring systems that address ecosystem and groundwater integrity.

[7] The methodologies to implement these measures for the protection of groundwater resources are in the developmental phase, however present thinking on the use of the different instruments provided in the Act is summarised in Braune, 2000.

2.3 Challenges to the sustainable development of groundwater resources

The challenges in delivering groundwater-based services to communities lie in overcoming constraints and uncertainties, which range from limited understanding of groundwater conditions in fractured rock aquifers, to institutional arrangements necessary for Integrated Water Resource Management (IWRM).

Implementation paradigm: coverage before sustainability

Lack of basic services, such as water supply and sanitation, is the norm in rural areas of South Africa. A concerted effort is being made to deliver the services, however emphasis has been placed on construction for increased coverage rather than sustainability. The lack of sustainability leading to failure has been a result of implementing agencies operating in an environment in which they design technical solutions and then take no further responsibility to make the solutions work despite emphasis on the need for community involvement at all stages of the process (DWAF, 1994).

Water scarcity

Water resources management in Southern Africa is complicated by the following factors:

- Approximately two-thirds of South Africa is classified as semi-arid to arid[8].
- South Africa's rainfall is highly variable and seasonal, with an average rainfall of 500mm/annum, just over half the world's average (Goldblatt et al, 1999).
- Population growth and socio-economic development is compounding water scarcity.
- Southern Africa is likely to experience chronic to absolute water scarcity from 2020 (Muller, 2000).
- The annual average water availability for South Africa in 1995 was 1200m^3 per person per year (Muller, 2000). With projected population increases, this will deteriorate to 730m^3 per person per year in 2025. However, the impact of AIDS in South Africa adds uncertainty to these figures, and compounds the accurate prediction of water demand projections (Ashton and Ramasar, 2001).

Resource sustainability

While groundwater development may be comparatively easy and economical, achieving sustainable aquifer management is complex. Poor assessment of groundwater resources, inadequate analyses of the consequences of groundwater exploitation, lack of technical understanding and inadequate institutional frameworks, may lead to management decisions that could cause irreversible loss of groundwater or even the aquifer storage capacity (ASCE and IHP IV, 1997). Key challenges to sustainable aquifer management include (after Foster *et al*, 2000):

- Development of groundwater decision support systems.
- Assignment and consolidation of groundwater use rights and introduction of realistic abstraction charges.
- Increased stakeholder participation in local groundwater management and decision-making.

[8] Arid and semi-arid conditions are defined as the following - arid lands have less than 250 mm of annual rainfall, and semi-arid lands have a mean annual precipitation of between 250 mm and 500 mm (Strahler, 1969).

- Recognition (by all stakeholders) that groundwater recharge varies markedly in a temporal sense with long-term climatic cycles and changes; with surface water engineering works; and with changes in irrigated agriculture and urban water-service systems.
- Recognition of the linkages between groundwater and surface water resources, which often favour their conjunctive use.

Environmental issues

Implementation of IWRM also requires protection of the environment, the philosophy being that the protection of the ecosystem structure and function will maintain resilience and sustain the resource (MacKay et al, 2000). Groundwater plays a number of key roles in the hydrological system, and sustainable management of groundwater resources therefore requires an understanding of these roles, particularly how vegetation influences recharge and how groundwater discharges influence ecosystems (Le Maitre et al, 2000; Parsons, 1998). The nature of the dependency is poorly understood and there is a great deal of uncertainty how far the actions of humankind influence the environment.

Inadequate monitoring and evaluation systems

Development of appropriate monitoring and evaluation (M&E) systems is crucial to resource sustainability. It forms the basis for decision support and provides a means to assess progress in meeting groundwater sustainability (including water security) objectives. M&E systems should be holistic, addressing issues beyond the resource, such as biological integrity. M&E systems should also provide continuous feedback to enable assessment and ensure that problems are identified at source so that corrective action can be taken. While this might represent an ideal scenario, the situation on the ground with respect to M&E is often very different.

Multi-objective analysis

IWRM and the implementation of the NWA require multi-objective decision-making. The challenge of water resource planning and management is to make decisions that result in optimal use of the resource, while protecting the environment and similarly contributing to economic development. Non-trivial decision-making of this kind involves multiple goals with some measure of trade-off between conflicting goals or objectives (Stewart *et al*, 2000).

2.4 Progress in implementing the NWA in relation to groundwater

Prior to 1998, the use of groundwater was in practical terms largely beyond the jurisdiction of the state. The NWA rectified this situation and treats groundwater as an integral and equal component of the hydrologic cycle. The Act provides the legal framework for groundwater management and will be implemented through specific regulations. The framework through which groundwater will be allocated is illustrated in Figure 4.

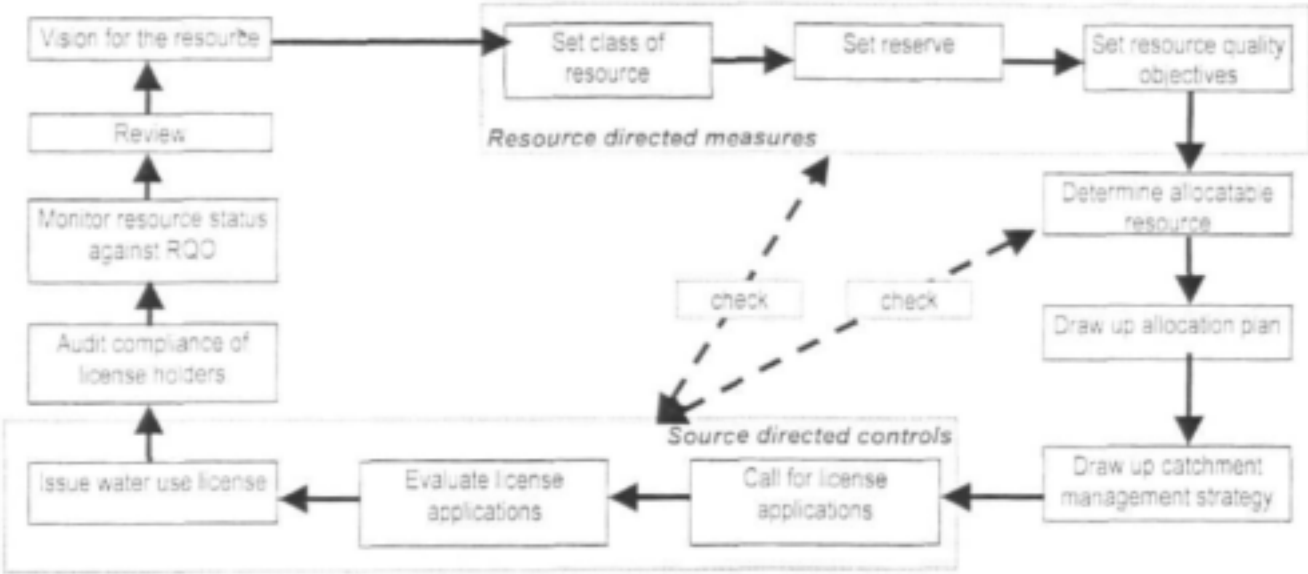

Figure 2.1 Legislative framework for groundwater management (MacKay, 2000).

1. The **first step** is to establish a vision for the resource at national level (through the National Water Resources Strategy) and in each WMA (in consultation with stakeholders).
2. The **second step** is to implement RDM to protect the capability of groundwater resources to support utilisation in the long term. The generic procedure for RDM determination is the following:
   a) *classify the resource* to establish the desired level of protection of groundwater dependent ecosystems and maintenance of aquifer integrity.
   b) *determine the reserve* to protect aquatic ecosystems and to ensure sustainability of groundwater-based community water supplies.
   c) set *RQOs* to specify the groundwater management regime.

   The challenges that the legislation poses through the use of RDM as a tool for groundwater protection are manifold and include (after Xu *et al*, 2000):

   - The translation of the principles of sustainable development and IWRM into reality
   - The ecological functioning of groundwater, currently considered only in terms of its impact on surface water resources (based on the current definition of the reserve), needs to be viewed from a broader perspective.
   - All ecosystems that are dependent on allocatable water, including groundwater-dependent ecosystems, have the right to a reserve.
   - How will the reserve for groundwater be specified?
   - Groundwater systems and their linkage to surface water and related ecosystems are still poorly understood.
   - The reserve is spatially referenced. What about temporal variability?
   - What is the volume of accessible water that satisfies basic human needs.
   - Verification of methodologies (so that they are legally defensible)

- Developing 'acceptable' methodologies within a framework of limited financial and human resources

3. Once the RDM measures have been determined, the **third step** is to determine the allocatable portion of the resource which must address issues such as social and economic development. The right to use of water is established in the National Water Act on condition that one or more of the following stipulations apply:
   - It is permissible under Schedule 1 (minimal or no impact)
   - It is permissible as a continuation of an existing lawful use
   - It is permissible in terms of a general authorisation (low risk of unacceptable impact)
   - Authorisation by a licence (high risk of unacceptable impact if not controlled)

To alleviate the burden of licensing, general authorisations for groundwater have been given for South Africa based on the groundwater harvest potential map, which attempts to determine available groundwater resources. In arid zones only schedule 1 uses are permitted, while subterranean water control areas (see Map A.2) are excluded from general authorisations for groundwater abstraction.

4. The **fourth step** is to implement source directed controls (regulations and incentives) to prevent or minimise impact on groundwater resources.
5. The **final step** is a monitoring and evaluation system to determine whether the policy goals are being implemented and having the desired outcomes.

2.5 Existing lawful use, general authorisations and compulsory licensing

Importantly, the NWA makes provision for specific tools and strategies to address issues of equity and access through the regulation of water use[9]. As noted above, water use must be licensed *unless* it is a Schedule 1 use[10] in terms of the NWA, is an existing lawful use or is permissible under general authorisation (Braune, 2000b). Responsible institutions are required, in terms of the Act, to utilise these tools in order to manage water resources equitably, sustainably and beneficially.

The continuation of existing lawful use[11] of water is permitted under certain conditions, including that it is not limited, prohibited or terminated by the Act (RSA, Act 36, 1998, sections 32-35).

[9] Water use is defined in the NWA as: "...taking water from a resource, storing water, impeding or diverting the flow of water in a watercourse, engaging in stream slow reduction activity..., discharging waste or water containing waste into a water resource..., disposing of waste in a manner which may detrimentally on a water resource, disposing in any manner of water which contains waste from, or which has been heated in, any industrial power generation process, altering the bed, banks, course or characteristics of a watercourse, removing, discharging or disposing of water found underground is it is necessary for the efficient continuation of an activity or for the safety of people, and using water for recreational purposes." (RSA, Act 36, 1998 section 21)

[10] Schedule 1 water uses are those that have a low or normal impact on water resources, including reasonable domestic use, domestic gardening, animal watering, emergency water use (human consumption and fire fighting) and recreational use (RSA, Act 36, 1998, schedule 1).

[11] Defined in the NWA as: "...a water use which has taken place at any time during a period of two years immediately before the date of commencement of this Act and which was authorised by or under an law which was in force immediately before the date of commencement of this Act; is a stream flow reduction activity...; or is a controlled activity...; or which has been declared an existing lawful water use under section 33 and which was authorised by or under

Licensing is not required to continue with existing lawful use until a responsible authority requires a person to do, when the license (or the failure to give a license) then becomes the source of authority for water use. Under these conditions, existing lawful water use is therefore protected by the NWA.

Section 27 of the NWA (Chapter 4, Part 2) provides guidance for authorities to exercise discretion when issuing licenses and general authorisations by outlining the considerations, conditions and essential requirements of general authorisations and licenses. Section 27 also sets out the features of licenses (including effective periods, purposes and places for which they may be issued). Factors that should be considered when issuing general authorisations and licenses include amongst others, existing lawful water uses, the need to redress the results of racial and gender discrimination, efficient and beneficial use of water in the public benefit and the socio-economic impacts of the water use(s) or of failing to authorise the water use(s) and the impacts of the water use on the resource and other users.

These provisions provide an opportunity for an authority, when required to issue licenses and general authorisations, to address issues of equity, sustainability and beneficial use. Specific issues, which may be addressed through the provisions made in Section 27 of the NWA include the needs of emerging water users and competition between water users. Although Section 27 provides the legal requirements to address these and other issues through licensing, challenges to its effective implementation lie in the need for emerging and small-scale users to represent their needs to authorities, and a lack of information about the resource on which to base licenses.

Finally, compulsory licensing provides authorities with a specific instrument to address water resources in areas which are, or are soon likely to be, under 'water stress' (e.g. demands exceed supply, water quality or water resource quality threatened) or where it is necessary to review prevailing water use to achieve equity in access to water (RSA, Act 36, 1998, section 43). The Act further requires that special consideration must be given to certain categories of applicants. Licenses issues under this section replace entitlements to existing lawful use. This section of the Act explicitly provides for addressing issues of sustainability, equity and beneficial use. It provides an opportunity in terms of licensing, to address existing allocations which may exceed the capacity of the resource, or problems of inequity in access to and use of water resources.

The NWA sets out provisions for addressing issues of equity in water use, specifically through the requirements of Section 27 and compulsory licensing (Section 43). These and other requirements ensure that the authorities responsible for groundwater management have the tools to promote sustainable and equitable use of groundwater resources.

2.6 *Concluding remarks*

The focus of groundwater management in South Africa, for the foreseeable future, will be on:

- meeting basic human water needs,
- maintaining resource integrity, and

any law which was in force immediately before the date of commencement of this Act; is identified as a stream flow reduction activity...; or is identified as a controlled activity...." (RSA, Act 36, 1998 section 32, as amended)

- equitable allocation for economic development

However, the challenge remains to implement these principles in reality. Management strategies will need to be developed to address the unique characteristics and roles of groundwater within the context of a socio-economic development paradigm.

Proper allocation of groundwater resources will require integrated planning, including the:

- development of scientific measures to assess fractured rock aquifers.
- development of verifiable objectives for groundwater management (equity principles).
- identification of groundwater management problems, constraints and uncertainties.
- development and analysis of alternative strategies (including measures) and uncertainties (multi-objective analysis).
- selection of the best compromise solution (robust solution).

3. PROFILE OF THE STUDY AREA

The project is located in the area defined by the proposed WUAs in the dolomitic terrains of the North West Province (see Map A.2), where water users are directly or indirectly dependent on groundwater. Towns included in the study are those either currently using or those needing to augment their water supplies using dolomitic groundwater in the near future (see Table B.1, Annexure B) for water consumption figures for towns).

The land-use around the urban settlements is largely rural, and characterised by cultivated or grazing land (commercial and subsistence agriculture), undeveloped land and scattered rural settlements, many once part of the former Bophuthatswana. The main land uses (see Map A.3) in the study area include agriculture, small industrial and mining operations, urban and rural settlements, and conservation.

3.1 Socio-economic characteristics of the study area

Demographic data (see Box 3.1) reveals strong imbalances and disparities in living conditions and opportunities between rural and urban areas. Conditions in rural areas, particularly in former Bophuthatswana districts, have poor standards of infrastructure and basic services, as well as low levels of employment and livelihoods opportunities.

Box 3.1 Development conditions in the study area

- In general, *population densities* are low, with around 6 people per km^2 for most of the study area. Densities are slightly higher in the south, around Lichtenburg, Coligny and Ventersdorp (6-15 people/ km^2), and notably higher in the former Bophuthatswana districts around Mafikeng (63-96 people/ km^2) and in areas north of Zeerust.
- The population *age distribution* is concentrated in the 5-19 year group, indicating a young, rapidly growing and dependent population with a low percentage of the population currently economically active.
- Employment figures range between 12% in Zeerust and 23% in Ventersdorp, with figures in Lichtenburg and Mafikeng 22% and 19% respectively, indicating *high rates of unemployment*.
- Of those employed, the majority are in elemental/unskilled *occupations*, mostly in farming (Ventersdorp), followed by social services (Mafikeng and Zeerust).
- The average monthly *household income* is less than R1500 (63% earn under R1500/mnth in the Ventersdorp area).
- *Migration patterns* reflect a movement from rural and farming areas to the urban centres.
- *Education* levels are low, with 20-28% of people with "no education". Of those with education, the majority have a primary education (30-37%).
- Although statistics show that most people have *water* supplied to their dwellings, higher densities and better service levels in urban areas introduce an urban bias in these figures. Public taps supply water to 60% of the population in Zeerust, while in Mafikeng 35% of the population receive water from public taps and a further 25% from boreholes. These figures are more indicative of conditions in rural areas.
- *Light* throughout most of the study area is from candles, particularly Ventersdorp. Municipal electricity is only the second largest source of electricity/light, followed by paraffin.
- Pit latrines (esp. Zeerust and Mafikeng) are predominantly used for *sanitation*, followed by water borne sewage. A small (but not insignificant) percentage of people use a bucket system or no sanitation system.
- The North West has the second lowest growth in *GGP* in South Africa, and the lowest contribution to the *GNP*.
- Disparities in growth and economic activity between former Bophuthatswana and Transvaal districts:
  - Overall *GGP contribution*: 0-7%
  - High *GGP growth* around Dinokana: 3 and 7%, and around Mafikeng: 7 & 12% (former Bophuthatswana)
  - Low/negative GGP growth south of Zeerust and around Ventersdorp (-2 & 3%), and north of Lichtenburg (-7 & -2%), indicating a rapid decline in economic growth in these areas

Agriculture has played a key role in the economy of the region, providing employment and livelihoods, both in agriculture and related services. Indications are that future economic growth in the region will rely heavily on agriculture. However, GGP figures show that the growth and contribution of agriculture is declining, which poses significant implications for economic development.

Future regional development will be facilitated through the North West Spatial Development Initiative, a long term planning initiative designed to promote economic growth and job creation through manufacturing, mining, agriculture and tourism activities. However, the availability of sufficient water supplies is a key factor affecting development, which needs to be carefully evaluated in planning initiatives. Currently, Mafikeng, Zeerust and Lichtenburg are the growth nodes of the region and most future developments there will take the form of housing as none of the existing industrial activities are planning significant expansion (DWAF, 2000a).

3.2 Geohydrology of the study area

The dolomitic deposits in the North West region included in the investigation cover an area of about 5000km^2 with virtually no surface water drainage but an abundance of groundwater (see Map A.4 and A.5). The *average annual recharge* of the dolomite aquifer (estimated at 10% of the rainfall) is 300x10^6 m^3 and the *underground storage* is 5000x10^6 m^3 (estimated thickness = 30m and storativity = 0,03) which represents the equivalent of *two Vaal Dams*. This figure is the average sustainable volume of water but would fluctuate depending on periods of above or below average rainfall.

The dolomite basin lies on the Black Reef Formation, and comprises of alternating layers of:

- *chert-poor* dolomite with *lower occurrence of groundwater*, and
- *chert-rich* dolomite with a *greater abundance of groundwater* due to more extensive karstification of the dolomite.

Clays and mudstone of the Karoo Sequence occur south of the dolomite outcrop. Superficial deposits, over 20m thick in places, overlie much of the dolomite. The major deposits are:

- alluvial gravel (and calcrete) in places over 20m thick,
- alluvium consisting of black organic clay derived from decomposed reed beds near springs and seepage along stream courses,
- residual chert and red soil covering large parts of the area.
- Large parts of the area are covered by good soils that are presently cultivated.

Groundwater occurs in fractures and dissolution channels that have formed over geological times due to the dissolution of carbonate by rainfall. The thickness of the groundwater aquifer could be inferred from drilling logs, but also from a linear relationship between the moving average rainfall (MA) and the groundwater levels[12].

A network of diabase dykes subdivides the dolomite into smaller compartments (see Map A.4 and A.5). Based on major dykes the study area has provisionally been subdivided into five groundwater

[12] For further discussion, see Appendix: Technical Report

units falling in three main Water Management Areas (see Map A.2). Because of their lower transmissivity, these dykes act as partial boundaries, in some places giving rise to springs that sustain a perennial flow, which provides water supplies to towns, villages and for irrigation. Major springs form the source of rivers such as the Molopo, Marico and Schoonspruit (see Map A.4), and are important ecosystems, supporting a variety of floral and faunal populations, including rare and endemic fish species, such as the *Barbus paludinosus* and *Barbus previpinnis* (see Table 6.1).

The Grootfontein unit and surrounding dolomite has been the focus of several groundwater studies aimed at refining techniques and developing new methods to obtain reliable assessments of the groundwater resource. Monitoring of groundwater levels has been maintained at several points and records for the Wondergat[13] (see Map A.4) exist back to 1923. The flow of several springs has been gauged and has been impacted by abstraction and so have water levels. Irrigation abstraction in the Grootfontein/Lichtenburg areas has been inferred from the electricity consumption of pumping installations over several years (van Rensburg, 1987).

Irrigation from boreholes comprises about 800ha in the Grootfontein unit[14], 700ha in the Lichtenburg/Itsoseng unit, 4000ha in the Schoonspruit (Ventersdorp) unit, over 3800ha in the Grootpan area and a much smaller irrigated area in the Zeerust unit.

The status quo of the dolomitic aquifer of the Northwest region is that the water supplies of several towns, rural areas and irrigation are directly dependent on groundwater supplied from springs and boreholes. There are limited alternative options for water supply due to a lack of suitable dam sites and the virtual absence of surface runoff. Shallow groundwater levels, wetlands and springs sustain the aquatic environment and certain vegetation.

Occurrence of groundwater in dolomitic aquifers covering the entire area is essentially not different to that of fractured hard-rock aquifers. In the dolomite the dissolution of carbonate by rainfall has effected large storage of subterranean storage being recharged from rainfall. Rapid drainage of groundwater via springs and wetlands could occur along highly permeable channels that have been leached underground. However the rate of drainage of groundwater is impeded by diabase dykes acting as overflow and partial leaky boundaries, which subdivide the dolomite into smaller compartments. The compartments could become isolated units in the case of severe depletion of the groundwater levels due to the dykes becoming less impermeable with depth. Interflow between different compartments is still an uncertain factor and needs to be addressed.

The natural balance between the groundwater recharge and output determines the *piezometric levels*. Apart from *recharge* the latter is controlled by *outflow*, which is governed by:

1) the hydraulic head and permeability of the aquifer;
2) the discharge of springs and river base flow; and
3) evapotranspiration losses by vegetation and wetlands.

[13] Wondergat is a natural sinkhole formed by the collapse of dolomite into a subsurface cavity over 60 m deep.

[14] Units refer to the areas broadly defined by the proposed water user associations (see Map A.2), the boundaries of which are based on aquifer sub-compartments.

The regional piezometric levels determine the drainage pattern, which generally conforms to the topography of the area (see Map A.1), although sudden water level drops could occur over the dykes. The natural groundwater levels fluctuate according to variations of rainfall during wet and dry periods. The natural vegetation and aquatic environment have been established according to the long-term average hydrological balance and would be affected by artificial abstraction of groundwater. Large expansions of irrigation from boreholes have had an impact on water levels and the flows of springs. In the same way the natural quality of the groundwater could be affected by pollution due to effluent disposal, spillage and farming activities such as cattle feedlots and use of fertilizers in crop growing.

Hydrological surveys and studies of the dolomite of the Northwest region over several years have greatly advanced the knowledge about groundwater occurrence and the quantification and management of the dolomitic resource, using simplistic methods as well as complex hydrodynamic models (Taylor, 1983; Botha, 1993; Polivka, 1987; Bredenkamp, et al 1995; van Rensburg, 1995; Bredenkamp and Nel, 1997).

The recharge is estimated at 10% of the average annual rainfall and the storativity of the aquifer varies between 1.5 to 5%, although in highly leached zones it is much higher. The aim of effective management of the groundwater resources of the region is to ensure sustainable development within tolerable limits of the detrimental impacts on the natural conditions imposed by abstraction.

In terms of quality, the flows of most springs have been affected by irrigation abstraction and some have even dried up, (e.g. the Grootfontein that has previously supplied Mafikeng with water). The impact of abstraction could be quantified reliably (Bredenkamp 1999, Bredenkamp et al 1995) and natural flow rates have been shown to vary proportional to the average rainfall over several years, or to the cumulative departures of rainfall from the average precipitation.

The quality of the groundwater has not yet been seriously affected. This is partly due to the vast volumes of water stored in the aquifer, the high rate of recharge and dilution effected by flow along large underground conduits. Overall the water is still of excellent quality but pollution by poor sanitation close to boreholes supplying local communities, is a matter of concern. The temporary hardness of the water due to bicarbonate in solution is not a serious problem.

4 EXISTING INSTITUTIONAL ARRANGEMENTS

4.1 Dept of Water Affairs and Forestry: National Office

As the public trustee of the South Africa's water resources, National Government, through the Minister of Water Affairs and Forestry, is ultimately responsible for ensuring that water resources are "protected, used, developed, conserved, managed and controlled in a sustainable and equitable manner, for the benefit of all persons" (RSA, Act 36, 1998).

Within DWAF, the organisational approach is based on centralised planning and policy-making, and decentralised implementation at the regional and catchment level (DWAF, 2000b). The establishment of catchment management agencies is a major initiative currently being driven at the national level. This delegation of water management to the lowest practical level, according to regulatory/operational and service functions, has the potential to enhance groundwater management and increase participation[15]. Once established, CMAs will have delegated responsibilities for licensing of water use and water allocation, according to specific catchment management strategies for all water resources (including groundwater) in their boundaries.

The challenges in implementing this management structure, as perceived at a national level, are that the knowledge of geohydrology within some regional level institutions is limited and that the capacity to manage groundwater at a catchment scale, with current resources is limited. There is thus an urgent need to enhance skills and capacity in catchment agencies and water user associations. From a national level, groundwater management needs to become a stronger element of water resources (catchment) management.

4.2 Emerging institutions: CMAs and WUAs

Ultimately, as organs of state, CMAs will be the institutions responsible for the management of groundwater (as a resource) in a particular water management area (WMA). Where necessary/required, CMAs will be supported at a local level by WUAs who would undertake more operational management functions (Murray and Dindar, 1998; DWAF, 2000b). This institutional structure has the potential to benefit groundwater management, through decentralised and localised management of resources, and a supportive and participatory approach.

However, a challenge posed to groundwater management by this new arrangement is that WMAs have been defined primarily according to surface water systems and flow patterns, sidelining the importance of groundwater in the management of water resources. This has resulted in cases where aquifers extend through a number of WMAs, raising complex transboundary management issues, as illustrated in this study (see Map A.2). In these cases, groundwater management structures needs to extend across managerial boundaries, in an integrated system, capable of addressing both technical groundwater issues, as well as social and transboundary management issues.

In defining institutional arrangements, the role of CMCs and WUAs in addressing transboundary management issues needs to be considered. Distinction is also needed between responsibilities for

[15] Braune, E. 2001. personal communication, Pretoria, 20 July.

resource management functions (intended for CMAs/CMCs) and day-to-day operational functions (intended for WUAs, municipalities).

CMAs in the study area

The CMAs, and therefore the institutions to be responsible for managing the dolomitic aquifer, include (see Map A.2):

- Crocodile West-Marico (managed by DWAF Gauteng and North West regional offices[16])
- Middle Vaal (managed by the DWAF Free State regional office)
- Lower Vaal (managed by the DWAF Northern Cape regional office)

The implications of this impending management structure and its boundaries are that management of the aquifer (at a resource level) will be divided among three catchment management agencies, in different stages of establishment, possibly adopting in different management policies and practises, and different pricing structures for users of the same aquifer.

For practical purposes, an agreement has been made between the regional offices of DWAF that the North West regional office will be responsible for managing sub-quaternary CA31 - a portion of the dolomite that falls into the Northern Cape regional area around Lichtenburg[17]. Although this represents a step towards reducing the number of regional offices involved in direct management of the aquifer, there remain portions of the dolomite in the Northern Cape management area and as a result, does not resolve the problem (see Map A.2). The implications/benefits of this decision therefore require further consideration. If all areas of the Northern Cape dolomite are managed by the North West Regional Offices, this will effectively shift the Crocodile West-Marico CMA boundary to the southern boundary of the aquifer.

WUAs in the study area

A need was identified to manage the dolomite as a single water resource. However, the option of establishing one WUA for all users of dolomitic groundwater was rejected owing to the vast area of the dolomite, the numerous stakeholders and complexity of management issues. Five WUAs, defined according to internal boundaries of compartments within the aquifer[18], have therefore been proposed and are in different stages of establishment. The proposed WUAs are (see Map A.2):

- Lichtenburg-Itsoseng
- Grootfontein
- Grootpan
- Ventersdorp
- Zeerust

Although WUAs should represent all water users using a resource, commercial farmers, who have had to register their water use in terms of the NWA, are driving the establishment of WUAs in the

[16] In this CMA, responsibilities for geohydrology and catchment management functions are shared between the North West and Gauteng regional offices.

[17] Van Dyk, G. 2001. personal communication, email, 31 August.

[18] The optimal boundaries of the WUAs, according to geohydrological criteria, need to be resolved as an outcome of this project.

study area. While representatives of WUAs acknowledge the need to involve all water users in the area[19], attempts to involve groups outside municipalities and the commercial farming sector, in establishing WUAs have largely proven futile. If this situation is not addressed, existing patterns of imbalance and inequity in the use and management of water, and resulting development opportunities, may be entrenched through WUAs. The membership and voting systems of the management committees of WUAs are issues that also need to be considered. For example, should representation be on the basis of the amount of water used, or the number of water users?

Concerns raised by WUA representatives include:

- management problems caused by the lack of knowledge of groundwater[20].
- defining the optimal boundaries for WUAs, which may run through a farm, thus placing the farmer in two WUA areas[21].
- the need for clarity or assistance from DWAF on the membership and mandates of WUAs, details on boundaries, and establishing WUAs
- how to involve other water users and small-scale farmers in establishing WUAs[22]
- the need for interaction between surface and groundwater users (e.g. around Schoonspruit)
- issues around water charges and their impact on the viability of farming[23]

4.3 Dept of Water Affairs and Forestry: Regional Offices

The regional offices of DWAF are decentralised national offices, acting as implementing agents for policy. Although the study area falls within the North West province, the existence of three CMAs has involved the regional offices responsible for each CMA in the management of the aquifer. Once the CMAs are established, the regional offices will most likely continue to exist, although in a reduced, and largely supportive, capacity[24].

At this stage, the regional offices involved in managing the dolomite are:

- North West Regional Office
- Gauteng Regional office
- Free State Regional Office
- Northern Cape

Regional management of groundwater seems beset with problems. Claims are made that groundwater management is not well organised at this level, and indeed, no clear and integrated management structure seems obvious. Issues of institutional capacity, together with a history of neglect of groundwater due to its status as private water, appear to lie at the root of these

[19] Beyers, A. 2001. personal communication, Lichtenburg, 21 June.

[20] Beyers, A. 2001. personal communication, Lichtenburg, 21 June; Lohann, M. 2001. personal communication, telephonic, July.

[21] Lohann, M. 2001. personal communication, telephonic, July.

[22] Kruger, D. 2001. personal communication, telephonic, 10 July; Lohann, M. 2001. personal communication, telephonic, July.

[23] Van Zyl, H. 2001. personal communication, telephonic, 19 July.

[24] Botha, R. 2001. personal communication, telephonic, July.

problems. The following constraints affecting groundwater management at a regional level were identified:

- the neglect of groundwater in overall water management
- a lack of knowledge on the functioning of the aquifer, cross-flows between compartments and the impact of current levels of abstraction on aquifer[25]
- the failure to implement the recommendations from recent research on groundwater[26]
- the perceived lack of control of the use of irrigation systems[27]

As implementing agents of policy, regional offices currently occupy pivotal roles in decentralised water resources management. Issues of capacity, clarity of management functions, roles and responsibilities, and interaction with CMAs will have to be addressed in a management system.

4.4 Water boards

Water boards are organs of state established to provide water services to other water services institutions within its service area (RSA, Act 108, 1997). The water board in operation in the greater part of the study area is North West Water Supply Authority (NWWSA), originally established under the old Bophuthatswana government to supply water to Bophuthatswana (see Map A.6). There is currently no water board serving the southern portion of the study area around Ventersdorp. The existing arrangements of services and functions supplied by NWWSA to towns in the study area are provided in Table 4.1 below, in section 4.5. However, the future role of water board is a subject of debate, particularly in terms of the economic viability of water boards as opposed to local and district councils in providing water services[28].

NWWSA would like to see a framework for groundwater management which includes representatives from CMAs, water boards as well as local and district councils. There should be a formalised structure and a clear division of functions between the tiers of government, with a clear delegation of functions from national to local government, in line with the institutional capacity available to undertake these functions.

4.5 District and Local Municipalities

In terms of the Water Services Act, local government (district councils and local municipalities) has been tasked with the responsibilities of water service authorities, and are responsible for the planning and implementation of water services and infrastructure to ensure acceptable minimum levels of provision to their constituents (DWAF, 2000a). While not tasked with any specific resource management functions, they are important agents in the operational aspects of water management (e.g. provision), and their level of capacity and resources are critical factors in the efficiency of service delivery and local management.

[25] Botha, R. 2001. personal communication, telephonic, July.

[26] Botha, R. 2001. personal communication, telephonic, July.

[27] Van der Merwe, P. 2001. personal communication, telephonic, July.

[28] strongly argued by ward councillors from the Ditsobotla Municipality (21 June 2001).

District councils are responsible for the bulk service functions of old regional service councils, and in some cases, they provide municipal services directly to the public (Murray and Dindar, 1998). In general, local municipalities are responsible for the planning, implementation, operation and maintenance of the water services infrastructure within their municipal area. However, there is a lack of clarity and considerable confusion around the division of roles and functions between local and district councils[29]. As water managers, the district and local councils occupy a key role in the institutional structure for the management and supply of water. In addition, their role as major users of water must not be overlooked and they need representation in water management structures, in terms of their own local management and use practises, and as representatives of their constituents.

The study area includes portions of two district councils[30]: the Central District Council and the Southern District Council. Municipalities in the study area include Mafikeng, Zeerust, Lichtenburg and Ventersdorp (see Map A.6).

In terms of institutional capacity, the Central and Southern District Councils appear confident that they are addressing issues of delivery within their service areas, and that they have the institutional and financial resources to continue this function,[31] although these views would have to be validated in communities served by the district councils. In contrast, the ability of municipalities to fulfil their roles as service providers and water managers is hindered by a lack of capacity and financial resources, and the lack of clarity in terms of divisions of roles and functions between local and district councils, particularly with respect to rural settlements included in municipal areas following the demarcation process (e.g. Grasfontein near Lichtenburg)[32].

The following arrangements (Table 4.1) at a district council and municipal level, for water supply, operation and maintenance are identified in DWAF (2000a) and in the Ventersdorp WSDP[33].

District Councils	Town (Municipality)	Water Board	Bulk Water Supply		Municipal O&M
			Ownership	O&M	
Central (DC 38)	Lichtenburg (NW 384)	NWWSA	Central DC	Own	Own
Central (DC 38)	Itsoseng (NW 384)	NWWSA	DWAF	NWWSA	Own
Central (DC 38)	Zeerust (NW 385)	NWWSA	Own	Own	Own

[29] This issue was raised in almost every interview with municipal managers.

[30] Although they currently do not use water from the dolomite, should the towns of Koster and Swartruggens (situated north of the dolomite boundary) require water from this source in future, the Rustenburg District Council would be included as part of the study area. However, in terms of current planning, the expense of supplying these towns with dolomitic groundwater precludes this option, as they are some distance from the dolomite area.

[31] Mokhele, J. 2001 personal communication, Mafikeng, July; Labauschagne, F. 2001. personal communication, telephonic, July.

[32] Harde, M. 2001. personal communication, Lichtenburg, 18 June; Dandashe, B. 2001. personal communication, Zeerust, 20 June; Smit, H. 2001. personal communication, telephonic, 4 July.

[33] Labuschagne, F. 2001. 2001. personal communication, telephonic, July.

Central (DC 38)	Lehurutse (NW 385)	NWWSA	DWAF	NWWSA	Own
Central (DC 38)	Mafikeng (NW 383)	NWWSA	DWAF	NWWSA	Own
Central (DC 38)	Mmabatho villages (NW 383)	NWWSA	DWAF	NWWSA	Central DC
Southern (DC 40)	Ventersdorp (NW 401)	None	DWAF	Own	Own
Southern (DC 40)	Villages (NW 401)	None	n/d	n/d	n/d

Table 4.1 Water supply in district councils and local municipalities (after DWAF, 2000a; Ventersdorp WSDP, 2001)

4.6 Ward councillors and ward committees

The election of ward councillors and ward committees is essentially the forth and lowest tier of governance. These committees are/will be responsible for the representation of the community's needs and, depending on the circumstances in the area, may have key roles in local water management.

Currently, different systems are in operation at a local level. In some communities (e.g. Sheila), water committees are well established and functional, performing tasks such as the collection of payments, conveying problems to the councillor and undertaking repairs to pipes and pumps in the water supply system. In other communities, water committees do not exist or play a major role in the management of water. This was evident in communities (e.g. Dinokana) where water is managed locally by the tribal authority, which interacts with the ward councillor.

At a local level, particular systems of managing a water source/supply that work well and are suited to the local culture may be in existence. Cognisance must be taken to identify these structures, and where appropriate, utilise them in the broader water management structure, rather than instituting external systems in an area.

4.7 International water management arrangements

Geological information shows that the dolomites do extend into Botswana (see Map A.5). The SADC Water Sector Coordinating Unit describes the dolomitic resource in the study area as a "small but very important transboundary aquifer in the dolomites of the Transvaal Group, which is used on both sides of the border. ... The aquifers are mentioned in general terms by South Africa as part of shared water resources of the transboundary Limpopo basin..."[34] At this stage no (formal) international arrangements are evident between Botswana and South Africa for the use/management of transboundary dolomitic aquifers[35].

Issues related to internationally shared aquifers include:

- the use and management of transboundary aquifers and how practises on one side of the border affect the resource as a whole, for other users

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[34] Pûyoo, S. 2001. correspondence via email, 21 June.

[35] The Karoo aquifer between Botswana, Namibia and South Africa is being used as a starting point for the development of transboundary aquifer management - an initiative being promoted by the Internationally Shared Aquifer Resource Management (ISARM).

- the interaction between ground and surface water systems across international borders, for example, how surface water developments (e.g. dam-building) affect transboundary groundwater resources (e.g. in terms of recharge)

Information is needed from Botswana regarding current and projected demand patterns (in relation to the dolomite) a well as existing institutional arrangements for managing the dolomite aquifer in Botswana. This would assist in mapping the institutions required in managing the aquifer.

5 WATER USER PROFILE

5.1 Water use and demand in the study area

Water use and demand in the study area is characterised by the following factors:

- All water users in the study area are either directly or indirectly dependent on groundwater.
- In most areas, current water supplies are able to meet *existing* demands, but any increase in water demand will exceed local supplies.
- There is not enough bulk water in the region to meet the projected *future* needs of *all* consumers, including domestic use, irrigated agriculture and mining (DWAF, 2000a:1). However future bulk water demands for *primary (domestic) consumers* can be met from *local resources* (DWAF, 2000a). See Annexure C for a regional water balance, drawn from DWAF (2000a).
- The following conclusions relevant to this study were established in DWAF (2000a):
  - the major growth sector in terms of water use is the domestic sector
  - mining and cement production (industry) are not expecting any growth
  - agriculture is a major factor in water consumption and irrigated agriculture has recently witnessed significant growth[36]
  - most settlements will require additional bulk water by 2030, with priorities being Swartruggens, Zeerust, Lehurutse and surrounding villages

The main users o f groundwater in the study area include agriculture, domestic/urban, industry, conservation/environment, recreational, and small-scale/emerging users. Despite their presence in most user groups, small-scale and emerging users are discussed separately as these groups face similar constraints and need particular attention in terms of their involvement in management structures.

The total water demand, per sector, from the dolomitic compartments in the NW province is indicated in Table 5.1 (Source, DWAF, 2000a):

Compartment	Total for Water Use (Mm^3/a)				Total
	Irrigation	Domestic	Mining	Environ.	
Zeerust	31.222	10.008	2.665	0.000	43.895
Grootfontein	29.845	9.097	0.000	7.455	46.397
Lichtenburg	22.824	11.831	2.117	0.000	36.772
Groot Marico[37]	60.366	0.000	0.000	0.000	60.366
Total	**144.257**	**30.936**	**4.782**	**7.455**	**187.430**

Table 5.1 Summary of Water Use per Sector from Dolomitic Compartments (Source: DWAF, 2000a)

[36] Use of irrigation in agriculture has grown, despite declining GGP contribution of agriculture (see section 3)

[37] The Groot Marico compartment referred to in DWAF (2000a) includes both the Ventersdorp and the Grootpan compartments in this study.

5.2 Agriculture

Agriculture is a major economic activity in the study area, around which many towns and activities have developed. The contribution of agriculture to the local formal and informal economy, particularly in terms of employment, livelihoods and supporting rural communities, is significant. In addition, agriculture has been identified as a key sector for future economic growth in the region. However, alongside this important role in providing livelihoods and economic growth, there are disparities associated with the agricultural sector related to water consumption and access, particularly between commercial and emerging farmers. The development of water management strategies, particularly in an agricultural context, is likely to be highly contentious, and these issues need to be clearly understood and addressed. In addition, water resource management needs to look beyond the narrow focus on irrigated agriculture, but also to consider the broader needs of 'agricultural crop water use[38]' which is an important part of integrated sustainable rural development policy.

Issues of representivity and organisation are factors to consider in the agricultural sector, particularly with respect to involvement and representation in the establishment of WUAs. Issues of payment for agricultural water use are controversial amongst both commercial farmers, whose access to water has been protected and 'free', and amongst emerging farmers, who are entering the agricultural market needing support, and often with perceptions that water was and is 'free'. This debate includes positions where commercial farmers have personally placed large financial investments in developing water supplies on their farms[39].

Through years of experience in the area, and with water central to their livelihoods, farmers see that they have a central role in managing the dolomite aquifer at a local level, provided they receive accurate information on safe water yields and aquifer boundaries from DWAF[40] and they operate within the broader framework of an aquifer monitoring system.

5.3 Domestic water users

The availability, use and management of water at a local level has profound implications for health and development opportunities, and management and decision-making at this level must be considered against the background of inequity and uneven development. The domestic users profile is separated into those served by district councils and those served by municipalities, as issues differ accordingly[41].

[38] 'Agricultural crop water use' encompasses more than irrigated agriculture, but also the use of water through rainwater harvesting and other conservation techniques to improve agricultural productivity.

[39] Swanepoel, Mr. 2001. personal communication, telephonic, 19 July.

[40] Beyers, A. 2001. personal communication, Lichtenburg, 21 June, van Zyl, H. 2001. personal communication, telephonic, 19 July.

[41] This is largely because municipalities have not been able to address problems in their new service areas (including newly incorporated rural areas) while standards in the old service areas (mainly towns) are generally adequate.

District councils

Central to the provision of water and sanitation services in district council areas, are the many rural settlements[42] (some once part of the former homeland state of Bophuthatswana, others recent settlements or the result of land reform initiatives), which rely directly on groundwater. The level of services within rural settlements varies enormously, from areas with no local water supply and no services, to those with basic RDP standards, others with a nearby water source (e.g. spring), to those with household supplies. Addressing standards of water supply and sanitation services are immediate challenges for the new district councils where there are many communities in desperate need of water and sanitation. One of the significant threats to groundwater quality and the health of local communities is contamination of water from cattle kraals and the location of poorly constructed pit latrines in proximity to groundwater supplies[43].

Payment for water services is a controversial issue at the district level and methods of payment are varied. Sparse information on government's 'free basic water' policy has further complicated attempts to encourage payment for water services. In addition, conflicts and tensions between tribal authorities and local municipalities compound problems around payment[44]. A thorough understanding of local systems and problems affecting payment is needed, and where necessary, education and awareness is needed to instil an appreciation of the value of water and the need to pay.

Local Municipalities

Overall, the level of service provision and water supply within the original service areas of local municipalities is adequate. However, certain areas now included in municipalities following the demarcation process have not yet received sufficient attention from local authorities in terms of addressing their needs. Municipal managers were quick to point out that they were unfamiliar with conditions in the areas newly included in their boundaries, which in many cases, are still served by district councils.

Concerns amongst local authorities across the study area included pollution to groundwater from pit latrines in informal areas, and the quality of domestic water in informal areas. Compounding factors included the lack of knowledge in municipalities on the effects of pollution on groundwater quality, and their lack of capacity to address this through regular monitoring[45]. Issues of urban growth, the impact of growing water demands on existing supplies as well as the implementation and implications of the 'free basic water' policy were concerns in some municipal areas.

[42] District councils include many small settlements, each with particular problems, ways of addressing them, internal community structures, water supply systems and so on, which management systems must take care to consider. However, to provide an understanding of the types of problems that groundwater management needs to address, I will provide an overview of some of the more representative issues and problems that communities in district councils experience regarding their water and sanitation systems.

[43] Mokhele, J. 2001 personal communication, Mafikeng, July; Labauschagne, F. 2001. personal communication, telephonic, July.

[44] Thubise, D. 2001. personal communication, Dinokana, June.

[45] Harde, M. 2001. personal communication, Lichtenburg, 18 June.

Table B.1 in Annexure B provides information related to consumption patterns, unaccounted for water and monitoring within municipal areas. However this information was sourced from data and reports, mostly preceding the municipal demarcation process in 2000, which have not been recently updated.

5.4 *Industry*

The existing formal industrial activities include cement factories and lime quarries, small alluvial diamond mining operations, and other mining operations (peat, fluorite, slate, etc.). Small-scale/emerging industrial operations (e.g. brick making) are discussed separately in section 5.7.

The water needs of these industries are generally limited and none of the existing industries is planning any expansion of their operations, or expecting any increase in water consumption. Although none of the industries experience any problems in accessing a regular and sufficient water supply, a concern raised that the recent increase in large-scale irrigation may affect groundwater levels to the detriment of other user groups[46].

While there is wastewater discharge from most of the industries, this is first treated and monitored for quality and most plants use recycled water to some extent in their operations. All industries undertake some form of regular monitoring of water levels, and in some cases, microbiological quality testing. Indications from industry are that there is minimal environmental impact occurring as a result of their operations (the exception being limited aesthetic scarring from mining).

A closer analysis of the environmental impact (e.g. impacts on the hydrological landscape, dust, visual pollution, flora, fauna, etc.) of industrial operations, particularly those in proximity to communities and sensitive systems (e.g. springs), is required. Furthermore, Nel et al (1995) mention the significant effect that mining activities has on the water table by dewatering of shafts through pumping. Due to the extent of the underground caverns, a mine could have a far-reaching effect on the water table within an underground chamber. Assessing the overall impact of mining should also consider economic and social impacts such as employment creation, infrastructure etc (Nel et al, 1995).

Although there are no short term plans for the expansion of existing industry in the area, rural-urban migration and the growth of Zeerust and Mafikeng, are creating an increased demand for employment that needs to be addressed, possibly through industrial growth (e.g. North West Spatial Development Initiative). However, growth in the industrial sector will have a significant impact on water use in the province, particularly if water demand management is not implemented. Future industrial development initiatives will therefore have to be carefully planned, balancing the capacity of water resources with development needs.

5.5 *Conservation*

The water needs of conservation must be considered in managing groundwater. Springs in the study area provide unique habitats, which have developed in near isolation, some sustaining endemic species, which would be threatened should groundwater levels drop (see section 6). Of concern to

[46] Meyer, P. 2001. personal communication, telephonic, 5 July.

environmental managers in the area is that only one of the eyes (the Malmani eye) has any formal conservation status[47]. The springs and wetlands require careful management and protection in a broad sense, understanding the impacts on these habitats should water levels or water quality deteriorate.

Other management issues, from an environmental perspective, include[48]:

- the impact of high levels of abstraction on groundwater-dependent ecosystems
- the impact of large-scale irrigation on water levels and soils
- the introduction of alien fauna (e.g. bass) in water systems
- the impact of alien vegetation species (e.g. eucalypts and acacias) on water levels[49]
- water quality issues (impacts of pesticides and fertilizers), and the lack of knowledge of the long term effects of these pollutants on the aquifer
- the impact of mining operations around springs (e.g. peat mining near Schoonspruit)
- the impact of seasonal influxes of holiday-makers at recreational sites near the eyes, particularly increased impacts from septic tanks (e.g. Molopo Eye).

The North West Department of Agriculture, Conservation and Environment currently has no active role in groundwater management, although they have capacity and would like a limited role in functions such as groundwater monitoring[50]. This raises the question of departmental mandates and the policy of cooperative governance, which needs to be practically addressed in defining the activities and resources needed for sustainable and equitable groundwater management[51].

5.6 *Recreational use*

Groundwater also has a valuable role in recreational and tourism activities in the area, and the needs of these users must be considered, as well as impacts resulting from these activities. Recreational uses include diving and swimming, fishing, camping, bird watching, etc. Small infrastructure developments have occurred around the eyes to support these activities (e.g. Wondergat and Molopo eye). Clearly, if water levels decline, the viability of these activities will be threatened, whilst at the same time, they have potential to impact on groundwater (e.g. pollution, disturbance, etc.)

5.7 *Emerging and small-scale water users*

Discussion around the water use of small-scale and emerging water users has been separated from the sectoral discussions above. The needs and problems affecting emerging users, across sectors,

[47] Mangold, S. 2001. personal communication, telephonic, 26 July.

[48] Mangold, S. 2001. personal communication, telephonic, 26 July.

[49] Blue gum trees, for example, are know to use up to 220l of water per day - comparing this to basic water needs raises questions about the overall impact of alien vegetation on the aquifer and the need to increase alien clearing programmes.

[50] Mangold, S. 2001. personal communication, telephonic, 26 July.

[51] As an example, at least three provincial or regional departments, as well as local government, have some role to play in water quality monitoring, however, very little is currently done in this regard.

have generic trends and specific attention needs to be given to following an integrated approach that involves emerging/small-scale users in water management structures such as CMAs and WUAs.

The water uses of emerging/small-scale groups, for income or subsistence purposes, include amongst others, vegetable gardening, stock watering, brick making, diamond digging and small-scale commercial farming operations.

Involving small-scale and emerging water users in the management of groundwater is a major challenge, given the lack of organisation and formal representation of these groups, but is an essential component of equitable management systems. With their lack of representation in water management structures, current patterns of inequity are likely to be perpetuated, as emerging groups' needs are unlikely to be adequately represented. In many cases, representation of small-scale water users is through local government structures (e.g. ward councillors). However, local politics and conflicts may prevent the concerns of small-scale water users from being heard, thus causing small operations to collapse (e.g. Grasfontein)[52]. Although these are internal issues, the lack of alternative representation for small-scale water users, as well as gender issues, reinforces the problem in communities.

The impacts of overabstraction are real threats to users whose access to water is primarily from spring flow. For small-scale farmers who do not have the resources to pump water should springs dry up, seasonally or completely, this will effectively block access to this water resource, limiting the livelihoods opportunities.

Gender issues are particularly relevant in the context of access to water and representation in these groups. The important role of women in food security and providing or supplementing household incomes, and their access to water and representation, is disproportionate. The knock-on effects in the community, in terms of health, empowerment, livelihoods and opportunity are considerable. In addition, the needs and customs of tribal communities are important in managing water. For example, the lack of access to water for stock watering leads to conflicts with local farmers when cattle wander into their property in search for water,[53] which again affects livelihoods and security.

[52] Mahlaba, F. 2001. personal communication, Grasfontein, 19 June.

[53] Milton. 2001. personal communication, Grasfontein, 19 June.

6 GROUNDWATER-DEPENDENT ECOSYSTEMS

Groundwater resources sustain important habitats and ecosystems in the associated springs, streams, wetlands and subterranean chambers. These ecosystems are dependent on groundwater resources in terms of quality and quantity, and as a result are highly sensitive to fluctuations in water level and water quality.

Globally, freshwater wetlands are threatened ecosystems, which perform essential ecological functions such as the filtration and purification of water. Wetland systems and the species they support are particularly vulnerable due to the increasing water demands being placed on the aquifer. These systems highlight the interaction between ground and surface water, and need for an integrated approach to managing ground and surface water.

Due to the relative geographical isolation of these habitats, many of the springs and wetlands sustain rare or endemic flora and fauna. Each dolomitic eye supports ecological communities evolving independently of one another, driven by particular local factors (e.g. temperature, flow etc). For example, the algal and diatom community in the Molopo eye are different to that at the Malmanies eye, indicating that each eye could be a unique ecosystem (Nel et al, 1995). Distinct morphological and behavioural changes have been recorded in the *Pseudocrenilabrus philander* (southern mouthbrooder) and *P. crenilabrus* in the various eyes indicating species specification (Nel et al, 1995).

Other points of conservation significance related to groundwater dependent ecosystems include (Nel et al, 1995):

- dolomite eyes are highly sensitive to invasion by exotics (e.g. Black Bass at Molopo); indigenous species are sensitive to the introduction of alien predatory fish due to the water clarity
- the reed beds around the eyes and wetlands provide important avian refuges and roosting areas
- very little is known about the flora and fauna of subterranean dolomitic chambers, which may be important in terms of biodiversity. Small crustaceans (amphipods) have been recorded at depth and it is likely that higher forms of life may exist in the underground chambers
- little is known about the present potential for the groundwater dependent ecosystems to serve as mammal refuges
- the wetland vegetation of the of the dolomitic area is not rare, but the systems are ecologically important in terms of the numerous services they provide

Table 6.1 provides a summary of the indigenous aquatic biota found in freshwater bodies in the area (Skelton et al, 1993):

Species	Molopo eye	Wondergat	Malmani eye	Marico eye (Kaaloog)
Southern Mouth Brooder (*Pseudocrenilabrus Philander*)	Occur in shallow area surrounding the jetties Move from channel to lagoon - utilized by female brooders	Breeding and migration of all species appears to be unaffected and no decline in populations has been observed.	Consistent supply of water to the wetland should be ensured. *Being a nature conservation area should maintain the environmental assets.*	Dense vegetation protect Tilapia
Banded tilapia (*Tilapia sprarrmanii*)	Occur in shallow area surrounding the jetties. Follows the same patterns as *P Philander*	*Anthropogenic impact on the Wondergat (e.g. diving activities) should be limited.*	This species occurs in spring, vlei area and above and below weir	Observed in the eye
Large mouth bass (*Speudocrenilabrus philander*)	Large increase after culling of *M salmoides*, breed successfully in Molopo. Populations have decreased.	*Land owners should adopt a management plan and educate visitors on the importance of sustaining this species*	This species occurs all over the aquatic regimes	Movement of bass during hunting limited due to thick vegetation
Sharp-tooth catfish (*Clarius gariepinus*)			*This eye represents a unique case of undisturbed wetland ecosystem.*	*Importance of conservation of the site and management of the system (pumping from the eye not recommended)*
Straight fin barb (*Barbus paludinosus*)	Threatened by habitat loss - endemic species		Occurs in spring, channel and vlei area	Only occur in the vlei area
Short fin barb (*Barbus previpinnis*)	Only habitat in the Orange river system for this species - endemic			
Micropterus salmoides	Threat to all species			Occurs in vlei, upstream and downstream of waterfall.
Barbus motebensis			Occur in the eye	Present in vlei and downstream of waterfall
Amphilius uranoscupus				Only present in vlei
Chiloglanis pretoriae				Only present upstream of waterfall

Table 6.1 Summary of indigenous aquatic biota of different springs in the dolomite terrains of the NW Province
(Source: Skelton et al, 1993)

Five natural (groundwater-dependent) water bodies occurring in the dolomite of the North West region have been studied, namely the Molopo eye, Malmani eye, Wondergat, Marico eye (Kaaloog) and Schoonspruit eye (Skelton et al. 1993). The natural aquatic ecosystems of these terrains are similar in respect of some of the fish and faunal populations that they support. In addition however, each water body sustains a unique ecological habitat that evolved in isolation from the others (see Table 6.1).

The aquatic systems are particularly vulnerable because springflows and water levels fluctuate according to the natural varying rainfall over the recharge area. This has been the case up to about 1980. Thereafter both groundwater levels and spring flows have also been affected by increasing abstraction demands, imposing an additional threat to the sustainability of the aquatic environment. Figure 6.1 illustrates the decline in springflow from the Molopo eye with increased abstraction since the 1980s. The discrepancy between the natural flow and the affected flow in Figure 6.1 represents the effect on the groundwater-dependent ecosystems. The greater the discrepancy between the natural and affected flows, there will be a greater the impact on the ecology (exponential relationship). The critical levels have to be determined.

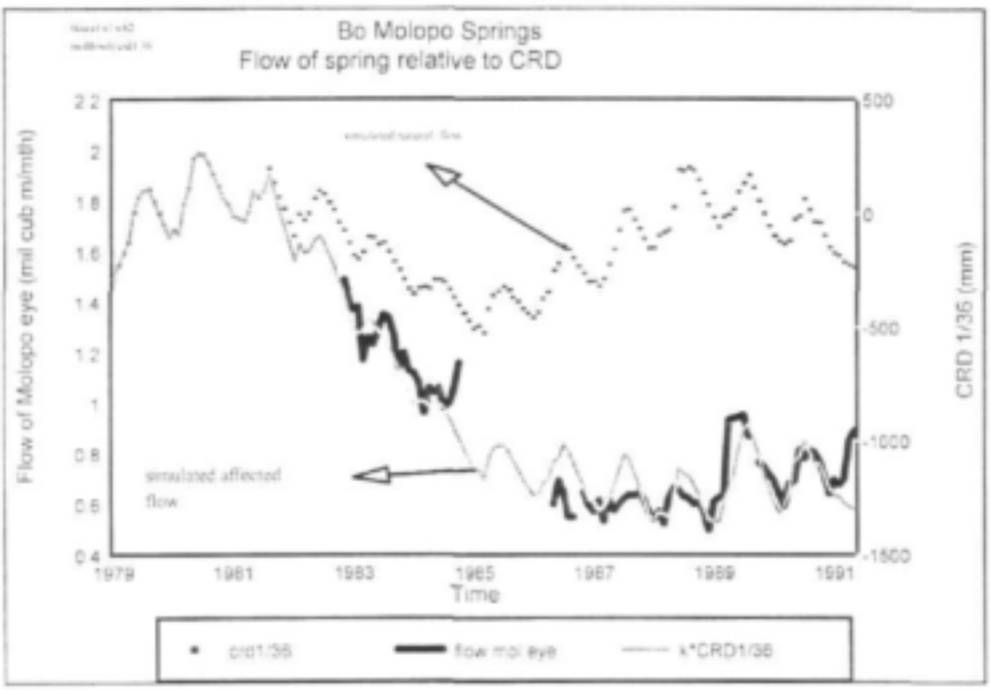

Figure 6.1 Flow of Molopo eye in relation to the cumulative departures of rainfall (CRD) from the average, clearly indicating that the flow of the eye has been affected by abstraction in the region (Source: Bredenkamp, 1999).

The following threats to the dolomitic ecosystems are noted in Nel et al (1995:27):

- extraction of groundwater from the dolomites leads to a lowering of the water table to the degree that surface water is no longer discharged
- pest control using aricides to control queleas (birds)
- introduction of alien fish species

- excessive collection of rare species
- sinkhole formation
- canalising and drying up of wetlands
- unsustainable management practices/land uses related to fires, lands, draining, dams and weirs

The conservation potential of the dolomitic eyes has not been determined and only one of the springs in the area (the Malmani eye) has any formal conservation status (Nel et al, 1995). However, each of these systems provides a valuable but threatened habitat, and performs key environmental functions. In addition, springs, and Wondergat, are being used increasingly as popular recreation sites, and in this respect, are also valuable local resources. Management of these sites is therefore of critical importance, both ecologically and socially, and needs to be seen as an integral component of groundwater management.

For all of the five sites listed above (and others where necessary) it has been recommended that:

- management plans, in accordance with the requirements of the different stakeholders, are formulated
- due to the diverse water requirements there are bound to be conflicting issues, requiring participation of all stakeholders
- the flows of the eyes should be monitored and abstraction measured, enabling the effects of abstraction on groundwater levels and dependent ecosystems to be determined (culminates in determining the ecological reserve)
- the water quality of the springs be regularly monitored to detect and address any contamination at an early stage
- land use patterns and activities close to the eyes should be carefully assessed and regulated
- an awareness and education campaign should be implemented to inform the public of the vulnerability of aquatic ecosystems, activities that threaten these systems and how they can assist in conservation-related activities.

7 GROUNDWATER QUALITY

Groundwater quality refers to the water chemistry and micro-organisms present in the water. The level of total dissolved substances (TDS) in groundwater determines its salinity. One of the objectives of responsible groundwater management is to be aware of the land use and activities in the area, and sites which area potentially vulnerable to pollution. Chemical monitoring of groundwater is important for the purpose of establishing reference concentrations for the identification of pollution.

Chemical data obtained in the study area during surveys and follow-up studies (from 1977 to 1996) did not show any serious signs of pollution when undertaken (see Table 7.1). Only in the case of the Renosterfontein eye, southeast of Zeerust, has clear evidence of pollution been obtained (see Figure 7.1).

Bo Molopo Dolomitic springs	TDS mg/l	HCO_3 mg/l	Ave Cl mg/l	SO_4 mg/l	Comment
Dinokana Upper (some recharge from banded ironstone)	351	207	4,9	6,6	Pristine spring, low TDS and Cl indicating higher recharge
Molopo (100% dolomitic)	326	199	4,8	5,3	No contamination
Vergenoegd (100% dolomitic)	399	244	4,9	6,6	Natural spring, no contamination
Skilpadfontein (100% dolomitic)	442	272	5	6,5	Natural spring, no contamination
Rhenosterfontein (Transvaal shales and quartzites, only partially dolomitic)	395	209	25*	12	The chemistry is clearly different to that of normal dolomite, spring also indicates pollution

*sporadic influx of pollutant

Table 7.1 Comparison of the chemistry of different springs in relation to the characteristics of the recharge areas

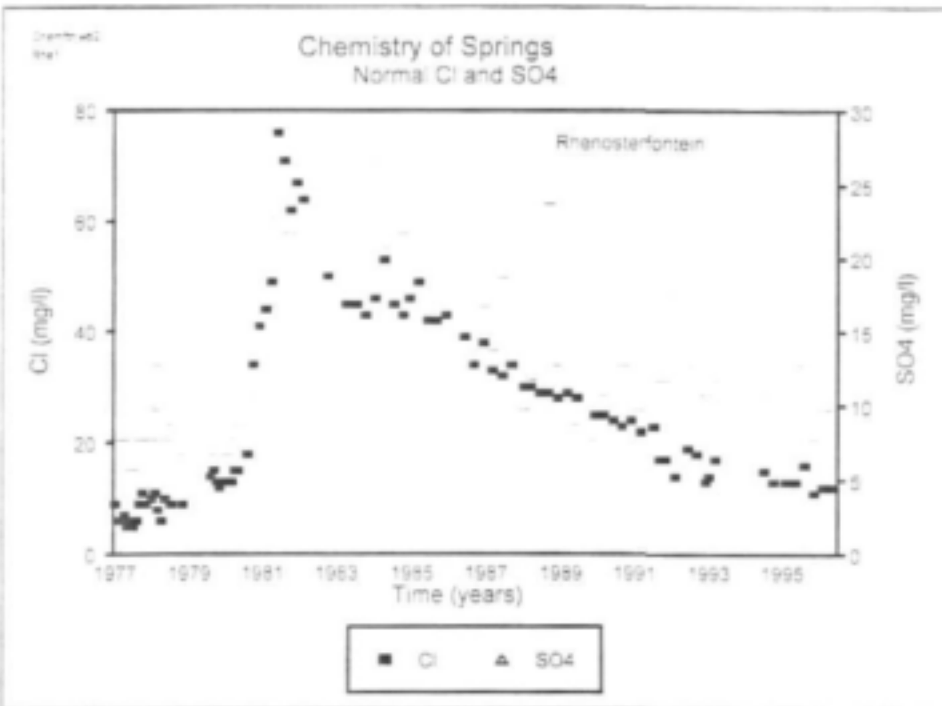

Figure 7.1 Comparison of the chloride and sulphate concentrations of Renosterfontein, clearly indicating that pollution has occurred around 1981

Figure 7.1 is a good indication of the effects of gradual dilution of pollution in the aquifer, due to recharge and high aquifer storage, which is a general characteristic of dolomitic aquifers.

Dysentery, cholera and gastro-enteritis are examples of diseases transmitted by bacteria in water. Such microbiological pollution is definitely a cause of concern in areas where informal dwellings with poor sanitary systems are built close to the source of drinking water (e.g. near the Polfontein eye and Grasfontein near Lichtenburg). Pollution to groundwater, particularly within proximity to rural settlements is becoming a significant constraint on its utility (Nel et al, 1995).

Addressing groundwater quality is an important component of proper groundwater management and needs to be considered in the development of a management framework. Issues that must be addressed include the development and implementation of appropriate monitoring systems, addressing existing/potential points of pollution, building capacity to enable regular and accurate monitoring, the communication of data and recommendations between institutions/communities, ensuring early identification of contamination and remediation, as well as an effective education and awareness campaign directed at local residents to enable them to assist in quality monitoring, the prevention and early warning of groundwater pollution, and informing them of the dangers and health effects of pollution.

8 IMPACTS ON GROUNDWATER RESOURCES

The dolomitic groundwater resources have been subject to a range of impacts, in terms of both groundwater quality and quantity, which are either naturally induced or the results of anthropogenic activities. Examples of impacts to groundwater include:

1) Natural fluctuations in groundwater levels due to *variable rainfall* caused by prolonged periods of below average rainfall (or droughts), leading to a decline in water levels and diminished spring flows. A record of the water levels for the Wondergat sinkhole between 1923 and 1980 represent natural conditions and corresponds linearly to the flow of the springs.

2) Since 1981, the water levels of Wondergat and the flow of the springs have been affected by *abstraction* (see Figure 6.1), however the natural water levels and the spring flows could be simulated by means of the cumulative departures of rainfall from the average (CRD method), or according to the moving average rainfall over several months (MA method; Bredenkamp, 2000). Both the CRD and MA methods could be used to incorporate the abstraction as an equivalent depth of precipitation, and by removal of the stress component the natural groundwater fluctuations and spring flows could be obtained.

3) The water quality of production boreholes could deteriorate as groundwater that has been *polluted either chemically or biologically*, is captured and drawn in by pumping borehole.

4) Excessive *lowering of the groundwater levels* could trigger the formation of sinkholes. It is generally assumed that if the water levels decline more than 8 metres, the risk of sinkhole occurrence is high. However, the stability of the dolomite in the area has been good, as even at drawdowns of up to 30m at the Grootfontein eye, no sinkholes have yet occurred. The determination of the Reserve should address this issue.

5) The excessive lowering of the groundwater levels, either as a result of low rainfall or abstraction, could have serious *secondary impacts* on the water supply of local communities, as well as on the groundwater-dependent ecosystems occurring in springs and wetlands. The knock-on effects of these impacts are considerable.

6) Irrigation from groundwater resources results in the *recirculation of water* carrying fertilizers, resulting in the pollution and salination of the groundwater. Thus far however, the high natural recharge and large subterranean reservoirs of the dolomite have curtailed such impacts. The long-term effects of these patterns need to be determined.

These examples of the impacts that have or might affect groundwater resources, either through natural or anthropogenic events, provide some indication of the complexity of groundwater management, particularly when considering potential knock-on impacts, affecting both communities and ecosystems that are dependent on groundwater resources.

9 DELINEATING ENVIRONMENTAL ASSETS AND DETERMINING THE RESERVE

Delineating ecological regions in which fauna and flora are dependent on groundwater and sensitive to its fluctuations, must take into consideration riparian habitats of rivers and wetlands (Van Tonder and Dennis, 2001). Such areas in the dolomitic terrain include the major water impoundments at Molopo eye, Wondergat, Malamani, Marico Kaaloog eye, Schoonspruit eye, the Lichtenburg and Grootfontein eyes (see Map A.4). In addition, numerous smaller springs and wetlands, such as those occurring in the Malmani River, the Polfontein downstream area and upper Molopo River channel also have to be delineated and designated appropriate levels of conservation status and management.

Considerations that need to be addressed before determining the amount of water that can be allocated include the reserve (both human needs and ecological needs), international obligations (e.g. Botswana) and water needed to sustain the integrity of the resource. Only after taking into account these requirements, can water be allocated to users. Depending upon the significance of the resource in question, the reserve determination could be a preliminary or a comprehensive estimate.

The following steps are part of an initial Comprehensive Reserve Determination for groundwater to be applied in the NW dolomitic area (Parsons, 1998):

1. delineation of the resource (i.e. type, significance and water quantity);
2. determining the geohydrological region (i.e. general climatic and topographical features boundaries, aquifer characteristics and identifying groundwater-dependent ecosystems);
3. obtaining reference conditions and setting the current management class;
4. quantifying the reserve;
5. setting resource quality objectives (RQOs), which for ecological impacts have to be provided by ecologists and
6. establishing follow-up monitoring.

RQOs can be defined as a numerical or descriptive statement of the conditions that should be met in the receiving water resource, in terms of the resource quality (and quantity) to ensure the resource is protected (MacKay, 1998). Determination of the reserve for aquatic ecosystems entails investigation of the relationship among major interactive components of the water cycle, namely surface water bodies and groundwater. Validation of the determined reserve would be subject to review at a period of five years.

Groundwater plays a key role in the reserve determination wherever there is a direct hydraulic connection between groundwater and surface water bodies, which jointly sustain the aquatic ecosystems. In such situations the often-complex role of groundwater (in terms of recharge, volumes, movement and distribution), in supporting the ecosystem and human population, has to be ascertained.

Sustainability takes into account the balance between protection and utilisation. The two important parameters that should be considered for a borehole protection area are:

- the radius of influence of the borehole (as the impact of abstraction from the borehole will have a zero influence on water levels outside the radius of influence), and
- the capture area of the borehole which will be used to estimate the safe yield of the borehole; and to determine the impact of pollution.

Van Tonder and Dennis (2001) have derived the piezometric levels and drainage of the system according to the water balance:

CHANGE IN STORAGE = INFLOW - OUTFLOW

which incorporates:

- the recharge and aquifer storativity,
- lateral inflow/outflow and
- pumping and evapotranspiration.

Fulfilling the demands of the basic water requirements entails sustaining groundwater levels within certain limits. The following approach is advocated to determine the 'reserve':

- A steady-state water balance is required, and the status of the aquifer has to be considered ensuring that flow across international boundaries remains unchanged.
- It is assumed that the maximum riparian ecological requirements are equal to the water flow towards the river.
- The inflow/outflow from/to deeper aquifer systems is regarded as zero as a first approximation.
- The water demand of an impoundment, which could be circular or in the case of a linear feature would be equal to the rate of water flowing to the water system.

The amount of groundwater needed for basic human needs can be determined by multiplying the population that is dependent on groundwater by the minimum basic needs requirement of 25*l* per day. Future changes in the size and needs of the groundwater-dependent population must also be considered. After the estimation of the different components, the water balance equation could be used to estimate the potential groundwater for allocation to a catchment. The term 'potential' allocation is used because water balance components on a large scale have been estimated under steady state conditions. Local impacts due to abstraction must still be evaluated separately (e.g. abstraction close to a river can cause the water level gradient to be reversed leading to undesirable conditions). In practice, the groundwater to be allocated will be less than the potential volumes to be allocated. Basic guidelines, principles and approaches to effectively manage and control a groundwater system have been presented by Van Tonder and Dennis (2001), however the equitable allocation of groundwater is a complex problem, requiring a high levels of professional expertise.

10 MANAGEMENT CHALLENGES

The following challenges to achieving equitable and sustainable management of groundwater have been identified. Institutional arrangements need to be developed and equipped with the resources, tools and capacity to address these and other challenges through the management of groundwater.

10.1 Geohydrological uncertainties

In terms of technical management of groundwater, particularly with respect to the accuracy of groundwater data on which key decisions are based and the ability to predict the response of the aquifer to certain conditions, several uncertainties need to be addressed to achieve sustainable use of the aquifer.

Water Balance

Key components of the water balance that need to be quantified reliably include:

1) Reliable estimation of both the *average recharge and its variability*. Several methods could be applied, for example:
   a. The ratio of *the chloride concentration* of rainwater relative to that of spring water will provide an average recharge integrated in time and space (Bredenkamp et al 1995).
   b. Relating the abstraction during selected periods *of equal volume status* of the aquifer to the input rainfall. The correct rainfall in accordance with the Moving Average method has to be used (Bredenkamp 2000).
   c. According to the corrected natural outflow of springs during periods starting and ending with the same flow (*equal-flow periods*), also in relation to the correct rainfall input. Reliable estimation of the recharge area is required. According to this method the recharge derived from the flows of the Buffelshoek eye shows an exponential increase with higher rainfall.
   d. If the storativity of the aquifer has been derived in a reliable way, the recharge could be inferred from the cumulative rainfall departure (CRD method) and moving average rainfall (MA method).
2) Estimation of the *aquifer storativity* by:
   a. Special water balance interpretations yielding a bulk estimate (Van Rensburg, 1995).
   b. Pumping test analysis according to the latest methods (Van Tonder and Xu , 1999).
   c. Insertion of the recharge into the CRD and MA regression fits between rainfall and water levels.
3) Reliable *estimation of abstraction* based on the irrigated areas and crop water requirements, or according to the electricity consumption of the irrigation installations (Van Rensburg 1995).
4) Deriving the *depth of the aquifer* by means of a regression between the Moving Average rainfall and water level fluctuations (Bredenkamp, 1999).

Aquifer modelling

Reliable simulation of the aquifer response to recharge, abstraction and inflow/outflow particularly with regard to the assessment of impacts at critical points by means of a hydrodynamic model, would be an essential element of effective management of the aquifer.

Such a model would have to accommodate flow between different sub-compartments and preferably also the heterogeneity of the aquifer both laterally and with depth. The 2-dimensional AQUAWIN model (Van Tonder, 1996) has been applied with reasonable success to part of the Grootfontein unit and to the Zeerust groundwater unit (Bredenkamp and Nel, 1997) with the flow of springs introduced as variable pumps. Since then it has been established that the flows of the springs have been incorrectly determined and would have to be reassessed before a new simulation is carried out.

At this stage it seems as if the MODFLOW aquifer model, which is capable of simulating the aquifer both two and three-dimensionally would be the best model to apply. This would enable a comparison of a 2 and 3 dimensional models and would also be a more suitable model to simulate the flow of springs and impacts of abstraction.

The CRD and MA methods representing a simple though effective hydrological model of the aquifer could also be used to simulate the impact of abstraction at specific points - after an initial calibration. Additional developmental work and programming would be required to model the integrated water level impact to simultaneous pumping from different points by means of a CRD/MA response-matrix.

Once the piezometric groundwater levels could be simulated in a reliable way the impacts on spring flows and environmental stress could be addressed according to quantitative response-criteria that would facilitate the assessment of more effective management scenarios, especially with regard to environmental impacts.

In the next phase of the investigation it is recommended that the entire dolomitic area under investigation, be simulated by means of a suitable model.

10.2 Social and institutional constraints

A further set of challenges and constraints are found in the institutional and social conditions in the study area.

Information about the resource

Leading on from section 10.1, is the lack of accurate information about the supply and functioning of the aquifer. Managers and users simply do not have the information needed to make informed decisions about groundwater, or the ability to develop this information base through monitoring. Information is needed by managers at all levels, and equally by users, that is both trusted and easily accessible by all stakeholders), to enable them to participate in an informed way in groundwater management, and to understand the consequences of certain actions. The following information needs to be collected to enable informed decision-making regarding groundwater: groundwater levels, abstraction rates, rainfall, and groundwater quality (Murray and Dindar, 1998).

Institutional capacity

Addressing issues of institutional capacity at every level in the management structure, from local government through regional/provincial levels to the national level, is a central factor that affects sustainable and equitable management. This is currently a significant problem and an issue that has been raised repeatedly as a challenge to groundwater management, in both existing and emerging institutions.

Issues of cooperative governance and departmental mandates need to be practically resolved in line with the management needs of the resource (e.g. monitoring), and the capacity and resources available to undertake these functions. Roles, functions and responsibilities need to be clarified in the context of the available capacities and resources, and channels of communication for data, information and recommendations need to be established within and between the institutions.

Small-scale and emerging user groups

The lack of organisation and representation of small-scale and emerging user groups, to represent their needs and concerns with respect to the access to and use of water (including resources, services and benefits) and thus to participate in decision-making and management is a critical issue that needs to be considered in developing the institutional arrangements for the management of groundwater. Compounding factors related to the capacity of this group include internal power relations, the role of women, cultural traditions and the integration of formal and informal systems. Without the appropriate interventions, the lack of capacity within this group and the lack of involvement in formalised management structures will entrench existing patterns of imbalance, inequity and poverty.

Representation

An issue related to both of the above points, is the strength and representivity of local structures (including both local government and WUAs). This is particularly relevant where local politics and unbalanced power relations prevent the needs of disempowered groups from being articulated and addressed. Issues of culture, empowerment and vested interests prevent marginalized groups from gaining access to resources that would contribute to their livelihoods and levels of empowerment, and possibly upsetting existing power relations. Establishing representative organisations, such as WUAs, without facilitating proper participation through building capacity and awareness, will simply lead to the entrenchment of existing patterns of unbalanced use and inequity, and create problems of buy-in and ownership.

Competition between water users

Competition and conflict between different user groups have been articulated, particularly between agricultural, domestic and industrial water users, and between more powerful and weaker users. These matters need to be resolved through allocations and local management of the resource. Dominance of certain groups in the process must be addressed.

Formal and informal systems of water management

In some areas, particularly in rural communities where formalised institutional structures have had minimal influence, informal systems of local water management have developed. In some cases, these systems serve all members of the community adequately and equitably, while in others, they entrench unbalanced power relations to the detriment of certain groups. When developing and implementing formal systems of management, consideration must be given to identifying informal systems (which may contain valuable knowledge and skills) and where appropriate, integrating them into the management structure of the resource.

10.3 Preliminary Criteria for Institutional Arrangements

Although Phase 1 has largely been a desktop study to examine the body of knowledge on the aquifer, and thus to identify gaps in knowledge and management challenges, some preliminary criteria for institutional arrangements have emerged based on information in existing research. These would clearly have to be workshopped widely with stakeholders in the following phase of the project. In Section 1.3, the concept of 'institutional arrangements' was discussed and defined as the:

- principles, objectives and institutional approach for groundwater management
- overall institutional structure and implementing agencies
- roles, responsibilities and functions of implementing agencies
- requirements and support needed to ensure functioning institutions

Preliminary suggestions for the institutional arrangements for groundwater management are:

- *Principles and Objectives*

  The broad principles and objectives set out in policy and legislation form the guidelines/framework within which institutions carry out their activities. These include, amongst others:

  - all persons should have access to potable water and an environment that is not harmful to their well-being
  - equity, sustainability and efficient and beneficial use
  - resource integrity
  - recognition of the unity of the hydrological cycle and the interdependence of all its elements
  - water is a common resource to all, subject to national control, consistent status of all water in law
  - there is no ownership of water, only a right to its use or authorisation for use (not granted into perpetuity)
  - meeting international obligations
  - investments already made and to be made by the water user in respect of the water use
  - integrated water resource management
  - decentralised management of water resources

- *Institutional Approach*

  The institutional approach adopted in policy is one based on:

- participative management of water resources
- decentralised water resource management through institutions at a regional level and local (CMAs and WUAs)

However, the institutional structure defined within this approach does not necessarily address transboundary management issues and the specific characteristics and role of groundwater. A *co-management approach*[54] would seem appropriate to address transboundary management issues, where equity and sustainability are crucial goals. This approach enables multiple stakeholders to be incorporated into natural resource management in a variety of roles.

The main principles of co-management include (Borrini-Feyreabend et al, 2000):

- recognition of *different values, interests and concerns* involved in natural resource management, both outside and within local communities
- seeking *transparency and equity* in natural resource management
- allowing *civil society* to assume ever important roles and responsibilities, leading to natural resource management *partnerships*
- harnessing the *complementarity* of the capacities and comparative advantages of different institutional actors (collaborative governance)
- *linking entitlements and responsibilities* in the natural resource management context
- appreciating that the *process* is more important than short-term products
- *learning by doing through on-going revisions and improvements in natural resource management*
- no blueprint, but a considerable *flexibility* in developing co-management arrangements

These principles of co-management are supported by the legislative framework for water in South Africa. Both CMAs and WUAs are examples of institutions where participative and cooperative management is crucial to their success.

While the context in this project suits a co-management approach, with clear benefits to the resource, and both users and managers, the challenge is to develop the institutional arrangements that would enable co-management of the dolomitic aquifer.

➢ ***Institutional Structure and Implementing Agencies***

The institutional structure and implementing agencies set out in legislation and policy provide the broad framework within which specific institutional arrangements, suited to a particular context, need to be developed.

In terms of *groundwater resource management*, the institutional structure is provided by the following implementing agencies (their current roles and responsibilities have been discussed earlier) are:

- DWAF, national office and regional offices

[54] Co-management is defined as "*a situation in which two or more social actors negotiate, define and guarantee amongst themselves a fair sharing of the management functions, entitlements and responsibilities for a given territory, area or set of natural resources*" (Borrini-Feyreabend et al, 2000:1).

- CMAs
- Catchment management committees

At an *operational* (supply) level, the following institutional structures exist:

- WUAs
- Local authorities (district and municipal)
- Water boards
- Ward councillors and ward committees

Several recent studies have examined the operational (supply) level of groundwater management (see analysis in Stephens 2001). In addressing the sustainable management of the dolomitic aquifer, the challenge is to define institutional structures at a resource management level that are equipped (in terms of information, resources, capacity, representation) to deal with transboundary issues. Thereafter, the operational structures can be defined through a participative process.

The National Water Act (Section 82(5)) makes provision CMAs to "establish committees (including an executive committee and consultative bodies), to perform any of its functions within a particular area, or generally or to advise it, and must determine how they must function" (RSA, 1998, Act 36). A committee may therefore be established to manage specific resources, such as sub-catchments within a WMA, which require particular attention (e.g. they may be water-stressed). Establishing a committee for the purposes of aquifer management and through representation, equipping it to handle transboundary issues, is a preliminary option for managing aquifers that transcend WMA boundaries.

The following broad structure (see Figure 10.1) is presented as a preliminary recommendation in which management of the aquifer could take place through a Dolomitic Aquifer Management Committee:

- The *Dolomitic Aquifer Management Committee* (in terms of Section 82(5) of the NWA) would be responsible for managing the aquifer as one system, within the broader context of catchment management in the region. The Dolomitic Aquifer Management Committee would therefore 'span' the three WMAs with representation from these bodies. This would ensure an IWRM approach is followed, recognising and understanding the interaction between ground and surface water. As an example of its role, the Committee would undertake to ensure that CMA policies and catchment management strategies are consistent in terms of management functions and practices, pricing, etc.

- A *Technical Committee*, with sub-committees for specific functions as necessary, would undertake or oversee certain groundwater management functions (e.g. monitoring and data collection) to ensure management is guided by sound geohydrological knowledge of the aquifer. Consultants (e.g. engineer, geohydrologist, etc.) may be appointed as necessary (possibly as a Technical Secretary). The committee would interact closely with the DWAF, Directorate: Geohydrology.

- *DWAF* (at a regional and national level), the *CMAs* and *WUAs* would participate in the management of the aquifer through representation on the Dolomitic Aquifer Management Committee. Water users and other stakeholders would participate through WUAs. This may present problems if issues related to WUAs, such as representation, are not addressed.
- *International issues:* There would need to be some mechanism to enable international stakeholders to participate, through the Dolomitic Aquifer Management Committee, in cooperative aquifer management. However, the nature of international issues requires further clarification in this respect.

The following important issues are central to the functioning of such a committee and require thorough consultation through workshops and focus groups with stakeholders to resolve:

- powers (advisory or executive)
- roles, functions and responsibilities
- information and support requirements
- issues of accountability and representation
- broader participation of stakeholders
- resources (human and financial)
- channels for communication and recommendations
- implementation of recommendations
- collaborative governance and representation of other government departments with a role in groundwater management
- mechanisms for dispute resolution

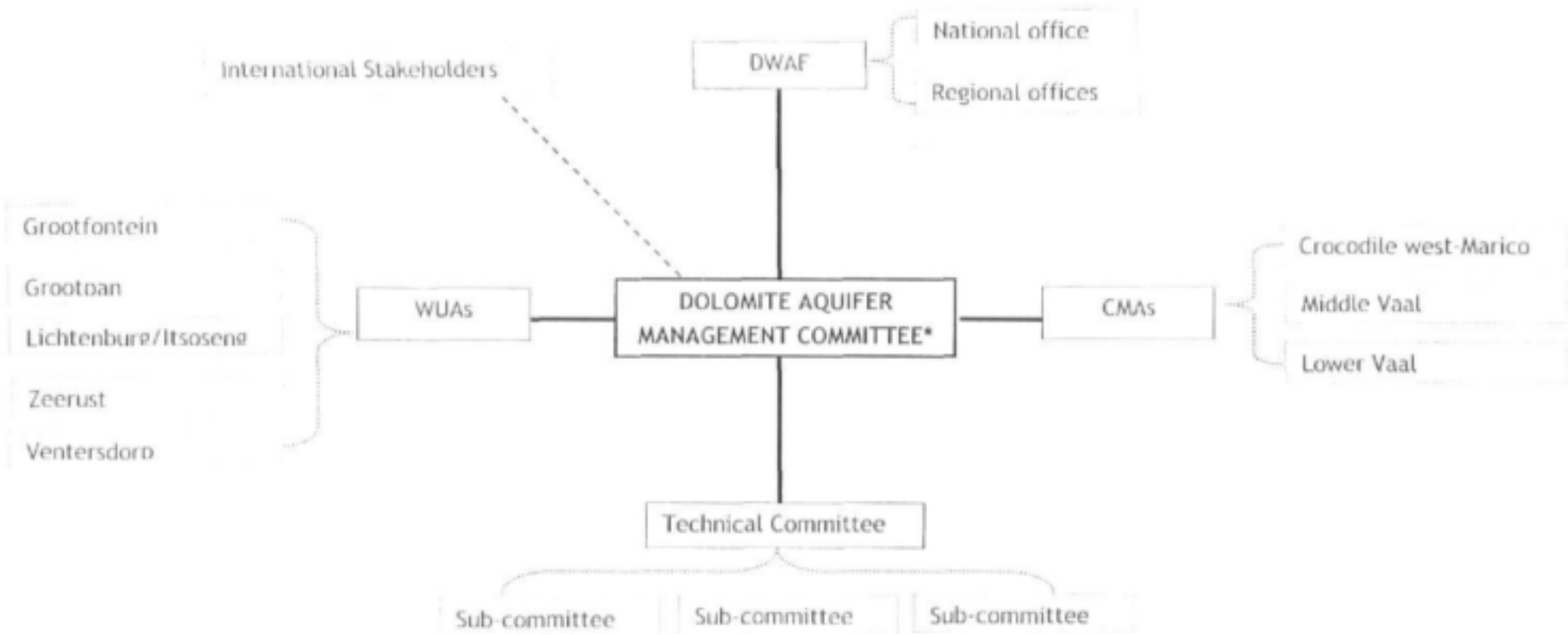

Figure 10.1: Proposed Institutional Framework for Groundwater Management in Dolomitic Terrains

* Established in terms of Section 82(5) of the National water Act (Act 36 of 1998)

11 CONCLUSIONS AND RECOMMENDATIONS

11.1 Conclusions

Following the Phase 1 situation analysis, during which the body of existing research was examined, several gaps in the existing knowledge base have emerged which need to be addressed. Gaps relate to the level and accuracy of geohydrological understanding as well as specific information regarding the users and institutions involved in groundwater. These gaps pose constraints to the development of institutional arrangements for the sustainable and equitable management of groundwater.

One of the greatest barriers affecting sustainable and equitable aquifer management is the lack of information on the supply and availability of water from the aquifer. At one level there are gaps in the knowledge base (mentioned above), which need to be addressed through research. At another level, where information does exist, it needs to be effectively disseminated to users/managers to enable informed decision-making and negotiations.

A great deal of geohydrological information of the different dolomitic units is available and essential aquifer parameters (e.g. recharge, pumping, spring flow, aquifer storativity, transmissivity and aquifer depths) have been obtained. However, in the light of improved techniques and data series, refinement of the estimates is necessary in order to improve our understanding of the aquifer and its functioning. This would also assist in providing information needed to define possible boundaries for water user associations. Improved understanding and accuracy of the following factors is needed, through hydrodynamic modelling of the entire aquifer system:

- the groundwater drainage of the total area;
- the leakage between compartments, and outflow to and inflow from adjacent geological formations;
- the effect of dykes acting as leaky boundaries;
- a water balance of the total area;
- delineation of the probable recharge areas of the different springs in relation to the water quality (chloride concentrations);
- simulation of the aquifer response to different scenarios of abstraction and recharge;
- quantification of the water level impacts at the different springs and ecological sensitive water impoundments.

Further, a certain degree of controlled overabstraction would help to assess the aquifer response to abnormal stress, an in better understanding the role of dykes. A better understanding of the long- and short-term effects of pollution (from sanitation systems, pesticides or fertilisers) on the water quality in the aquifer, and the impact on health is also needed.

In terms of social and institutional issues related to the use/management of groundwater, the following issues need attention:

- small-scale/emerging groups, with particular emphasis on the role and importance of water in their operations, problems they experience in accessing water, how this affects their activities and livelihoods, the nature and structure of any management systems they employ, internal systems of organisation and channels of representation, as well as internal power relations and traditions.
- the relationship between access to water, livelihoods and development opportunities needs to be clearly understood in the context of the study area (Where are the critical areas where there are problems with access to a reliable and sufficient water supply and services to meet basic needs, and how can these be addressed through the management of groundwater? What is needed in management of groundwater address these problems?)
- reliable projections of future water demand in the area, considering the implications of planning initiatives (e.g. the North West Spatial Development Initiative) for water demand
- clarification of international issues related to the dolomitic aquifer (e.g. the interaction between ground and surface water systems in cross-border context, as well as the relationship between the transboundary aquifers between South Africa and Botswana)

11.2 Way forward: Phase 2

There are two important issues that need to be clarified *before* proceeding into the field research components in Phase 2 of this project. These broadly relate to the scope of the project and the integration of this project with other water management projects underway in the study area.

The first issue relates to the need for integrated planning processes - to what extent and how should this study relate to other development planning initiatives in the area, and other water management planning processes? Interaction/interaction with catchment management agency processes is important to identify opportunities for the projects to support each other. However, the implication of integrating this project with two CMA processes, at different stages of establishment, and following different approaches needs thought.

Stakeholder involvement is an issue relating to integration with other studies that needs attention. The various water management studies currently underway have lead to a degree of confusion and stakeholder fatigue. How does this groundwater project, which depends on a broad and participative process in the development and ultimate implementation of a management framework, proceed in this context?

Before proceeding with further research, these issues need to be resolved. Thereafter the following research and field investigations are needed in Phase 2 of the project:

Geohydrological research

As a preliminary measure, a conceptual model of the aquifer will be developed, showing basic geohydrological parameters and other relevant information (e.g. environmental sensitivity, social features etc) gathered during Phase 1 of the project. This will serve as a tool, to assist decision-making related to the social and institutional issues.

Thereafter, although an initial determination of the 'reserve' could be based on available information, assessments of critical parameters (recharge and aquifer storativity) and a simple approach towards estimation of the ecological requirements, the preparation of a *proper hydrodynamic simulation of the aquifer is recommended* using both a 2- and 3-dimensional model. This would require:

- reassessment of critical parameters according to different methods;
- collation of all available information and monitoring data in a suitable data base;
- screening of all data to validate the integrity of the information,

The following specific investigation/research could be carried out:

- More reliable estimation of abstraction.
- Obtaining the natural pristine condition of the aquifer water levels and spring flows.
- Development of a simple model based on the CRD and MA rainfall relationships
- Determining resource quality objectives.

Quantifying ecological impacts from controlled abstraction could be done near an impoundment (e.g. the Marico-Kaaloog) where the groundwater levels could be drawn down several metres. The water that is pumped could be discharged into the Marico River to temporarily augment the flow of the river. Alternatively the Molopo eye could be put under stress and excess water could be delivered to the channel of the Molopo River. In the latter case the water could not be used as beneficently as at the Kaaloog.

Social/institutional research

Further social/institutional investigations are needed in order to complete the situation analysis and to assess and refine the preliminary criteria for institutional arrangements presented in Chapter 10. Research is needed on the following range of issues:

- detailed research and analysis into the social, cultural, political and institutional interactions taking place with respect to groundwater use and management in the study area, looking particularly at:
  - issues that would facilitate or hinder the implementation of groundwater management in the area,
  - the type of groundwater management systems that would both gain support from users and managers, and promote issues of equity and sustainability, against preliminary recommendations
  - stakeholders' vision for groundwater use/management - whether there is a common vision, or where points of conflict may exist
- a thorough investigation into issues of institutional capacity and resources, the roles, functions and responsibilities of different lines and levels of government, as well as departmental mandates and issues of cooperative governance, communication channels, technical assistance and information sharing between departments with respect to groundwater management
- further research into the use patterns, representation, management arrangements (formal and informal) and concerns of small-scale/emerging user groups as well as how to address

issues of capacity, organisation, representation, education/awareness, empowerment, etc., particularly within marginalized groups through groundwater management

- through the involvement of stakeholders in Botswana, information is required on current and projected demands for consumption from the dolomite aquifer, management problems, existing institutional arrangements, etc to clarify international issues that would affect the development of institutional arrangements
- assessment of the feasibility of adopting a co-management approach in developing institutional arrangements for groundwater management
- an analysis of the economic implications of proposed institutional arrangements on various user groups and economic activities

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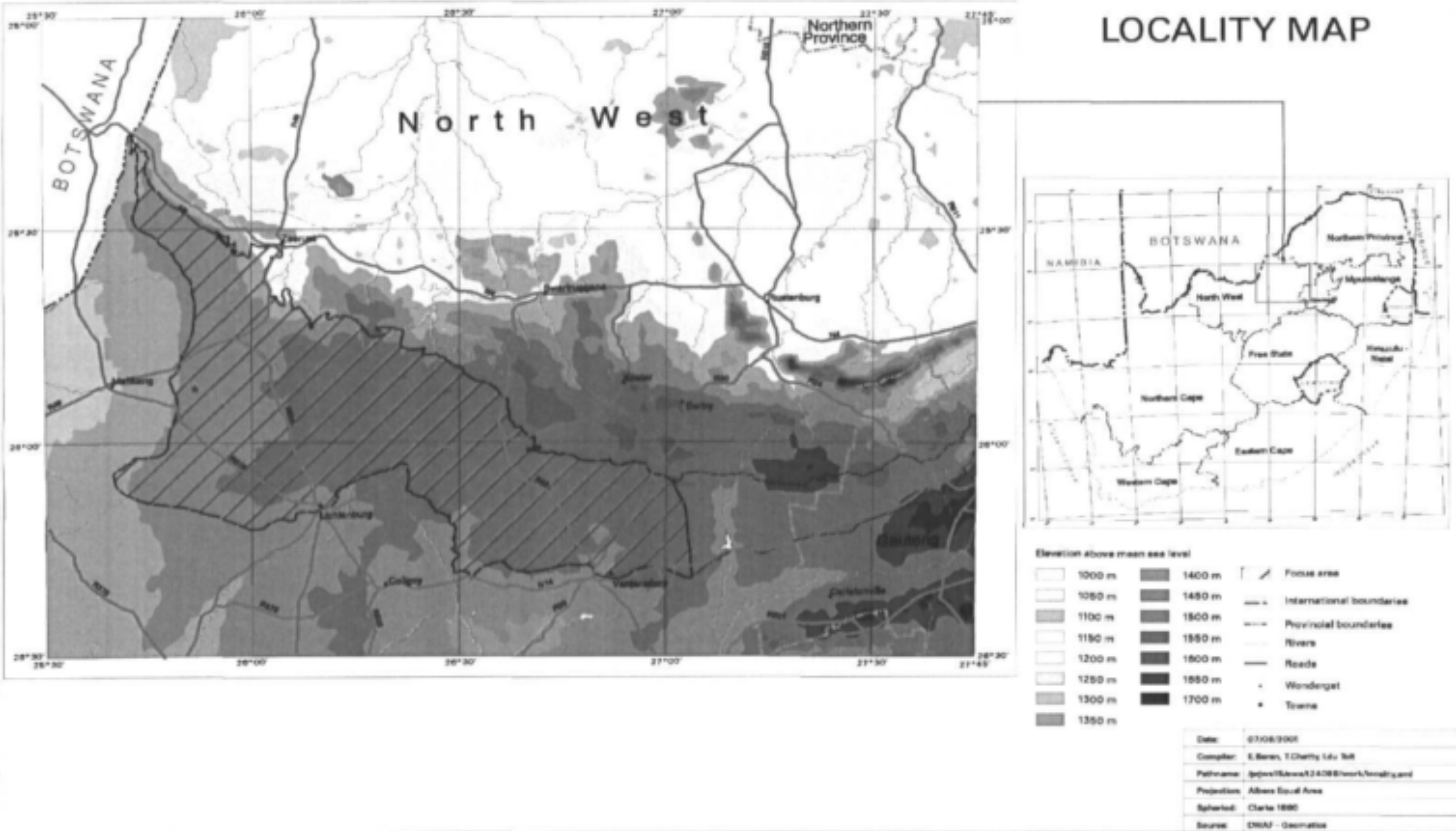
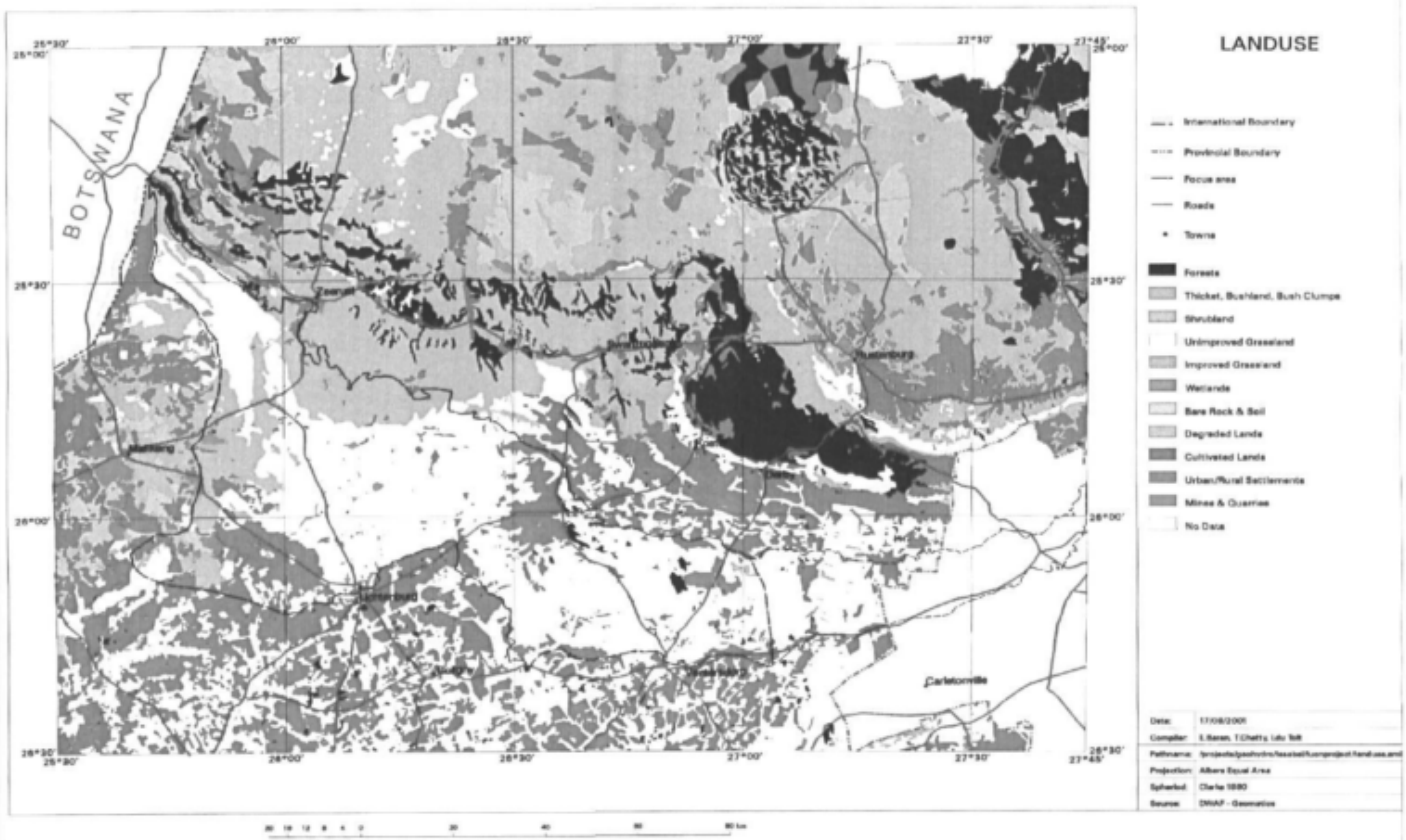
Annexure A: Maps

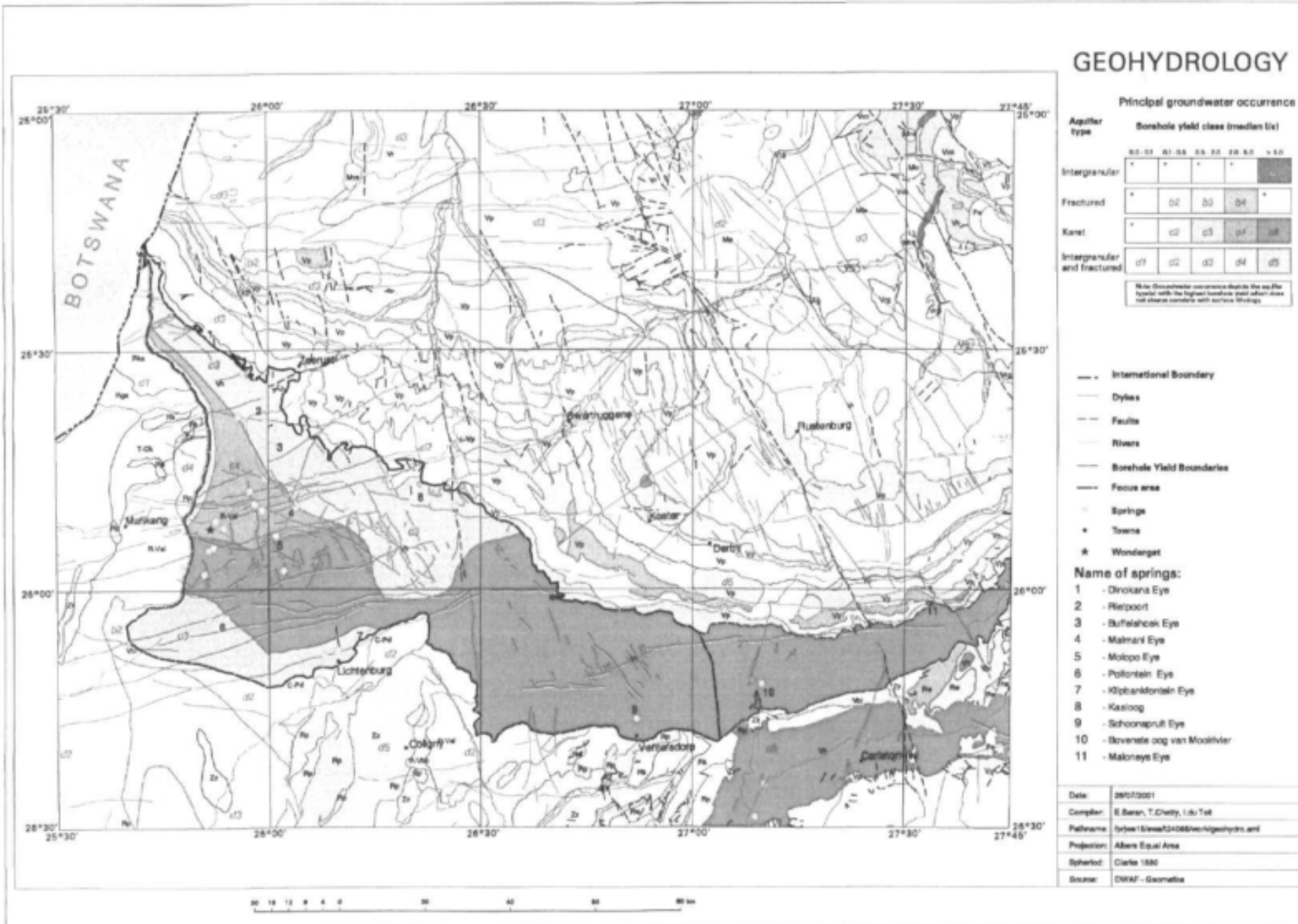
List of Maps

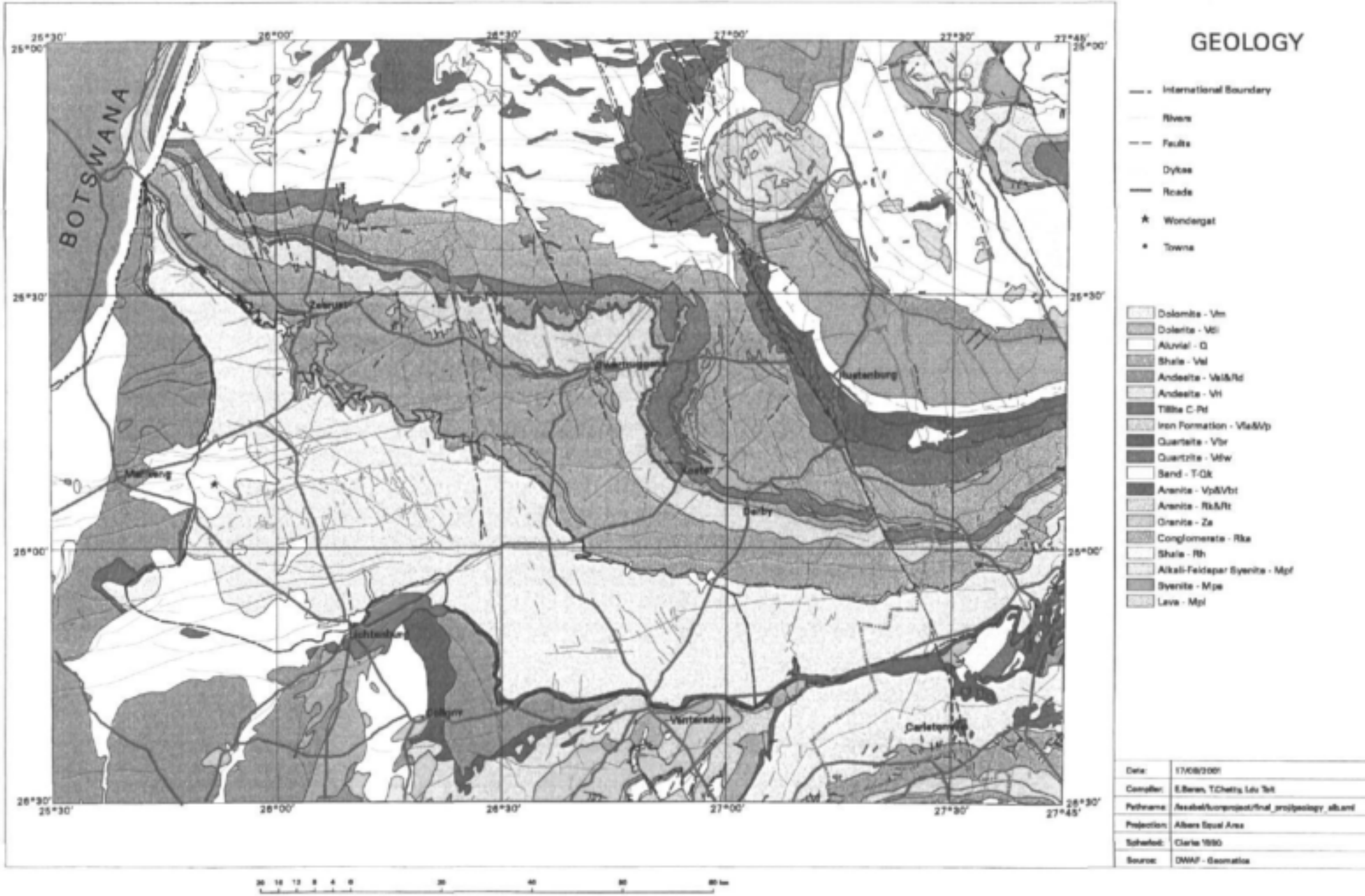
LOCALITY MAP



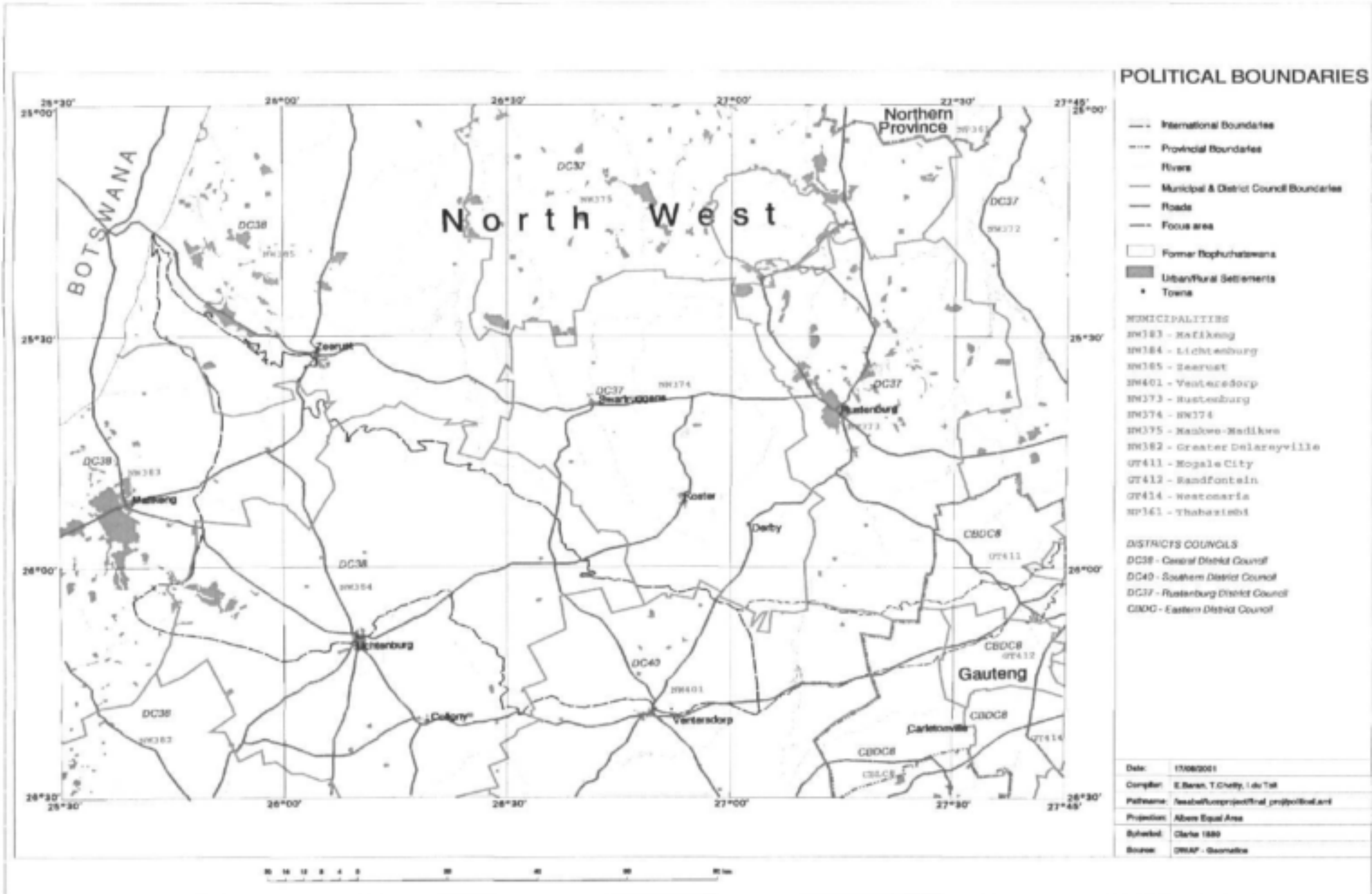

WATER MANAGEMENT
North West
Northern Province
BOTSWANA
Crocodile West - Marico
W M A
Zeerust
Swartruggens
Rustenburg
Zeerust
Bo Molopo
GWCA
Mafikeng
Koster
Derby
Groot Pan
Extended Grootfontein
Schoonspruit
GWCA
Itsoseng/Lichtenburg
Lichtenburg
Ventersdorp
Gauteng
Lower Vaal
W M A
Coligny
Ventersdorp
Carletonville
Middle Vaal
W M A
Upper Vaal
W M A
International Boundary
Provincial Boundaries
Proposed Water User Association Boundaries
Groundwater Control Area Boundaries
Water Management Area Boundaries
Focus area
Quaternary Catchment Area
Rivers
Groundwater Control Areas
Towns
Water Management Areas
Groundwater Control Areas
Date: 26/07/2001
Projection: Albers Equal Area
Source: DWAF - Geomatics

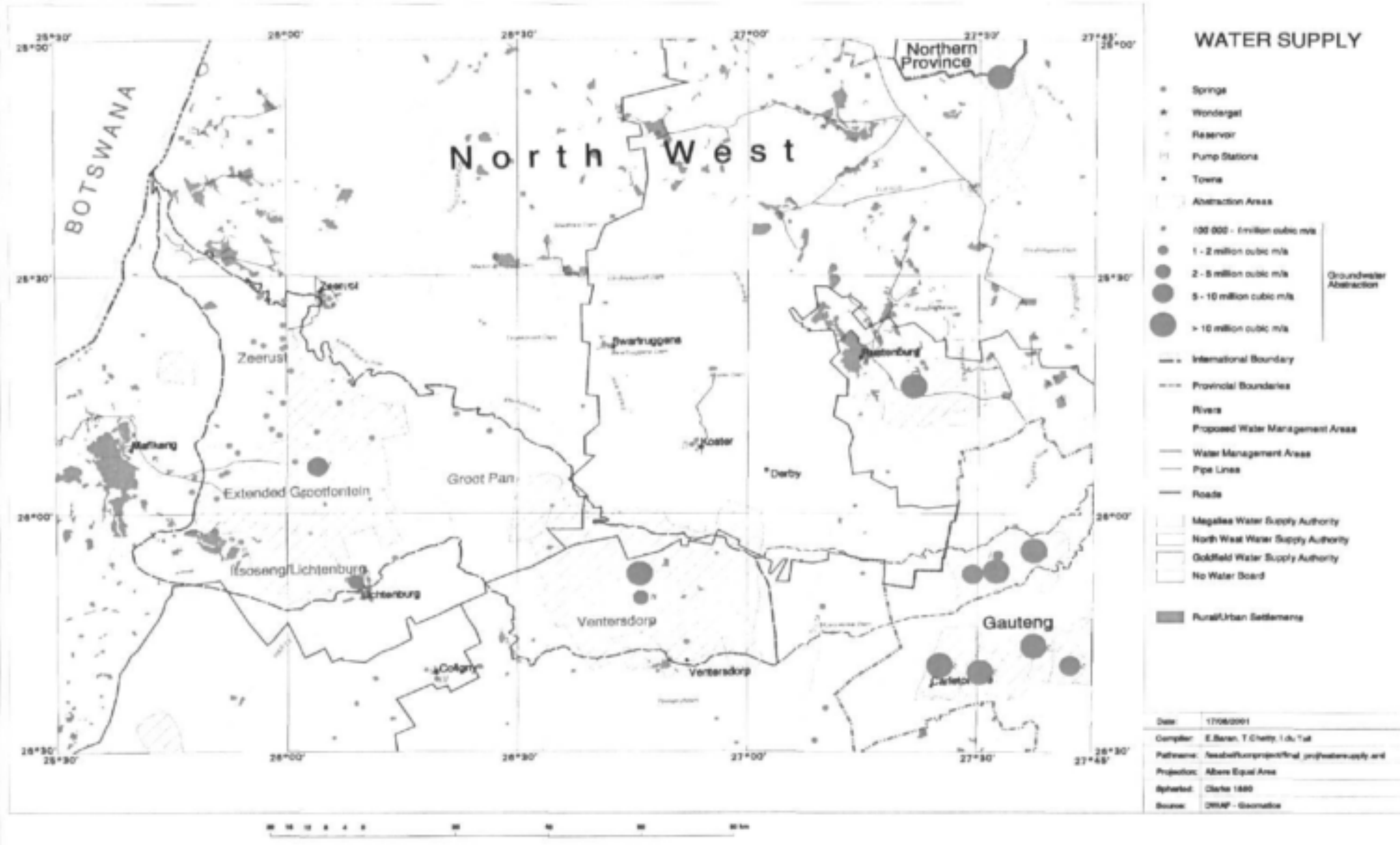

LANDUSE
International Boundary
Provincial Boundary
Focus area
Roads
Towns
Forests
Thicket, Bushland, Bush Clumps
Shrubland
Unimproved Grassland
Improved Grassland
Wetlands
Bare Rock & Soil
Degraded Lands
Cultivated Lands
Urban/Rural Settlements
Mines & Quarries
No Data
BOTSWANA
Rustenburg
Carletonville
Projection: Albers Equal Area
Source: DWAF - Geomatics


GEOHYDROLOGY
Principal groundwater occurrence
Aquifer type
Borehole yield class (median l/s)
Intergranular
Fractured
Karst
Intergranular and fractured
b2
b3
b4
c2
c3
c4
c5
d1
d2
d3
d4
d5
International Boundary
Dykes
Faults
Rivers
Borehole Yield Boundaries
Focus area
Springs
Towns
Wonderfontein
Name of springs:
1 - Dinokana Eye
2 - Rietpoort
3 - Buffelshoek Eye
4 - Malmani Eye
5 - Molopo Eye
6 - Polfontein Eye
7 - Klipbankfontein Eye
8 - Kaaloog
9 - Schoonspruit Eye
10 - Bovenste oog van Mooirivier
11 - Maloneys Eye
Date: 28/07/2001
Compiler: E.Baran, T.Chetty, I.du Toit
Projection: Albers Equal Area
Spheroid: Clarke 1880
Source: DWAF - Geomatics
BOTSWANA
Zeerust
Swartruggens
Rustenburg
Mafikeng
Koster
Derby
Lichtenburg
Ventersdorp
Coligny
Carletonville
25°30'
26°00'
26°30'
27°00'
27°30'
27°45'
25°00'
25°30'
26°00'
26°30'



GEOLOGY
International Boundary
Rivers
Faults
Dykes
Roads
Wondergat
Towns
Dolomite - Vm
Dolerite - Vdi
Aluvial - Q
Shale - Vsl
Andesite - Vsl&Rd
Andesite - Vri
Tillite C-Pd
Iron Formation - Vla&Vp
Quartzite - Vbr
Quartzite - Vdw
Sand - T-Qk
Arenite - Vp&Vbt
Arenite - Rk&Rt
Granite - Za
Conglomerate - Rka
Shale - Rh
Alkali-Feldspar Syenite - Mpf
Syenite - Mps
Lava - Mpl
BOTSWANA
Zeerust
Rustenburg
Koster
Derby
Mafikeng
Lichtenburg
Coligny
Ventersdorp
Carletonville
25°30'
26°00'
26°30'
27°00'
27°30'
27°45'
25°00'
25°30'
26°00'
26°30'
Date: 17/08/2001
Projection: Albers Equal Area
Spheroid: Clarke 1880
Source: DWAF - Geomatics


POLITICAL BOUNDARIES
International Boundaries
Provincial Boundaries
Rivers
Municipal & District Council Boundaries
Roads
Focus area
Former Bophuthatswana
Urban/Rural Settlements
Towns
MUNICIPALITIES
NW383 - Mafikeng
NW384 - Lichtenburg
NW385 - Zeerust
NW401 - Ventersdorp
NW373 - Rustenburg
NW374 - NW374
NW375 - Moses Kotane
NW382 - Greater Delareyville
GT411 - Mogale City
GT412 - Randfontein
GT414 - Westonaria
NP361 - Thabazimbi
DISTRICTS COUNCILS
DC38 - Central District Council
DC40 - Southern District Council
DC37 - Rustenburg District Council
CBDC - Eastern District Council
Date: 17/08/2001
Compiler: E.Baran, T.Chetty, I du Toit
Projection: Albers Equal Area
Spheroid: Clarke 1880
BOTSWANA
North West
Northern Province
Gauteng
Zeerust
Swartruggens
Rustenburg
Mafikeng
Koster
Derby
Lichtenburg
Coligny
Ventersdorp
Carletonville
DC37
DC38
DC40
CBDC8
25°30'
26°00'
26°30'
27°00'
27°30'
27°45'


WATER SUPPLY
Springs
Wondergat
Reservoir
Pump Stations
Towns
Abstraction Areas
1 - 2 million cubic m/a
2 - 5 million cubic m/a
5 - 10 million cubic m/a
> 10 million cubic m/a
Groundwater Abstraction
International Boundary
Provincial Boundaries
Rivers
Proposed Water Management Areas
Water Management Areas
Pipe Lines
Roads
Magalies Water Supply Authority
North West Water Supply Authority
Goldfield Water Supply Authority
No Water Board
Rural/Urban Settlements
Projection: Albers Equal Area
Source: DWAF - Geomatics
North West
BOTSWANA
Northern Province
Gauteng
Zeerust
Extended Grootfontein
Groot Pan
Itsoseng/Lichtenburg
Ventersdorp
Mafikeng
Swartruggens
Koster
Derby
Rustenburg
Lichtenburg
Coligny
Carletonville

Annexure B: Water Consumption

Table B.1 Figures relating to water consumption for towns in study area

Data was taken from DWAF 2000a and Water Service Development Plans (where available). Data is useful only as an indication of trends and of the quality of data currently available from municipalities. Figures have not been updated following the municipal demarcation process in 2000. Outside urban boundaries, the rural areas included in these figures are variable (e.g. Dinokana is included in some of the data for Zeerust). (N/d = no data)

Area	Water source	Present demand (2000)	Estimated demand (2030)	Growth rate[55]	Consumption patterns	Demand centre	Water balance (excess/deficit) 2000	2030	Unaccounted for water[56]	Monitoring (quality at source)
Mafikeng	Grootfontein compartment (pumping), Molopo compartment (overflow), Setumo dam	13.27 Mm³/yr	41.25 Mm³/yr	7.8%	Growth is three times higher than normal	1st largest	18.216 Mm³/yr	-10.553 Mm³/yr	28%	N/d
Zeerust	Zeerust compartment (well field)	2.117 Mm³/yr	5.36 Mm³/yr	4.08%	Negative growth over past years	2nd largest	0.037 Mm³/yr	-3.688 Mm³/yr	9.1%	Yes (monthly)
Lehurutse[57]	Zeerust compartment (Dinokana eye)	0.829 Mm³/yr	N/d	34.35%[58]	N/d	2nd largest	0.976 Mm³/yr	-1.062 Mm³/yr	Unknown	N/d
Lichtenburg	Lichtenburg-Itsoseng compartment	3.752 Mm³/yr	13.3 Mm³/yr	1.85%	Less than theoretical demand	3rd largest	2.402 Mm³/yr	-6.642 Mm³/yr	10%	Yes (quarterly)
Itsoseng	Lichtenburg-Itsoseng compartment	1.784 Mm³/yr	3.4 Mm³/yr	4.3%	Equivalent to theoretical demand	3rd largest	1.197 Mm³/yr	-1.054 Mm³/yr	77.8%[59]	Yes (quarterly)
Ventersdorp	Schoonspruit eye (Ventersdorp comp.)	0.928 Mm³/yr	N/d	N/d	N/d	N/d	N/d	N/d	N/d	Yes (quarterly)

Source: DWAF, 2000a (except data for Ventersdorp which is from the Water Service Development Plan).

[55] Growth in water consumption, (DWAF, 2000a)

[56] figures within 10% are generally regarding as well within acceptable limits of unaccounted for water

Source: *Municipal Water Service Development Plans*

[57] including Dinokana and environs

[58] high growth rate due to high number of illegal yard connections in area

[59] contributing factors to the high figures for Mafikeng and Itsoseng are not so much water lost, but water not properly metered and billed

Source: *Municipal Water Service Development Plans*

Annexure C: Groundwater recharge and water balance

Dolomitic groundwater: recharge and consumption

The following tables of figures have been drawn from DWAF (2000a).

Compartment Name	Area (km^2)	Recharge (Mm^3/a)	
		Min	Max
Zeerust	591.0	30.727	43.895
Grootfontein	785.2	32.478	46.397
Lichtenburg	653.4	25.740	36.772
Groot Marico / Schoonspruit[60]	1723.8	42.256	60.366
Total	**3753.4**	**131.201**	**187.43**

Table C.1 Dolomitic compartments and recharge capacities
(Source: DWAF, 2000a)

Compartment Name	Total for Water User (Mm^3/a)				Total
	Irrigation	Domestic	Mining	Environ.	
Zeerust	31.222	10.008	2.665	0.000	43.895
Grootfontein	29.845	9.097	0.000	7.455	46.397
Lichtenburg	22.824	11.831	2.117	0.000	36.772
Groot Marico	60.366	0.000	0.000	0.000	60.366
Total	**144.257**	**30.936**	**4.782**	**7.455**	**187.430**

Table C.2 Water Use from Dolomitic Compartments
(Source: DWAF, 2000a)

[60] includes Ventersdorp and Grootpan compartments in this study

Regional Water Balance

Criterion	Volume (Mm^3/a)	
	2000	2030
Demand		
Zeerust region	7.761	16.083
Grootfontein region	13.366	41.854
Lichtenburg region	6.768	18.915
Groot Marico / Schoonspruit region	2.946	6.756
Sub-total	*30.841*	*83.608*
Resources		
Zeerust region	8.808	8.808
Grootfontein region	31.582	31.301
Lichtenburg region	10.367	10.367
Groot Marico / Schoonspruit region	4.947	4.947
Sub-total	*55.704*	*55.423*
Excess / Deficit	**24.863**	**-28.185**

Table C.3 Summary of present Regional Water Balances for Study area, including surface and groundwater resources (Source: DWAF, 2000a)

Region	Water Source (Mm^3/a)	
	Ground	Surface
Zeerust region	7.275	
Grootfontein region	10.553	
Lichtenburg region	8.548	
Groot Marico region[61]		3.016
Sub-total	*26.376*	*3.016*
Total		**29.392**

Table C.4 Summary of Additional Water Resources Required for Study area (Source: DWAF, 2000a)

[61] includes Ventersdorp and Grootpan compartments in this study

Annexure D

Table D.1 Key Informant Interviews: Phase 1

CONTACT	ORGANISATION/ROLE	INTERVIEW
	Water User Associations (WUA)	
Andries Beyers	Lichtenburg/Itsoseng WUA	Yes, 21/6/01
Manfred Lohann	Grootpan WUA	Yes, 5/07/01
Dawid Kruger	Ventersdorp WUA	Yes, 10/07/01
Hurter van Zyl	Ventersdorp WUA	Yes, 19/07/01
Mr Cordier	Zeerust WUA	Yes
Theuns du Plessis	Grootfontein WUA (Bo Molopo Water Board)	No
Hendrik Smit	Grootfontein WUA (Bo Molopo Water Board)	Yes, 5/07/01
	Water Supply Authorities	
Faan van Rensburg	North West Water Supply Authority (NWWSA)	Yes, 13/07/01
	Agricultural Unions	
Andries Beyers	North West Agricultural Union	Yes, 21/6/01
Paul Greyling	Transvaal Agricultural Union	Yes, 11/07/01
?	National African Farmers' Union (NAFU)	No contact
	Researchers/consultants	
Reinhard Meyer	Environmentek, CSIR	Yes, 10/07/01
Prof. B. de Villiers	Geology dept, Potchefstroom University	Yes, 2/07/01
Tim Hart	Resource Development Consultants	Yes, 12/07/01
Max Jordaan	Ernst and Potnes, Rustenburg	Yes, 4/07/01
	DWAF Regional offices	
Ismaël Khumoeng	DWAF - North West	Yes, 19/06/01
Paul van der Merwe	DWAF - North West	Yes, 14/07/01
Dr Johan van der Merwe	DWAF - Free State	Yes, 20/07/01
Rens Botha	DWAF - Gauteng	Yes, 15/07/01
	NW Province	
Kelebogile Sethibelo	Dept of Economic Development and Tourism	Yes, 17/01/01
Batlang Lekalake	Dept of Land Affairs, North West	Yes, 22/07/01
Stuart Mangold	Dept of Agriculture, Conservation and Environment	Yes, 26/07/01
	DWAF Head Office	
Eddy van Wyk	Directorate: Geohydrology	Yes, 20/07/01
Eberhard Braune	Directorate: Geohydrology	Yes, 20/07/01
	Local Government	
John Mokhele	Central District Municipality	Yes, 20/06/01
Felix Labuschagne	Southern District Municipality	Yes, 4/07/01
Dirk Lombard	Engineer, Ditsobotla (Lichtenburg/Itsoseng) Local Municipality	Yes, 21/06/01
Manfred Harde	Health Inspector, Ditsobotla (Lichtenburg/Itsoseng) Local Municipality	Yes, 18/06/01
Hendrik Smit	Mafikeng Local Municipality	Yes, 4/07/01
Mr Dandashe	Engineer, Zeerust Local Municipality	Yes, 20/06/01
Mr van Niekerk	Head of Health Services, Ventersdorp Local	Yes, 3/07/01

	Municipality	
Mr Boshoff	Treasurer, Ventersdorp Local Municipality	Yes, by fax
Mr Bester/Mr van Staden	Koster Local Municipality	Yes, 2/07/01
Mr Harmse	Town clerk, Swartruggens Local Municipality	Yes, 2/07/01
Tommy Pienaar	Coligny Local Municipality	Messages
	Department of Agriculture	
Walter Viljoen	North West, Dept of Agriculture	Yes.
Priscilla Kgosi	North West, Dept of Agriculture	Fax, awaiting info.
Mr Swanepoel	North West, Dept of Agriculture	Yes, 19/07/01
Dan Thubise	North West, Dept of Agriculture (Dinokana)	Yes, 20/6/01
	Industry	
Dennis Edgar	Lafarge Cement (Lichtenburg)	Yes, 3/07/07
Peter Meyer	PPC Cement (Slurry)	Yes, 5/07/01
Kostas & Dimitri Synodinos	Diamond mining operations, small scale (Grasfontein)	Yes, 19/06/01
Flip Wessels	Clover Dairy	Yes, 24/07/01
Derek Wolmarans	Alpha Cement	Yes, 5/07/01
	Ward Councillors	
Councillors	Ditsobotla Municipality	Yes, 21/06/01
	Other	
Charles Steyn	Grasfontein Community	Yes, 18/06/01
Irene Wapad	Grasfontein Community	Yes, 18/06/01
Setch Malebo	Grasfontein Community, pump attendant	Yes, 18/06/01
Ruth Celishane	Grasfontein Community	Yes, 19/06/01
Milton Manenza	Ward councillor, Grasfontein Community	Yes, 19/06/01
Flora Mahlaba	Grasfontein Community, women's group	Yes, 19/06/01
Alex Nqabasa	Bodibe Community	Yes, 19/06/01
Agnes Sepharaqatlha	Bodibe Community	Yes, 19/06/01
Petrus Mhlapo/Petrus Matsolo	Sheila Community	Yes, 19/06/01
Sheila Water Committee	Sheila Community - water committee	Yes, 19/06/01

INSTITUTIONAL ARRANGEMENTS FOR GROUNDWATER MANAGEMENT IN DOLOMITIC TERRAINS

PHASE 1: SITUATION ANALYSIS

SOCIAL ASSESSMENT

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Hatfield, Pretoria
0028

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LIST OF FIGURES AND TABLES

LIST OF MAPS

ABBREVIATIONS

CDM/C ....Central District Municipality/Council
CMA..Catchment Management Area/Agency
CMS ....Catchment Management Strategy
DoA ....Department of Agriculture
DWAF ....Department of Water Affairs and Forestry
GGP..Gross Geographic Product
ISARM ....Internationally Shared Aquifer Resource Management
IUCN ....World Conservation Union
IWMI..International Water Management Institute
NWA ....National Water Act (Act 36 of 1998)
NWWSA ....North West Water Supply Authority
O&M ....Operation and Maintenance
SADC ....Southern African Development Community
SDM/C ....Southern District Municipality/Council
WMA..Water Management Area
WRC...Water Research Commission
WSA...Water Services Act (Act 108 of 1997)
WSDP...Water Service Development Plan
WUA ....Water User Association

1 INTRODUCTION

1.1 Background

Groundwater has a history of neglect and unsustainable utilization in South Africa, and the recent process of water law reform, as well as international developments in water management, have drawn attention to the need to address the position of groundwater in water resources management (Braune, 2000). A management framework is needed that defines the institutional arrangements to both protect this valuable and strategically important national asset, taking into consideration the specific characteristics and role of groundwater, as well as one that addresses issues of vast inequity around the access to and use of water resources.

With high rates of evaporation and limited surface water resources South Africa is among the 20 most water stressed countries in the world (Braune, 2000). Water scarcity is further compounded by a growing population and an urgent need for economic development address poverty, job creation and social inequity. Access to water and water services is vital for improved health and development opportunities. Poverty alleviation therefore, has to be one of the focal points of water management. Groundwater is becoming one of the most viable sources of water to meet the urgent needs for water. Addressing its optimal management in this context is therefore a priority.

However, groundwater management is complicated by its unseen and invisible nature. Past and current planning has resulted in a challenging situation, where the boundaries of water management areas, provinces, local authorities and other initiatives do not coincide, a situation which is further compounded when incorporating geohydrological boundaries into the scenario (WISA, 1997). In addition, water management areas (and institutions) are largely defined by surface water patterns, further sidelining the importance of groundwater, and increasing the problems for its management.

The key challenge of this project, is thus to develop a framework for the management of groundwater that addresses issues of sustainability and equity in the management of a natural resource that is divided between management areas and institutions.

1.2 Objectives of this report

The purpose of this project is the development of institutional arrangements for the sustainable and equitable management of groundwater in dolomitic terrains. In achieving this purpose, the project has been divided into four phases.

- phase 1: situation analysis – desk-top review
- phase 2: situation analysis – research studies
- phase 3: workshop management options and approaches

- phase 4: preparation of management structure, institutional principles, and information system for groundwater management

This report forms part of phase 1, and provides the social and institutional context for the use and management of groundwater, with a particular focus on the conditions and issues in the dolomitic terrain of the North West province. As well as providing some theoretical background and a profile of the study area, there are three primary objectives to this report:

- to analyse of the legal and policy environment for groundwater management, and to determine the implications of the new legal and policy environment for groundwater use and management
- to analyse of the existing institutional arrangements, profiling the numerous institutions involved in managing groundwater, their roles and responsibilities and the implications for the future management of groundwater
- to profile the users of groundwater, indicating the main users, which users are dependent on groundwater, and where potential areas of conflict or discrepancy might arise between users

1.3 Methodology

The objectives of this phase of the project are to examine and synthesise existing research and other documented information related to groundwater management in dolomitic terrains, to identify gaps in the existing knowledge base, and to highlight issues for further investigation in later phases on the project.

Document analysis has therefore guided most of the research in this component of the project. This has included a review of relevant legislation and policy documents, research reports on groundwater and water management, papers and publications addressing groundwater/water management, and a review of information available on the internet.

In addition, two field visits were conducted – the first as an introduction to the study area, to gain an awareness of the geohydrological and environmental issues, and the second, as part of a stakeholder analysis, to conduct semi-structured/informal interviews, particularly amongst groups who were not accessible telephonically. This provided valuable insights into some of the social and institutional issues in the study area that need to be addressed. A series of telephonic interviews with key informants was also undertaken to gauge a conceptual understanding of the perceptions of stakeholders across the area, particularly those involved in the use and/or management of water, as well as experts.

Since much of the information in this report is gained from interviews, it is important to realise that the information presented is, in many cases, opinions and perceptions, and not necessarily fact.

However, as perceptions (or misperceptions) held by stakeholders, this information is valuable and important to consider in developing institutional structures for groundwater management that suit the social dynamics of the study area.

In addition, the use of socio-economic statistical census data following the municipal demarcation process in 2000 has provided an important socio-economic context to the study.

1.4 Other water management studies

In line with integrated water resource management, as well as integrated development planning, it is important that this project take into account other studies currently underway in the project area. This is particularly relevant in the case of water management projects, the outcomes of which will have significant implications on each other. This also provides an opportunity to share knowledge and resources where necessary.

The number of long term projects not only creates confusion, but also fatigue amongst stakeholders, affecting their level of interest, willingness to cooperate and to participate in the process and its outcomes. Participation is a key component of this project, particularly considering the array of stakeholders involved, and will significantly influence the results of the research. In addition, participation of stakeholders is an important element of water resource management, and is strongly emphasised in water law and policy. It is therefore essential that participation informs the development of a management framework, in which stakeholders will ultimately play a key role. As a result, it is necessary to plan and manage the public participation process of this study sensitively, with an awareness of, and possibly in conjunction with, similar processes in the area.

The establishment of the catchment management agencies are processes currently underway in the study area. However, the two CMA studies which affect this groundwater project are at different stages in their development and following different approaches. It is nonetheless important that, as water management projects, there is integration between the CMA studies and this groundwater project as the outcomes of these projects have the potential to significantly affect each other. This issue has been raised with the relevant institutions and the need identified for a process to be formally established to facilitate some form of integration.

A further DWAF project is underway in the study area, investigating the augmentation of primary water supplies to Zeerust, Mafikeng and Swartruggens. Contact has been made with this project team, and the need for integration or coordination, where necessary.

Local planning processes, which should also be considered where necessary, include the preparation of integrated development plans for the district councils in the area, as well as the preparation of water service development plans.

1.4 Structure of this report

Section two of this report begins with a theoretical background to the principles and practises of water resource management, including an overview of international trends in policy, the problems affecting groundwater at an international level and the need for a regional perspective when managing water resources. The changing paradigm of water management in South Africa is then examined, followed by a look at the concepts of equity and sustainability. Thereafter, recent research in South Africa addressing (ground)water management and institutional structures is reviewed, with attention to issues that need to be considered in this study.

The legal and policy environment for groundwater management is examined in detail in Section three, focussing particularly on the implications of the new policy and legislation for groundwater use and management.

Section four provides a profile of the socio-economic context and development framework of the study area in order to highlight the particular conditions and issues at a local level that groundwater management needs to address.

The existing institutional arrangements for groundwater management are presented in Section five, looking specifically at the roles and functions of institutions, from a national to a local level, that have some involvement in groundwater management. The emergence of new water management institutions is also examined.

In Section six, the needs and concerns, as well as use patterns of the user groups in the study area are outlined, highlighting potential issues of conflict, as well as areas that require further research.

Sections seven and eight present an analysis of the specific challenges to groundwater management, as well as gaps in the existing knowledge base, that have emerged during the social assessment and require particular attention in the following phase of this project.

2 WATER RESOURCES MANAGEMENT: PRINCIPLES AND PRACTICES

This section will provide a brief overview of the international experiences of groundwater management. The history and evolving discourse in water management in South Africa will be examined, followed by a discussion on the concepts which are informing water resources management – equity and sustainability. Finally, previous studies that have addressed groundwater management, and their implications for this project, will be outlined.

2.1 International experiences

At an international level, problems characterising the use and management of groundwater include depletion of groundwater levels due to overdraft, water logging, salinisation and pollution, with a common symptom being the general decline in water tables (Shah, et al, 2000b). These and other problems associated with groundwater are evident in regions such as China, and South Asia where population densities, and the numbers of people dependent on groundwater are far higher than currently in South Africa. Groundwater problems in these areas are therefore much more extreme than those we are beginning to experience in South Africa.

Other problems associated with groundwater over-exploitation include the devastation of wetland ecologies (with associated socio-economic impacts such as decline the in tourism industries), the loss of recharge area through the rapid growth of urban areas (e.g. near Beijing in China and Izmir in Turkey), land subsidence due to groundwater depletion, and the risk of saline intrusion into depleted coastal aquifers (Shah, et al, 2000b).

In addition, the complexity of groundwater management across international borders has not been addressed. The uncontrolled drilling of boreholes into aquifers that transcend international boundaries raises complex questions around issues of sustainability and management arrangements at an international level[1].

International water transfer schemes are an increasing topic of debate, and at the same time, a rapidly developing source of supply augmentation. Several projects are underway in South Africa, and a number are being planned for the Southern African region[2]. The interdependency of water resources,

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[1] Meyer, R. 2001. personal communication, Pretoria, July.

[2] Those currently underway include the Lesotho Highlands Water Project between South Africa and Lesotho, the North South Carrier in Botswana and the Eastern National Water Carrier in Namibia. Projects being planned within the Southern African region include the Matabele-Zambezi Water Project (to carry water from the Zambezi river to below Victoria Falls), a pipeline in Namibia to carry water from the Okavango River and a further project in Namibia to develop a dam at the Epupa Falls on the Cunene River (Turton, 1999). It is noteworthy that these are all surface water schemes –international aquifer management being relatively unchartered territory at this stage.

their use and management at a regional scale is thus a factor which begs consideration in developing management strategies for water resources.

While much of the focus of regional (and national) water management has been on surface water resources, we need to pay similar attention to the regional development and protection of "invisible water" or groundwater. This issue has been highlighted within the SADC Water Sector Unit and is evident in its regional Groundwater Management Programme (Molapo, et al. 2000).

Groundwater is the main source of water for 37 percent of the population of SADC countries and has a central role to play in the settlement and development of rural areas[3]. In many cases, it is the only source of water available during periods of drought. However, within the region, groundwater is poorly understood, and its occurrence and recharge is variable and complex.

At a *regional SADC level*, challenges to the management of groundwater are (Molapo, et al, 2000:984):

- a lack of understanding of the significance of groundwater resources due to poor knowledge of recharge and long-term viability of withdrawals
- undervaluing of groundwater potential, especially where surface water is abundant
- depletion of aquifers due to mine dewatering and pollution
- limited monitoring of groundwater, quality and abstraction
- lack of groundwater protection measures due to poor environmental regulatory framework and poor enforcement
- inappropriate water supply technology and management with respect to what is affordable and manageable for local communities
- insufficient or under-utilised institutional structures
- limited legal and regulatory measures
- limited research and training facilities

The main objectives of the Groundwater Management Programme for the SADC region, adopted in 1999, are to (Molapo, et al. 2000):

- promote the sustainable development of groundwater at a regional scale
- assess groundwater management issues in member states and provide technical support
- develop the groundwater component in the regional integrated water resources development and management approach, with a particular emphasis on the role of groundwater during droughts

[3] Groundwater accounts for 11.6 percent of the total quantity of water used (some 4000 million cubic meters) and 20 percent of the water used for domestic purposes within SADC (Molapo, et al. 2000).

- intensify links between national and regional levels of activities within a general framework of regional economic integration

Despite these problems, groundwater has a valuable role to play, particularly in poverty alleviation, if integrated management systems are implemented (Braune, 2000; DWAF, 2000b). The resilience of groundwater resources during droughts, due to the long lag time between changes in recharge and the responses in groundwater levels presents an important opportunity in arid and semi-arid countries (Colvin, 2001; Shah, et al, 2000b). In addition, groundwater offers numerous advantages in agriculture and plays a central role in livelihoods creation strategies.

In fulfilling this role, groundwater availability at a global and national scale appears well in excess of current use, however this needs to be contextualised within the growing demands on groundwater, and the spatial imbalances in its occurrence. The challenges facing groundwater today therefore, are not its development as a resource, but its sustainable management (Shah, et al, 2000b).

There are a few examples of sustainable management approaches for groundwater resources throughout the world. However, problems lie in transferring these lessons in water management between countries, taking into consideration very different local conditions within which such systems would be applied (Shah, et al, 2000b). Different base-line conditions, inadequate institutional capacity and a lack of information are some of the problems facing water resource managers in developing countries.

In their paper on "Limits to Leapfrogging", Shah, et al, (2000a) expose the challenges faced in transposing institutional models for water management from developed countries to the developing world. While institutional models for water management in developed countries may indeed hold some lessons, their application in developing countries has not always been successful, and in some cases has proved counter-productive, for the following reasons:

- the conditions in developing countries are vastly different, including hydrologic and climatic conditions, demographics and socio-economic conditions, and the organisation of the water sector
- the problems addressed by water managers in the developed world are often not the same as those which are of relevance in developing countries, partly due to their different stages of development

Shah, et al (2000a:16) argues the need to take a broader view of institutional development: to look beyond the narrow focus on the role of governments in institutional change, and incorporate all stakeholders (business, civil society, religion, etc.) in the development of institutions, with particular emphasis on the voices from the grassroots. An understanding of the realities within a specific context will best inform the institutional changes necessary for addressing that reality.

In developing an equitable and sustainable management strategy for groundwater resources in South Africa, the patterns and problems of aquifer management at an international and regional scale should be considered, distilling those of relevance to South Africa, and enabling us to apply lessons within the context of local biophysical and socio-economic conditions.

2.2 New paradigms for water management in South Africa

The move towards delegated and decentralised management of water resources in South Africa, evident in the establishment of catchment management agencies (CMAs) as an organ of state, is guided by notions of decentralised and participatory governance. As noted in Fakir (2000:9), the success of this policy is "largely a factor of political maturity, ownership, and institutional sustainability…in terms of social capital and financial viability". This new paradigm requires a shift from policing water users, to developing a culture based on partnerships, and through negotiations and capacity building, enabling stakeholders to engage on an equitable basis. Fakir (2000) argues that the challenge in achieving these goals lies in encouraging strong local institutions and social networks.

Turton (1999) argues the need for new theoretical underpinnings to inform the way in which we perceive of and manage water resources in South Africa. Such a discourse should be based on a synthesis of the tenets of ecological sustainability and economic growth, ultimately promoting a paradigm of "virtual water", also raised by others as an interim solution to regional water shortages (Allan, 2001; Shah, et al. 2000b and Turton, 1999).

These notions of decentralised and participatory governance, equity, sustainability and economic growth underpin the development of new water management institutions in South Africa. The challenge however, lies in operationalising these principles through viable and sustainable institutional structures that bring about and accommodate change, and in which all users can participate. In addition, these institutions need to ensure equal access to water, not only to meet basic needs, but to facilitate economic growth and development. This is related to the water resource allocations stipulated in new legislation. Only after the determination of the reserve, for both ecological and basic needs, water use allocations are then made for municipal use, industry and agriculture – in contrast to the provisions for water use under previous legislation where water for agriculture was prioritised.

This is directly related to water resource allocations stipulated in new legislation. Only after the determination of the reserve, for both ecological and basic needs, water use allocations are then made for municipal use, industry and agriculture – in contrast to the provisions for water use under previous legislation.

Despite developments in policy, and the importance of groundwater as a national asset and a strategically important source of water on which many rural communities depend, water resource management in South Africa is largely determined by surface water systems. Aquifers do not always comply with the nineteen catchment management areas, demarcated for the devolution of water resources management. This further emphasises the challenges in developing institutional arrangements for the management of groundwater in this project.

2.3 "Sustainability" and "equity"

"Water is a common good and a community resource, but it is…used as a private good or economic necessity; it is not only a recreational resource, but a basic necessity of life; it is imbued with cultural values and plays a pay in the social fabric of our communities. Applying principles of sustainability and equity will help bridge the gap between such diverse and competing interests" (Gleick, 2000:136).

In South Africa, the denial of water rights through exclusion from land under apartheid has had profound socio-economic and environmental implications (Turton, 1999). The uneven distribution of water and unequal access to water resources and services creates inequity, social injustice and poverty. Addressing these imbalances in access and distribution is therefore a fundamental aspect of achieving sustainability and equity.

In preparing a management strategy for groundwater management, institutional arrangements, which determine the management and provision of water, need to be structured to realize the combined goals of *social equity* and *sustainability*. These concepts are captured in the Department of Water Affairs and Forestry's slogan, "some, for all, forever"[4]. In other words, providing:

- ⇨ access to a limited resource (some)
- ⇨ on an equitable basis (for all)
- ⇨ in a sustainable manner, now and in the future (for ever). (DWAF, 1997)

Equity also needs to address access to water services, water resources and the benefits from water. The goals of equity and sustainability are thus the guiding objectives of the National Water Act (Braune, 2000:9).

The following figure 1 indicates the three components of sustainability that need to considered and informed by local needs and circumstances, and where necessary, trade offs made on this basis (WISA, 2000):

[4] expressed in 1998 by Prof. Kader Asmal, then Minister of Water Affairs and Forestry (Turton, 1999:20).

Figure 1: The concept of sustainability (Source: WISA, 1997)

In a definition that encapsulates both equity and sustainability, Gleick (2000:131) defines sustainable water use as "the use of water that supports the ability of human society to endure and flourish into the indefinite future without undermining the integrity of the hydrological cycle or the ecological systems that depend on it."

In achieving this goal, in some cases, new water supplies will need to be developed, while in others, more efficient water use and the provision of infrastructure will enable existing water supplies to meet these demands. In other words, increasing the efficiency with which current needs are met, and with which water is allocated among different uses is a means to this end (Gleick, 2000). In addition to the scientific factors of resource functioning, institutional and social acceptability are key considerations in moving towards sustainability (Braune, 2000).

In practice however, the challenge remains great. Huge disparities in access to water, distribution of water, poor infrastructure, social and institutional capacity, local politics and initiative are just some of the obstacles that need to be overcome, and around which management plans must be developed.

2.4 *Managing groundwater – a Review of Institutional Approaches*

In developing a framework for groundwater management, there are some basic criteria that have been suggested. These are:

1. groundwater is best managed at the lowest *practical* level according to specific functions[5]. Shah et al (2000b) point out that many groundwater interventions are too local in their approach, and groundwater resources need to be planned and managed at a catchment level;

[5] For example, day-to-day management of water supplies is most effective at the local level (e.g. community), while regulatory and operational management is most effective at the resource or catchment level.

2. any management system/framework depends on adequate and accurate information (through regular monitoring) regarding the characteristics, functioning and status of the geohydrological system;
3. the management of groundwater must be part of *integrated water resources management* (IWRM) as an important component of the hydrological cycle, and its interaction with surface water systems fully understood and taken into account;
4. any management system must be based on the principles of sustainability, equity, and beneficial use (efficiency);
5. Shah et al (2000b:16-17) also include the need for sustainable resource management strategies to include demand-side management measures (sustainable withdrawal) and supply-side management (augmentation of recharge)

Several recent projects have looked at developing structures to manage groundwater in an equitable and sustainable manner. These structures will be briefly reviewed in terms of their feasibility for the particular conditions in the study area, where urban growth and increasing domestic water demand are key factors. In addition, we need to develop a framework that brings together the emerging CMA institutions and groundwater issues into integrated management system, based on principles of equity and sustainability.

Murray and Dindar (1998) have produced a framework that defines the roles and responsibilities, as well as a management structure, for groundwater resources in rural areas. This structure begins with institutions and their functions at the lowest level, with village water committees and water service providers, through to catchment management agencies, and the regional and national offices of DWAF. The steps needed, as well as the potential costs entailed, in establishing a rural groundwater management system are detailed. The structure of this system, as well as flow paths for the transfer of data, are represented in figure 2. below:

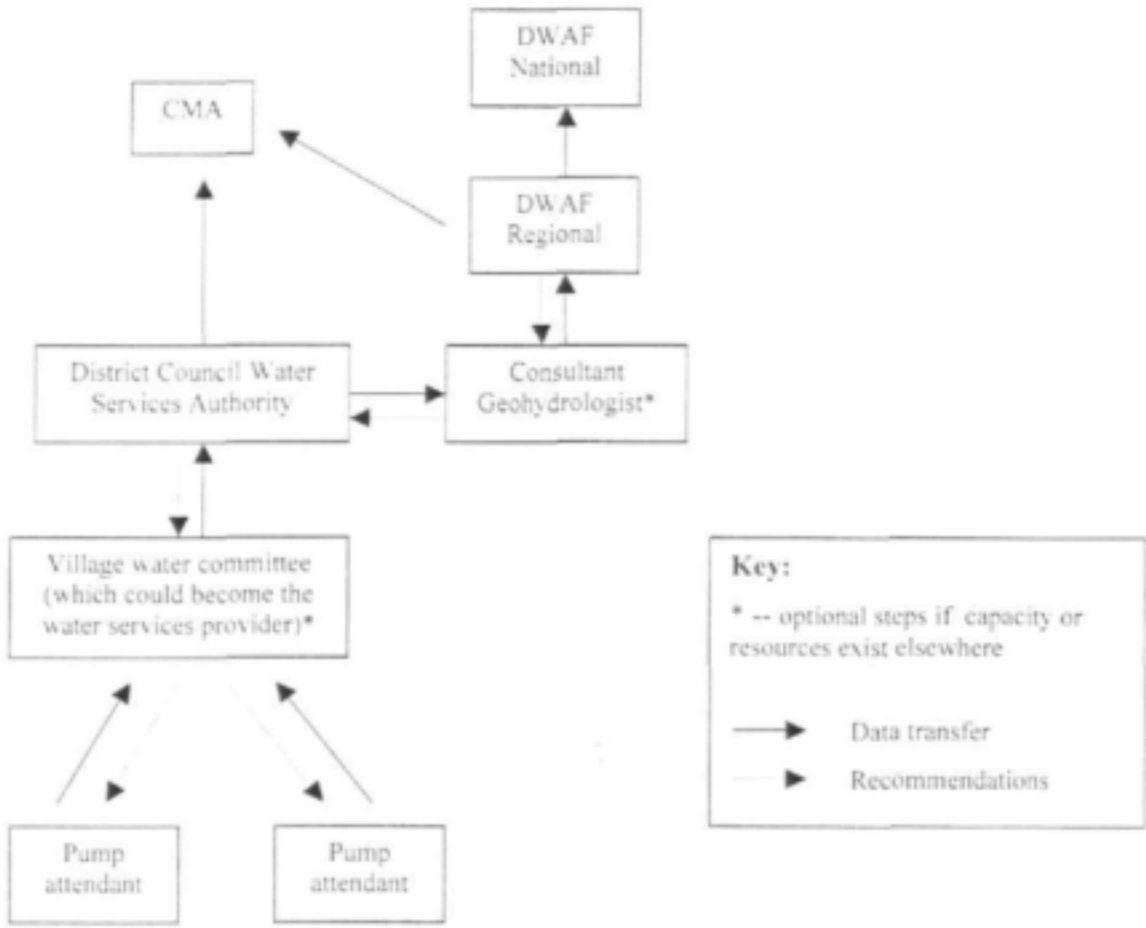

Figure 2: Proposed flow paths for the transfer of groundwater data and management recommendations (Source: Murray and Dindar, 1998)

Although a useful structure for project specific management, in the context of the objectives of this study, it simplifies issues of governance and limits representation. The important issues of water user associations, urban users, and WMA transboundary issues are not addressed. The framework relies heavily on the role of village water committees, which although key institutions in water management at the local level, are often plagued by weaknesses (Ralo, et al, 2000). While providing a valuable starting point, and indicating the necessary inputs, tools and system requirements, for groundwater management, that we would need to develop for a more complex institutional scenario the flow of recommendations needs to be more closely examined.

In a later study, Cain, Ravenscroft and Palmer (2000), develop a water management structure for rural areas. Although not specifically focussed on groundwater in its scope, the majority of rural communities in South Africa are dependent on groundwater. This model was developed out of concern for the long term management of completed water supply projects, in which greater emphasis was placed on coverage rather than the sustainability of service delivery, contributing to the failure of projects. Once completed, neither DWAF nor local government plays an active role in the continued operation and maintenance of the project. As a result, community-based structures have assumed informal responsibility for the operation and maintenance of such projects. The outcome is therefore based on an analysis of community management structures and lessons arising from these systems for more formal arrangements. The focus of this model is however at a local level and on the supply and service side of water management.

The following generic model (figure 3) was developed in Cain, Ravenscroft and Palmer (2000):

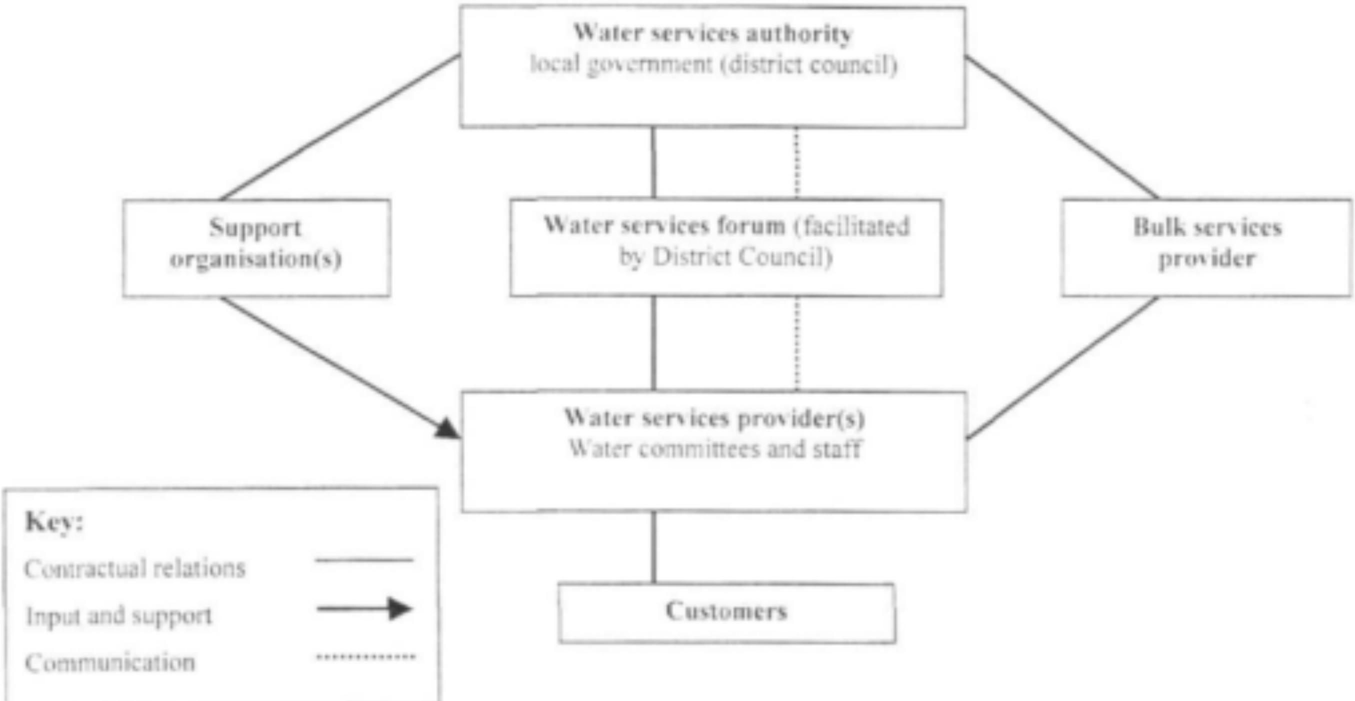

Figure 3: Generic model of institutional arrangements for the management of rural water supply (Source: Cain, Ravenscroft and Palmer, 2000)

Cain, Ravenscroft and Palmer (2000:vii) go on to outline the management, financial and technical management arrangements needed for this generic structure to function. Relevant points include:

- community-based water service providers are the most suitable option for rural water supply projects
- water is sold to village water service providers on a pre-paid basis
- formalised systems for community report-backs, including finances, need to be arranged
- the support function of the water services authority is crucial for ensuring sustainable operation and maintenance
- a sense of ownership and awareness (through participation, training and involvement of local government and tribal authorities), as well as a culture of payment, are vital to project sustainability
- technical assistance and support is vital for any upgrading, operation and maintenance and staff supervision

In a recent, more technical study Meyer, le Roux and Dindar (2001), develop a set of basic guidelines and criteria for managing rural groundwater at a local level. The following recommendations were among those made and are relevant for this project (Meyer, le Roux and Dindar, 2001:v):

- groundwater management depends on the monitoring of four basic geohydrological parameters, namely:
  - water level
  - rainfall
  - discharge
  - water quality
- groundwater management will improve as a longer time series of monitoring data develops
- adequate training, support and supervision of pump attendants is needed for operation and maintenance and to ensure no gaps occur in data
- cumulative rainfall monitoring equipment should be installed at all groundwater monitoring schemes
- information on consumption is more useful than information on abstraction for management
- flow meters should be installed at all boreholes
- a survey of each community's water needs and demands and the average expected water consumption is needed
- regular water quality monitoring is needed, particularly in rural communities using pit latrines, to monitor groundwater pollution

These and other recommendations provide a useful indication of the type of technical information and monitoring needed for rural groundwater management. These guidelines were developed in the context of the following problems affecting groundwater management in South Africa (Meyer, le Roux and Dindar, 2001):

- the lack of a regional groundwater management policy which defines the standards for regional and local groundwater management (although DWAF (2000b) addresses this matter)
- the lack of an efficient information retrieval and dissemination system
- the lack of an institutional structure that promotes effective groundwater management at local, regional and national levels
- the bias towards surface water
- the absence of strategies to involve the private sector and communities
- the lack of efficient monitoring and control systems regulating groundwater abstraction
- insufficient attention to the interactions between sanitation systems (e.g. pit latrines) and groundwater quality

- the separation of groundwater and surface water management due to their differing status under previous legislation

This overview provides a brief outline of recent research done on rural (ground)water management, as well as an understanding of the problems affecting groundwater management. While much of this research has focussed on management at the local level, it provides an important context within which the institutional arrangements can be developed for groundwater, which address transboundary issues, the interaction between surface and groundwater (integrated water resources management), as well as the priorities of an array of stakeholders.

3 LEGISLATIVE FRAMEWORK FOR GROUNDWATER

Kevin Pietersen (Water Research Commission)

3.1 Introduction

South Africa has gone through an extensive review of water legislation, since 1994. This resulted in the promulgation of the Water Services Act (DWAF, 1997) and National Water Act (DWAF, 1998). These acts provide a combination of legal obligations, rights, responsibilities and constraints for the sustainable development and management of water resources in South Africa.

The Water Services Act provides the framework for delivery of water services to the people of South Africa. The Act establishes water institutions and defines their roles and responsibilities, whilst acknowledging the authority of local government in respect of water services. The National Water Act provides the framework for the attainment of integrated water resource management (IWRM) principles. The Act recognises the unity of the water system, and the interdependency of all its elements, both in terms of quantity and quality. There is further recognition that the protection of water resources falls within a broader framework of integrated environmental management. This paper sets out to identify the challenges of implementing the National Water Act in South Africa to achieve sustainable use/management of groundwater resources.

3.2 Historical development of water policy in South Africa

The water law in South Africa prior to 1994 was based on the development needs (domestic, agricultural and industrial) of white settlers. Roman law, Roman Dutch law and later English and American law shaped South African water law (Kavin, 2000). The results of these influences were the distinction made between public and private water (riparian principle). The riparian principle entitled landholders unlimited use of private streams and groundwater resources found on their land. In 1912 the Irrigation and Conservation of Waters Act was introduced, which dealt mainly with irrigation. Priority use of water was given to agriculture. This legislation was repealed in 1956 through the introduction of Water Act. This was necessary due to the rapid growth of mining and industry. However, the Act entrenched the concept of private water and there was no obligation to share of resources equitably.

After 1994, water legislation was reviewed extensively through the publication of the following policy documents and legislation:

- Water Supply and Sanitation Policy Paper (1994)
- National Sanitation Policy (1996)
- National Water Policy for South Africa (1997)
- Water Services Act (1997)

- National Water Act (1998)
- National Forest Act (1998)
- National Veld and Forest Fire Act (1998)
- National Water Amendment Act (1999)

The Water Supply and Sanitation Policy (WSSP) was motivated by approximately 10 million people not having access to an adequate water supply and a further 22 million not having access to a basic sanitation service. The WSSP document stated government objectives to deliver water and sanitation services. The policy principles were (DWAF, 1994):

- Development should be demand driven and community based;
- Basic services are a human right;
- "Some for all" rather than "All for some";
- Equitable regional allocation of developmental resources;
- Water has an economic value;
- The user pays;
- Integrated development;
- Environmental integrity.

The rights to basic services were further enshrined in the constitution through the adoption of a Bill of Rights. The Bill of Rights secures access to potable water and an environment that is not harmful to the well being of the people of South Africa. This means access to sufficient water and food and to health services.

The National Water Policy establishes the principles for resource sustainability and security of water supplies. Water Law Principles were developed as a sound basis for management if water resources in South Africa (DWAF, 1997). The principles were translated in the following legislation, creating an enabling environment for sustainable use of water resources (DWAF, 2000):

- **Water Services Act No 108 of 1997:** This act aims to create a developmental regulatory framework within which water services can be provided. The Act establishes water institutions and defines their roles and responsibilities. Schedule 4 of the Constitution of the Republic of South Africa (Act 108 of 1996) vests the responsibility for water and sanitation services, limited to potable water supply systems and domestic waste- water and sewage disposal systems, in Local Government. However, the National Government has a constitutional responsibility to support and strengthen the capacity of municipalities to manage their own Affairs, to exercise their powers and to perform their functions, and also has the authority to see to the effective performance by municipalities of their executive authority. The WSA gives substance to these constitutional requirements and provisions, whilst acknowledging the authority of local government in respect of water services.

- **National Water Act No 36 of 1998 (NWA):** This act aims to ensure that South Africa's water resources are protected, used, developed, conserved, managed and controlled in a sustainable manner for the benefit of all persons. The Act establishes the National Government, acting through the Minister of Water Affairs and Forestry, as the public trustee of the nation's water resources, with power to regulate the use, flow and control of all water in the Republic.

The introduction of the National Water Act and Water Services Act has important implications for groundwater, providing a framework for sustainable use of the resource. However, while groundwater is now considered to be an integral part of the hydrological system, it is the part most prone to poor management, due to a lack of understanding of the occurrence, attributes and dynamics of groundwater.

3.3 National Water Act

The lack of accountability to the government for proper groundwater resource management and use commonly resulted in over-exploitation of groundwater resources (Lazarus, 1998). Examples are the Sand River valley north of Pietersburg, the dolomitic compartments at Tosca, weathered granite-gneiss at Coetzerdam, the Dendron-Vivo area, and in the northern and southern Springbok Flats (Dziembowski, 2000). The Water Act 54 of 1956 made the following distinction between different categories of groundwater (Lazarus, 1998; Kavin, 2000):

- **Subterranean water**. Subterranean water includes, 'water naturally occurring underground or obtained from underground in an area declared.... as a subterranean Government water control area. Subterranean water is not defined as either public or private water in the Act. It is a category of water, distinct from underground water and subject to different allocation rules. In terms of the Act 54 of 1956, as soon as a subterranean government water control area is declared, the right to the use and control of subterranean water, vests in the Minister. The provisions of section 30(1) of the Act limit the application of this section. This section implies a distinction between water that was allocated and used immediately prior to the declaration of a subterranean government water control area and water that was allocated and used immediately prior to the declaration of the control area vests in the land owners to which the right was allocated. The right to the use and control of subterranean water only vests in the Minister if the water was unallocated or unused immediately prior to the declaration of the area as a subterranean government water control area. The provision for the recognition of existing rights specifically made proper groundwater management virtually impossible.
- **'Public' Surplus water**. A second category of groundwater that is regulated by statute is that water which falls within the statutory definition of public water. Surface water (streams) qualified as public water and was further categorized as either normal flow or surplus water.

Since underground water cannot qualify as normal flow since this must visibly flow, it qualifies as surplus water which is any public water other than normal flow.

- **'Deemed' Private water**. The final category of groundwater that is regulated by statute is water that is pumped from underground such as the water from boreholes. Provided this water is not derived from a public stream, the Act deems this water to be private water. It is this categorization of groundwater as 'deemed private water' that has in the past created the greatest obstacles to water managers concerned with managing all water resources in the national interest. The sole and exclusive use and enjoyment of private water vests in the owner of the land on which it is found.

The lack of explicit recognition in the Water Act of 1956 was an inexplicable anomaly, because most hydrologists in the world recognises the continuity of the hydrologic cycle. The National Water Act of 1998 rectified this anomaly by recognising groundwater as public water. This is reflected in the Water Law Principles (DWAF, 1997):

- **Principle 2**: All water, wherever it occurs in the water cycle, is a common resource to all, the use of which shall be subject to national control. All water shall have a consistent status in law, irrespective of where it occurs.
- **Principle 4**: The location of water resource in relation to land shall not in itself confer preferential rights to usage. The riparian principle shall not apply.
- **Principle 5**: In a relatively arid country such as South Africa, it is necessary to recognise the unity of the water cycle and the interdependence of its elements, where evaporation, clouds and rainfall are linked to groundwater, rivers, lakes, wetlands and the sea, and where the basic hydrological unit is the catchment.
- **Principle 6**: The variable, uneven and unpredictable distribution of water in the water cycle should be acknowledged.

Because groundwater has the same status as surface water, the sustainable use of groundwater will be achieved through the same three policy goals, which have been formulated for surface water resources (DWAF, 2000). These as stated for groundwater resources are:

- To implement source-directed controls to prevent and minimise, at source, the impact of development on groundwater by imposing regulatory controls and by providing incentives;
- To implement resource directed measures (RDM) in order to manage such impacts as do inevitably occur in such a manner to protect the reserve and ensure sustainability for beneficial purposes recognized by the Act;
- To remedy groundwater quality where practicable to protect the reserve and ensure at least fitness for the purpose served by the remediation

Source directed controls are the "traditional" measures used to protect water resources, and aim to minimise the over-exploitation and degradation of groundwater (DWAF, 2000). They consist of:

- Establishing an understanding of the vulnerability to pollution of the country's groundwater resources;
- Establishing an understanding of the relationship between polluting activities (sources) and quality effects in the groundwater;
- The regulation and prohibition of land-based activities which may affect the quantity and quality of water, i.e. the location and nature of development in relation to impact on groundwater quality;
- Control of practices and use of measures to lessen the polluting effects of activities which threaten groundwater quality; and
- Controlling the aggregate impact of certain prescribed activities.

RDM, a series of measures to be progressively developed to protect water resources, are provided for in the National Water Act (DWAF, 1998). The RDM consists of three core concepts (DWAF, 1999):

(a) **Classification.** Under a national protection-based classification system, water resources can be grouped into classes representing different levels of protection. The risk, which can be accepted in each class, is related to the level of protection required for that class. This provides a nationally consistent basis and context for deciding on an acceptable level of short-term risk, against the requirements for long-term protection of a water resource. For water resources, which are especially important, sensitive, or of high value, little or no risk would be acceptable, and they would be assigned a high protection class. In other cases, the need for short to medium term utilisation of a water resource may be more pressing: the resource would still be protected, but would be assigned a class which reflected a higher risk

(b) **The Reserve.** This is defined by the act as "the quantity and quality of water required:

- To satisfy basic human needs by securing a basic water supply for people who are or who will in the reasonably near future be relying upon, taking water from, or being supplied from the relevant water resource; and
- To protect aquatic ecosystems in order to secure ecologically sustainable development and use of water resources."

(c) **Resource Quality Objectives (RQOs).** The RQOs for a water resource are a numerical or descriptive statement of the conditions, which should be met in the receiving water resource, in terms of resource quality, in order to ensure that the water resource is protected. RQOs are scientifically derived criteria, based on the best available scientific knowledge and understanding. They represent our best assessment of the resource quality, which is necessary to provide a desired level of protection to a water resource, with a particular degree of assurance or risk.

The methodologies to implement these measures for the protection of groundwater resources are in the developmental phase. Present thinking on the use of the different instruments provided in the Act is summarised in Table 1 (Braune, 2000).

To implement the requirements of the legislation will require the resolution of the following issues, without which there will be limited integration of groundwater in the broader water resource management framework (after Xu *et al*, 2000):

- Integrated classification to link delineated hydrogeological systems with eco-region classification systems;
- Approaches to establish reference conditions (conditions prior to impact)
- Approaches to identify and map groundwater dependent ecosystems;
- Understanding groundwater / surface water linkages
- Appropriate RQOs and adequate monitoring systems, addressing ecosystem and groundwater resource integrity.

Measures	Objectives and strategies
a. Basic human needs Reserve b. Ecological Reserve	- Ensuring sustainability of community water supplies where groundwater is an important or sole source (prevent over-pumping, pollution, intrusion of poor quality water etc) - Protecting groundwater dependent aquatic ecosystems (springs, baseflow in rivers, wetlands etc.)
Classification	- Protecting groundwater dependent terrestrial ecosystems (vegetation, geological features, etc.) - Protecting aquifer integrity (aquifer matrix, e.g. sinkholes, subsidence, aquifer-clogging etc.) - Providing of classification framework for systematic setting of the Reserve.
Resource Quality Objectives	- To specify the desired local groundwater management regime for all the above protection instruments (in terms of groundwater levels, water level fluctuations, minimum groundwater discharge constraints, water quality objectives, etc.)

Table 1: RDM for groundwater resource protection (Source: Braune, 2000)

3.4 Challenges to sustainable development of groundwater resources

The challenges in delivering groundwater-based services to communities lie in overcoming many constraints and uncertainties. These range from limited conceptualisation of groundwater conditions in fractured rock aquifers to institutional arrangements necessary for IWRM.

3.4.1 Implementation paradigm

Lack of basic services, such as water supply and sanitation, is the norm in the rural areas of South Africa. A concerted effort is being made through the Water Services Programme within DWAF to deliver the services. However, emphasis has been placed on construction for increased coverage rather than sustainability. This risk associated with the emphasis was recognised in 1997 (Pietersen and Dent, 1997) and has in fact, contributed to numerous scheme failures (Mvula Trust, 1998).

The lack of sustainability leading to failure has been as a result of implementing agencies operating in an environment in which they design technical solutions and then take no further responsibility to make the solutions work. This has happened despite the fact that the Reconstruction and Development Programme (RDP) and the Water Supply and Sanitation (WSS) Programme emphasise the need for community involvement at all stages of the process (DWAF, 1994). There has been only limited integration between technical and social issues. In an external evaluation of Mvula Trust the following success criteria were identified (Mvula Trust, 1996):

- Smaller projects comprising one community and developed from scratch are easier to manage and have more potential for success than larger projects comprising more than one community and which may be linked to existing (often failed) systems.
- Traditional Authority support for a project is crucial. Opposition can sink a project before it even gets a chance to start or prove itself.
- For most successful projects there have been no power plays between different community structures. Added to this, there has been an open and honest relationship between structures and with the community. Community decision taking (rather than committee decision taking) is viewed as extremely important.
- There needs to be absolute honesty and transparency by the Water Committee in dealing with all project related issues, most notably finances. Water Committee members need to demonstrate accountability to their membership.
- The community should be consulted on all aspects related to the project, even if this is time consuming. Everybody should be aware of what the project can offer and within which parameters. This is to avoid community tension and conflict arises normally when technical failure occurs.
- It is unrealistic to expect a 100% contribution by the community to the capital and O&M costs of the project. The Water Committee, community and the Mvula Trust should address this up front in order that all stakeholders are aware at the outset of the situation and develop contingency plans.
- Although the success criteria focus on social and institutional issues, they are nevertheless important pointers towards sustainability. Successful implementation requires community involvement and responsibility, which cannot be obtained through higher level planning approaches, but rather an approach that supports communities' innovation.

In meeting the objectives of sustainable rural livelihoods and completing the tasks required, the following key issues should be addressed:

- Security of water supply and improved sanitation facilities for the communities throughout the area.
- Community involvement and ownership of the improved facilities and processes agreed upon.
- Capacity building of local and regional governmental structures in implementing sustainable natural resources development programmes.

3.4.2 Water scarcity

Water resources in the Southern African region are uneven in space and time. This poses significant water management problems. The water scarcity to be coped with in Southern Africa is complex and related to essentially four types of environmental vulnerability (Falkenmark, 1994):

- Lack of green water (root zone water) to sustain plant growth
- Lack of blue water (feeding aquifers and rivers) to sustain human activities
- Recurrent droughts as part of the hydroclimate
- Vulnerable soils that easily get impermeable through crust formation, causing desiccation of the landscape ("desertification")

South Africa is not a country blessed with ample water, with approximately two-thirds of the country being classified as semi-arid to arid. Arid and semi-arid conditions are defined as the following – arid lands have less than 250 mm of annual rainfall, and semi-arid lands have a mean annual precipitation of between 250 mm and 500 mm (Strahler, 1969). Average annual rainfall for South Africa is 500 mm/annum. This figure compares poorly with the world average of 860 mm / annum.

Owing to population growth and social and economic development water is becoming ever scarcer (decrease in the volume of water available per capita over time), threatening the meeting of water demand for beneficial uses. This poses a significant risk for water security and Southern Africa is likely to experience chronic to absolute water scarcity from 2020 onwards (Table 2).

The annual average per capita water availability for South Africa in 1995 was 1200 m^3 / person / year (Muller, 2000). With projected population increase, this situation will become even more tenuous at 730 m^3 / person / year in 2025. This can be offset by decrease in population growth and economic growth to cope with resource constraints. However, limited water availability will influence economic growth.

Benchmark: m^3/person/year	Indicator
>1700	Will suffer only occasional or local water problems
1000 – 1700	Periodic or regular water stress
500 – 1000	Chronic water scarcity: lack of water begins to hamper economic development, and human health and welfare
<500	Absolute scarcity

Table 2: Water availability in terms of total annual renewable surface water per person of total population (Population Action International, 1993)

3.4.3 Resource sustainability

While groundwater may be comparatively easy and economical to develop, achieving sustainable and optimised aquifer management is complex. Poor assessment of groundwater resources, inadequate analyses of the consequences of groundwater exploitation, or lack of technical understanding and inadequate institutional frameworks, may lead to management decisions that could cause irreversible loss of groundwater or even the aquifer storage capacity (ASCE and IHP IV, 1997). Key challenges that will have to be addressed to achieve sustainable and optimised aquifer management are (after Foster *et al*, 2000):

- Development and application of groundwater resource decision support systems.
- Assignment and consolidation of groundwater use rights and introduction of realistic abstraction charges.
- Stimulation of stakeholder participation through the formation of aquifer associations.
- Breaking down the common resource management paradigm that groundwater recharge is a fixed parameter, and instead recognising that it varies markedly in a temporal sense with long-term climatic cycles and changes; with surface water engineering works; and with changes in irrigated agriculture and urban water-service systems.
- Recognition of the interaction and interdependence between groundwater and surface water resources, which often greatly favour their conjunctive use.

3.4.4 Environmental issues

Implementation of IWRM principles also requires protection of the environment. The philosophy being that the protection of the ecosystem structure and function will maintain resilience and sustain the resource (MacKay *et al*, 2000). Groundwater plays a number of key roles in the hydrological system (Parsons, 1998):

- Groundwater systems contribute to rivers and wetlands as an important component of baseflow.
- Groundwater bodies supply water to vegetation in the near surface zone.
- Groundwater bodies store water which can be abstracted (either naturally or artificially) long after recharge has taken place.

Sustainable management of groundwater resources therefore requires an understanding of both how vegetation influences recharge and of how groundwater discharges influence ecosystems (Le Maitre *et al*, 2000). The nature of the dependency is poorly understood and there is a great deal of uncertainty how far the actions of mankind influenced the environment (Table 3).

The interaction between groundwater and vegetation	
Impacts of vegetation on recharge	- Rainfall is intercepted and redirected by the plant canopy and branches (losses vary from 5% to 20%). - Organic matter from plants may prevent infiltration (through litter) or improve soil structure and promoting infiltration. - Root systems may provide pathways for preferential flow or tap the capillary fringe to extract groundwater for the plants to transpire.
Impacts of groundwater discharge on ecosystems	- Wetlands - Cave ecosystems - River floodplains - Endorhoeic systems - Estuaries and vegetation dependent on spring discharge - Riparian vegetation - Terrestrial

Table 3: The interaction between groundwater and vegetation (after le Maitre et al, 2000; Hatton et al, 1998)

3.4.5 Inadequate monitoring and evaluation systems

Development of appropriate monitoring and evaluation (M&E) systems is crucial to resource sustainability. It forms the basis for decision support. The development of M&E systems provides a means to assess progress in meeting groundwater sustainability (including water security) objectives.

Previous monitoring systems provided a narrow focus on the resource. However, the development of M&E systems should be more holistic to include issues such as biological integrity. Appropriate M&E systems provide continuous feedback to enable assessment and ensure that problems are identified at source so that appropriate action can be taken. Such problems include issues such as (Robins *et al.* 2000):

- Can the resource meet objective needs - now and in the future (quantity and quality)?
- Has an operation and maintenance plan been developed and agreed upon detailing roles, responsibilities and training requirements?
- Have cost recovery mechanisms been established?
- Have the necessary institutional arrangements been established?
- What is the impact of the project on the environment?
- What are the current water usage practices?
- Has the community been educated about the groundwater system (yield & quality aspects)?
- To what extent are the institutions functioning (including addressing issues of representativity of the various sectors in the community)
- Is cost recovery taking place? What are the factors influencing cost recovery?
- What is the progress on establishing the hardware requirements?
- Is training progressing as planned?

3.4.6 Multi-objective analysis

IWRM requires multi-objective decision-making. The challenge of water resource planning and management is to make decisions that result in optimal use of the resource, while protecting the environment and similarly contributing to economic development. Non-trivial decision-making of this kind involves multiple goals with some measure of trade-off between conflicting goals or objectives (Stewart *et al*, 2000). The decision-making process needs to be robust (the system can adapt to unexpected future changes in demands or purposes without substantial costs) and resilient (the system has an ability to recover and function properly after some unforeseen failure event). Implementation of the National Water Act, is essentially a multi-objective decision-making problem, because in issuing a general authorisation or licence (section 7) a responsible authority must take into account all relevant factors, including (DWAF, 1998):

- Existing lawful water uses;
- The need to redress the results of past racial and gender discrimination;
- Efficient and beneficial use of water in the public interest;
- The socio-economic impact-
  - (a) of the water use or uses if authorised; or
  - (b) of the failure to authorise the water uses or uses;
- Any catchment management strategy applicable to the relevant water resource;
- The likely effect of the water use to be authorised on the water resource and on other water users;
- The class and the resource quality objectives of the water resource;
- Investments already made and to be made by the water user in respect of the water use in question;
- The strategic importance of the water use to be authorised;
- The quality of water in water resource which may be required for the Reserve and for meeting international obligations; and
- The probable duration of any undertaking for which a water use is to be authorised.

3.5 *Progress in implementing the National Water Act from the groundwater perspective*

Prior to 1998, the use of groundwater was beyond the regulatory jurisdiction of the state. The National Water Act corrected this situation and considers groundwater as an integral part of the hydrologic cycle. The National Water Act provides the legal framework for groundwater management in South Africa, which will be put into practice through specific regulations. The Act introduces the following measures:

- Formal recognition of the unity of the hydrologic cycle;
- Provision for resource protection and sustainability;
- Confirmation of water as a national resource under national management;
- Special status to meet rights of and obligations to neighbouring states;
- Decentralisation of water management within a national framework;
- Limitation of rights into perpetuity;
- Water allocation specifically to achieve socially and economically optimal water use;
- A formal requirement for water conservation and demand management;
- Economic pricing of water.

The framework, within which groundwater resources will be allocated is summarised in Figure 4. The **first step** is the establishment of a vision for the resource. At national level this is done through the National Water Resources Strategy. This also needs to be done in consultation with the relevant stakeholders in each water management area (WMA). South Africa has been subdivided into 19 WMAs (Figure 5).

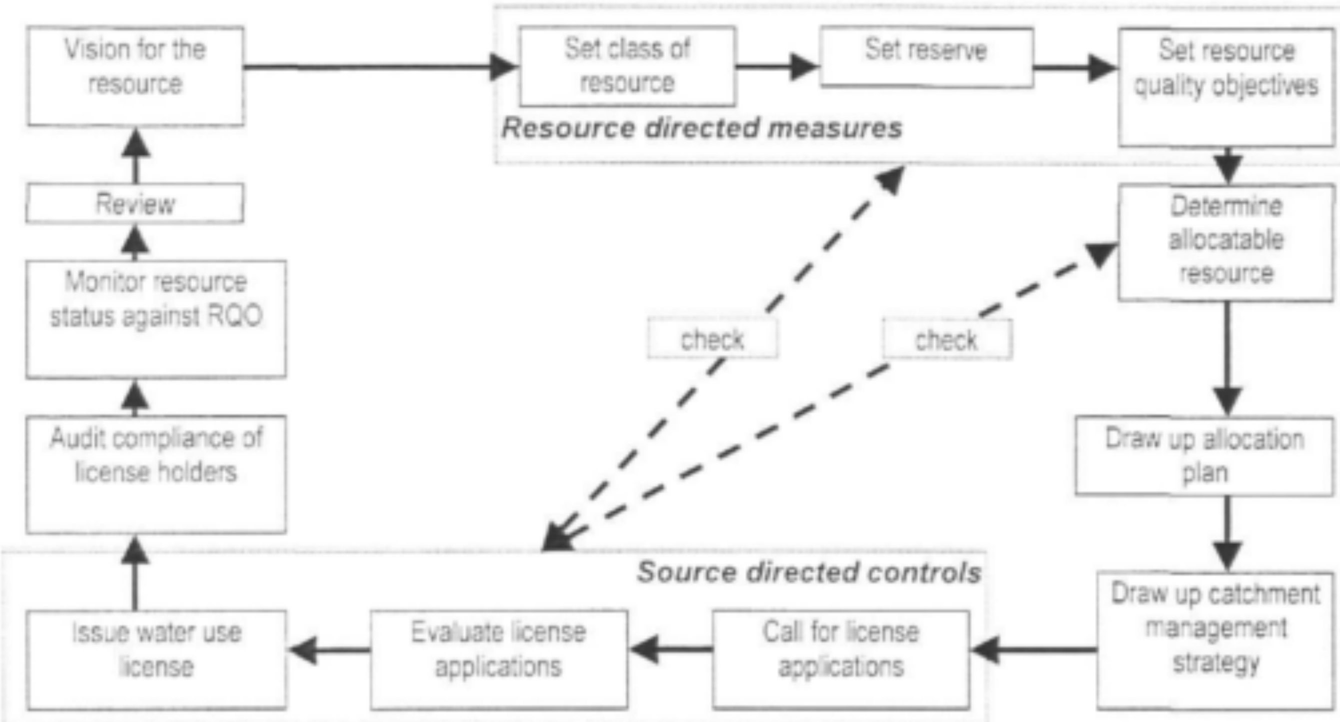

Figure 4: Legislative framework for groundwater management in South Africa.

Figure 5: Water Management Areas in South Africa

The **second step** is to implement RDM to protect the capability of groundwater resources to support utilisation in the long term (section 5). The generic procedure for RDM determination is the following:

- Delineate resource units
- Determine ecoregional or georegional type
- Determine reference conditions
- Determine present status
- Decide on future water management class
- Derive water quantity and quality and resource quality objectives
- Design monitoring programme to gather information for future comprehensive reserve determination

The first part of the RDM is to classify the resource. Classification needs to be done to establish the desired level of protection of groundwater dependent ecosystems and maintenance of aquifer integrity. The classification also provides the framework for the systematic setting of the reserve, the determination of which is the second part of the RDM process. The definition of the reserve is given in section 5. The reserve is to prevent resource degradation and to ensure sustainability of groundwater based community water supplies, where groundwater is an important or sole source of supply. The reserve is also used as a means of protecting aquatic ecosystems (springs, base flow in rivers and wetlands). The third part is to set RQOs to specify the groundwater management regime. Resource quality means the quality of all aspects of the resource, including (MacKay, 2000):

- The quantity, pattern, timing, water level and assurance of instream flow
- The water quality, including the physical, chemical and biological characteristics of the water
- The character and condition of instream and riparian habitat
- The characteristics, condition and distribution of the aquatic biota

The challenges that the legislation poses through the use of RDM as a tool for groundwater protection are manifold and include (after Xu *et al.* 2000):

- The translation of the principles of sustainable development and IWRM to reality in order to ensure sustainable groundwater management
- The ecological functioning of groundwater, currently considered only in terms of its impact on surface water resources (based on the current definition of the reserve), needs to be viewed from a broader perspective.
- Groundwater plays an important role in supporting terrestrial ecosystems, especially in a semi-arid country such as South Africa, as well as the ecosystems which are thought to exist within the aquifers themselves. All ecosystems that are dependent on allocatable water, including groundwater-dependent ecosystems, have the right to a reserve.

- How the will the reserve for groundwater be specified?
- Groundwater systems and their linkage to surface water and related ecosystems are still poorly understood.
- The reserve is spatially referenced. What about temporal variability?
- What is the volume of accessible water that satisfies basic human needs.
- Verification of methodologies (so that they are legally defensible)
- How to develop 'acceptable' methodologies within a framework of limited financial and human resources

The **third step** is to determine the allocatable portion of the resource, once the RDM measures have been determined. The allocation plan must address issues such as facilitating social and economic development. The right to use of water is established in the National Water Act on condition that one or more of the following stipulations apply:

- It is permissible under Schedule 1 (minimal or no impact)
- It is permissible as a continuation of an existing lawful use
- It is permissible in terms of a general authorisation (low risk of unacceptable impact)
- Authorisation by a licence (high risk of unacceptable impact if not controlled)

General authorisations for groundwater (Table 4) have been given for South Africa based on the groundwater harvest potential map. The groundwater harvest potential map attempts to determine available groundwater resources. In arid zones only schedule 1 uses are permitted, while subterranean water control areas are excluded from general authorisations for groundwater abstraction. The efficient and sustainable use of water resources is encouraged through the adoption of water conservation and demand management practices.

Zone 1	General Authorization (m^3/ha/annum)
1 (arid regions)	Only Schedule 1 use
2	≤ 60
3	≤ 300
4	≤ 750

Table 4: General groundwater use authorisations in South Africa (Source: Braune, 2000)

The **fourth step** is to implement source directed controls to prevent or minimise impact on groundwater resources. This is done through regulatory controls and incentives. DWAF proposes to effect its policy goals through, among other things:

- Establishing an understanding of the importance and vulnerability to pollution of the country's groundwater resources, and
- Establishing an understanding of the relationship between polluting activities (sources) and quality effects in the groundwater, i.e. understanding the origin of pollutants, the pathways which these pollutants could follow into the environment and the ultimate fate of these pollutants.

The **final step** is the monitoring and evaluation system to determine whether the policy goals are being implemented and having the desired outcomes.

3.6 Concluding remarks

The focus of groundwater management in South Africa, for the foreseeable future, will be on:

- meeting basic human water needs,
- maintaining resource integrity, and
- equitable allocation for economic development

The challenge remains to implement these principles in reality. Management strategies will need to be developed to address the unique characteristics and roles of groundwater. This needs to take place within the context of socio-economic development paradigm.

Proper allocation of groundwater resources will require integrated planning, namely:

- Development of scientific measures to assess fractured rock aquifers.
- Development of verifiable objectives for groundwater management (equity principles).
- Identification of groundwater management problems, constraints and uncertainties.
- Development and analysis of alternative strategies (including measures) and uncertainties - multi-objective analysis.
- Selection of the best compromise solution (robust solution).

Before allocation can take place, the reserve has to be determined. This means understanding groundwater contribution to surface water bodies, and identifying groundwater dependent ecosystems. This represents a challenge to balance environmental and human needs. Further, complicating factors are the already degraded aquifers. This includes understanding reference conditions. Sustainable use of groundwater resources will require a multi-objective decision-making framework.

4 PROFILE OF THE STUDY AREA

The following section provides a brief overview of the developmental and socio-economic context of the study area, in order to highlight the range of local characteristics and conditions within which groundwater management must take place.

4.1 Locality

The study is situated within the North West Province of South Africa (see Map A.1). The main towns included in the study include those either currently using or possibly needing to use dolomitic groundwater in the near future to augment their water supplies. These towns have developed around and grown to support the agricultural activities in the region, which underpin the local economy.

Larger urban settlements include:

- Zeerust and Lehurutse
- Mafikeng and Mmabatho
- Lichtenburg and Itsoseng
- Ventersdorp

Smaller towns on the periphery of the study area include:

- Slurry
- Koster, Swartruggens and Coligny lie on the periphery of the study area but are not planning to utilise dolomitic groundwater directly in augmenting their water supplies.

The area around the urban settlements is largely rural, and characterised by cultivated or grazing land (commercial agriculture), undeveloped land and smaller, scattered rural settlements and villages, many once part of the former Bophuthatswana.

4.2 Land use

The nature of land use is highly dependent on the availability of local water resources. Understanding the interaction between land use and water resources is an important component in developing sustainable management systems.

Land use in the study area is illustrated in Map A3.

Agricultural land uses consist of:

- irrigation farming
- dry land cropping
- livestock farming

Although the area does not have a major industrial base, there are several operations in the area, utilising local resources, which contribute towards employment:

- cement factories and lime quarries
- small scale alluvial diamond mining operations, primarily in the broader Lichtenburg/Mafikeng area[6]
- other small mining operations (chrome, fluorite, slate, etc.)

In addition to urban and rural settlements, there are several game reserves in the area, as well as government facilities (e.g. prisons).

Main roads connect the urban settlements in the study area, with a series of limited railway lines running between some of the towns (see Map A4). In general, infrastructure in the former Bophuthatswana areas is poorly developed compared to that in the former Transvaal (DWAF, 2000a).

4.3 Demographic information

4.3.1 Population densities

Municipal level population statistics are included in table 5:

Municipality	Total population	Female	Male
Lichtenburg (NW384)	130,362	67,643	62,719
Mafikeng/Mmabatho (NW383[7])	242,162	127,941	114,221
Ventersdorp (NW401)	31,917	16,237	15,680
Zeerust (NW385)	129,289	69,808	59,481
TOTAL	**534,485**		

Table 5: Municipal population figures (Source: Municipal Demarcation Board, 2001)

In general, population densities for the area are low, with around 6 people for km^2 for most part of the study area. Densities are slightly higher in the south, around Lichtenburg, Coligny and Ventersdorp (6-15 people/ km^2), and notably higher in the former Bophuthatswana districts around Mafikeng (63-96 people/ km^2) and in areas north of Zeerust (DWAF, 2000a). In these areas of high density (the former Bophuthatswana), service levels are low: many are barely at, or below, RDP levels (DWAF, 2000a:23).

[6] The Lichtenburg area was the sight of the world's largest diamond rush during the early 1900s. The landscape bears witness to this history of activity and digging (e.g. Malan's Pothole) and small operators still sieve the soils, looking for diamonds.

[7] Mafikeng Local Municipality includes both Mafikeng and Mmabatho.

4.3.2 Socio-economic characteristics[8]

In all municipalities, population age distribution is concentrated in the 5-19 year group, indicating a rapidly growing, young and dependent population with a low percentage of the population currently economically active. Figures for the over 65 age group were not significant within the overall age distribution.

Percentages of the population employed ranged between 12% in Zeerust and 23% in Ventersdorp, with Lichtenburg and Mafikeng 22% and 19% respectively. This indicates a high rate of unemployment across the four municipalities (students, pensioners and disabled people are included in this category).

High unemployment figures are consistent with conditions in rural areas in South Africa, where this has resulted in a high dependency on pensions, social grants, and remittances from migrant workers. In addition, unemployment and poverty are greatest barriers affecting the affordability of water, compounding living conditions in rural areas (Ralo, et al, 2000).

Of those employed, the majority are in elemental/unskilled occupations. The most employment opportunities are in the farming sector (ranging between 49% in Ventersdorp to 5% in Mafikeng), with social services employing the next significant number (36% in Mafikeng and 28% in Zeerust). They key role of agriculture in the local economy, providing employment and livelihoods is emphasised in these figures. Any decline in agricultural productivity will therefore have significant implications for employment opportunities and regional economic growth. In terms of annual household income, most people within the study area earn less than R1500 per month, particularly in the Ventersdorp area where 63% of people earn within this level.

Associated with employment opportunities are migration patterns in the area. In some communities, households receive remittances from relatives working in Gauteng. Within the study area, migration patterns reflect a movement from rural and farming areas towards the urban centres.

The Grasfontein community (NW 384, ward 14), near Lichtenburg, live in conditions of acute unemployment. In a community of some 350 households, 11 people are employed (ten in the nearby diamond mines, and one on a farm)[9]. Households within this community are highly dependent on elderly or disabled persons for their government pensions, or on contributions from relatives working in Gauteng, to cover all basic household necessities, including water, wood, food, clothes, education for children and transport, including daily transport of children to school[10]. There is thus a significant burden on the elderly, in terms of their role as breadwinners, at both the household and community level.

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[8] Data collected during the 1996 census and modified following the 2000 municipal demarcations provides useful information about employment, income, education and service levels in the study area.

[9] Celishane, R. 2001. personal communication, Grasfontein, 19 June.

[10] Steyn, C. 2001. personal communication, Grasfontein, 18 June.

Education levels are low throughout the study area, with percentages of people in the "no education" category ranging from 20% to 28% in Zeerust. Of those with education, the majority have a primary education (30-37%).

Poor standards of infrastructure and services (particularly water and sanitation) further reinforce the low levels of development, opportunity and health for the majority of the population living within the study area. Distance to water sources is of utmost importance in curtailing 'water-washed' transmission of disease (Ralo, et al, 2000).

According to census figures, most people have a water supply within their dwellings. However, at closer analysis, this figure holds a strong urban bias due to the higher densities and higher levels of services within urban areas. Water from public taps supply water to 60% of the population in Zeerust and 35% in Mafikeng. Water from boreholes is another source, supplying 25% of the population in the Mafikeng area. These figures would be more indicative of conditions and service levels in rural areas.

The Grasfontein community is an extreme example of a group living without access to basic water supplies and the effect of this on the community, their development opportunities and livelihoods. The community receives their water from a nearby borehole, however the borehole is too far for many people to be able collect their water. The pump on the borehole is privately owned and maintained, and the community pays for diesel to operate the pump. Those who are unable to collect their water have it delivered via donkey cart, paying R4 per 200*l* barrel for this service. Some households pay up to R28 a week for water, which then stands outside their houses in the barrels. This effectively amounts to R112/mnth for 5,6k*l* – compared to municipal water where each household's first 6kl of clean, treated domestic water are provided free. Based on the municipal tariff structure, for a monthly water bill of R112, households would receive almost 109k*l* of water from Ditsobotla Municipality per month – a staggering disparity indicating the impacts of a lack of access to water on the livelihoods of the poor.

The lack of access to water prevents the community from pursuing subsistence or income-generating activities like vegetable growing and internal politics has hindered any resolution of this problem. In contrast to Grasfontein, in villages such as Bodibe and Dinokana, the community has access to water from a local spring, which stimulates activity and creates a sense of opportunity, through the activities generated by the access to a water resource. Although water is supplied through handpumps, the proximity to the water source has enabled vegetable gardening, brick making and other enterprises to start up, providing food security and a source of income.

Light throughout most of the study area is from candles, with figures being the highest in the Ventersdorp area. Municipal electricity is the second largest source of electricity/light, followed by paraffin.

Throughout the study area, pit latrines (particularly in Zeerust and Mafikeng) are predominantly used for sanitation, followed by water borne sewage. The use of poorly constructed pit latrines in an area which receives most of its water from boreholes, is a problem in terms of pollution to groundwater, and health. The proximity of pit latrines to boreholes, the sensitivity of the aquifer in the area, as well as capacity to undertake regular monitoring are important factors which need to be addressed. These issues have been raised at a number of levels, and are or particular concern to some councillors in the study area[11]. While providing water borne sewage systems might not always be a feasible solution, the improved design and construction of pit latrines needs to be addressed.

Demographic data for the study area, especially at a ward level of analysis, represents a situation of strong imbalances and disparities between living conditions in rural and urban areas. Conditions in rural areas need urgent attention, in terms of basic service provision and livelihoods opportunities.

A lack of water presents a barrier to even basic local economic development or subsistence projects (e.g. food gardening and brick making). The impact of rural water schemes on local economic development needs to be realised in a broad sense. Very often, rural water projects represent the most significant development input in rural settlements, while in terms of gender, women are often the key beneficiaries (Ralo, et al. 2000).

4.4 Economic growth

The North West province shows the second lowest growth in GGP for all nine provinces in South Africa, as well as the lowest contribution to the GNP, despite the strong presence of primary economic sectors (mining and agriculture) in the province[12].

Key economic characteristics of the study area, identified in DWAF (2000a), are:

- In general, there are significant disparities in growth and economic activity (reflected in Gross Geographic Product – GGP[13]) between former Bophuthatswana and Transvaal districts. There is generally a lower GGP contribution in the Bophuthatswana districts but a higher growth, indicating a reliance on subsistence activities and the dormitory economies in the Bophuthatswana districts. This is evident in the following GGP figures:
    - throughout the region, GGP contribution is between 0-7%
    - GGP growth is highest in the former Bophuthatswana areas north of Zeerust (around Dinokana, 3-7%) while around Mafikeng and to the west GGP growth is between 7-12%. In contrast, in the area south of Zeerust, and around Ventersdorp, GGP growth is between –2 and 3%, while to the north of Lichtenburg, and around Coligny, Koster and Swartruggens, GGP growth is between –7 and –2%, indicating a rapid decline in economic growth.

These GGP figures highlight the key role that agriculture has played in the region, in terms of supporting the local economy, and providing employment and livelihoods in agricultural activities

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[11] Ditsobotla ward Councillors. 2001. Meeting. Lichtenburg, 21 June.

[12] Source: 1995 State of the Environment Report for the North West province.

[13] GGP represents the returns received from the production factors (land, labour, capital and entrepreneurship) for their production in a specific area.

and related services in the towns and rural areas. Of particular concern from these negative growth figures, is that this sector, which underpins the local economy and provides the majority of employment opportunities, is declining.

- In rural areas:
  - poor diversification outside the agricultural sector
  - low levels of formal employment in agriculture in former Bophuthatswana districts, compared to around 25% employment in agriculture in the former Transvaal
  - in rural areas, the non-economically active population is consistently above 60%, indicating a large young and unemployed population
  - there is a migration trend from commercial farming areas to townships
  - high levels of unemployment in rural areas tempered by a reliance on subsistence activities, although unemployment is estimated to be about 30-40%
- In urban areas:
  - high employment in social and community services in Bophuthatswana districts
  - general lack of activity in manufacturing, except in Lichtenburg where it contributes 4% of employment
  - unemployment in townships (partly due to influx from rural areas) is estimated to be over 60% (e.g. Boikhutso and Tlhabologang, near Coligny)
  - poor economic diversification hinders attempts to reverse high unemployment figures

4.5 Land reform

Most districts in the North West province have some kind of land reform projects within their boundaries – mainly production and some form of settlement, or a combination of the two[14]. In many cases, land reform communities are the very poorest, living without access to basic water and sanitation, and without employment and development opportunities. These conditions are illustrated in the case of Grasfontein, near Lichtenburg, which was a pilot settlement and production project during the early land reform process[15]. The District Councils are largely responsible for service delivery in these communities, after hand over from the Department of Land Affairs.

One of the problems affecting land reform projects is its lack of integration with local planning processes. Land reform is a national government responsibility, while local planning falls under local government. As a result, the integration of land reform and development opportunities is insufficiently addressed in local planning processes. This raises significant problems for communities,

[14] Lekalake, B. 2001. personal communication, email, 20 July.
[15] Lekalake, B. 2001. personal communication, email, 20 July.

particularly with respect to the provision of water supplies and sanitation services, which are basic requirements in providing livelihoods and development opportunities.

4.6 Future developments

The availability of water (and access to water) is a crucial factor in determining the potential for development and economic growth in a region. In planning any development, the availability of water needs to carefully assessed, as well as the impact of on water demand and availability, and the effects (particularly in terms of access) on other users.

Data available in the Land Development Objectives indicates that the most rapidly growing towns within the study area are Mafikeng and Lichtenburg. Growth between 1998 and 2003 is projected to be 4.5% and 5.0% for Mafikeng and Mmabatho, respectively (DWAF, 2000a). Growth between 2003 and 2013 is expected to slow to around 4% for the Mafikeng municipal area, including Mmabatho.

Most future developments within the study area will take the form of housing. In all municipalities, the lack of housing is a primary concern and several developments have been planned to alleviate this growing demand. As an example, some 14,000 residential erven are planned for development around Mafikeng (DWAF, 2000a). Further housing developments have also been planned in and around Zeerust and Lichtenburg.

None of the existing industrial activities are planning any significant expansion or growth, while two chrome mines in the area are in the process of rehabilitation (DWAF, 2000a). Future industrial development around Mafikeng is planned, although no specific plans have yet been developed.

The North West Spatial Development Initiative (SDI) is a project for the North West province designed to give effect to the macro-economic strategy of the country. SDIs aim to unlock the economic potential of a region by encouraging development along key transport routes or nodes. The Platinum SDI (which forms part of the Coast-to-Coast SDI linking Maputo with Walvis Bay via the Trans-Kalahari Highway) runs along the N4 from Pretoria to Botswana, via Brits, Swartruggens and Zeerust.

Job creation will be facilitated through the development of manufacturing, platinum mining, agriculture and tourism activities along this route. The NWSDI project is entering its next phase, which is to prepare pre-feasibility studies of two new areas in the province – the Mafikeng/Taung corridor and the Klerksdorp-Orkney-Stilfontein-Hartebeespoort (KOSH) corridor (Sunday Times, 2001). These areas have been declared as priority for the development of the province, and include some of the most poverty stricken areas. Key development sectors along these routes are agriculture in the Mafikeng area, and gold mining and jewellery manufacturing along the KOSH corridor (Sethibelo, 2001).

The availability of water resources for development needs to be considered as critical factors in these developments. Water is essential for industrial development and economic growth and its scarcity is one of the major factors hindering development in arid areas.

5 EXISTING INSTITUTIONAL ARRANGEMENTS

5.1 Dept of Water Affairs and Forestry: National Office

As the public trustee of the South Africa's water resources, National Government, through Minister of Water Affairs and Forestry, is ultimately responsible for ensuring that all water resources are "protected, used, developed, conserved, managed and controlled in a sustainable and equitable manner, for the benefit of all persons" (National Water Act, 1998).

Within DWAF, the organisational approach is based on centralised planning and decentralised implementation at the regional and catchment level (DWAF, 2000b). The national office undertakes policy-making responsibilities, while the regional offices of DWAF carry out its implementation. This delegation of management to the catchment level is aimed to improve community participation in water resources management.

In terms of managing groundwater, the national department currently carries out the following functions[16]:

- collating information about the functioning of groundwater resources
- protection of groundwater and definition of the Reserve
- building agencies responsible for devolved management of groundwater (CMAs)[17]

At a national level, the interaction between the Directorates of Geohydrology and Catchment Management, in terms of integrating groundwater into the overall management of water resources, as specified in the National Water Act, is limited. However, the specific focus on groundwater in a recently commissioned project to develop guidelines for integrated water resources management is a significant step in this direction.

The delegation of water management to the lowest practical level, according to regulatory/operational and service functions, has the potential to enhance groundwater management[18]. In delegating the water management functions to a catchment level, the establishment of catchment management agencies is a major initiative currently being driven at the national level. Once established, CMAs will have delegated responsibilities for licensing of water use and water allocation, according to specific catchment management strategies. While all attention is currently focussed on the establishment of CMAs, localised institutions (water user associations) need to be established, within this management framework, to manage common water resources.

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[16] Braune, E. 2001, personal communication, Pretoria, 20 July.

[17] Once the new agencies (CMAs) are established, the primary functions of the national department will be protection and the collection of information on groundwater resources.

[18] Braune, E. 2001, personal communication, Pretoria, 20 July.

The challenges to operationalising this management structure, as perceived at a national level, are twofold:

- that the knowledge of geohydrology within some regional/catchment level institutions is limited
- currently the capacity to manage groundwater is weak. Managing groundwater at a larger catchment scale, with current levels of capacity and resources will therefore be problematic. There is thus an urgent need to develop new skills and capacity within catchment agencies.

Leadership from national government, in terms of developing guidelines for catchment management, particularly with respect to groundwater, will thus be a crucial factor in the success of devolved water resources management and enhanced groundwater management.

5.2 *Emerging institutions: CMAs and WUAs*

5.2.1 Background

The development of new institutions and structures to manage water resources at a catchment level in South Africa has been set in place through the National Water Act. In terms of the Act, water resources will be managed at three levels, namely:

- *national government*
- *catchment management agencies*[19] (CMAs): organs of state operating at a regional level
- *forums* and *water user associations* (WUAs) operating at a local level

South Africa is currently in an 'institution building' phase – developing strategies and laying the groundwork necessary for new institutional structures to manage water resources. There is a need to focus on developing new institutional structures that work for all users, and can bring about and accommodate change. Ultimately, as an organ of state, CMAs will be the institution responsible for the overall management of groundwater in a particular water management area (Murray and Dindar, 1998; DWAF, 2000b). Where necessary, water user associations would be responsible for localised activities vital to the management of groundwater, such as monitoring.

This institutional structure has the potential to benefit groundwater management, through localised management of resources, and facilitating a supportive and participative approach, particularly through the establishment of WUAs. Although this new approach has great potential, its implementation is gradual. While all attention is currently on establishing the CMAs, the biggest challenge for water management in South Africa, will be to handle the next ten to twenty years of

[19] There are 19 catchment management areas across South Africa.

transition from the current centralised structure to emergence of new functional and participative institutions (Braune, 2000:12).

In addition, water management areas have been defined primarily according to surface water systems and flow patterns, sidelining the importance of groundwater in the overall management of water resources. As a result, and pertinent to this study, there are situations where aquifers extend through a number of CMAs, raising complex transboundary management issues. In these cases, groundwater management structures needs to extend across managerial boundaries, through an integrated system, capable of addressing both technical groundwater issues, as well as transboundary managerial issues. The role of WUAs in addressing this issue needs to be forefronted.

Until both catchment management agencies and water user associations are established and have sufficient capacity and knowledge to adequately address groundwater issues, the existing institutional structures will remain responsible for groundwater management. In the spirit of cooperative governance, once CMAs are established as an organ of state, DWAF will still be involved in the CMA in a supportive capacity (WISA, 2000). The success of the CMAs will depend on strong and supportive linkages between the CMA and other stakeholders (both within and beyond the spheres of government). In developing a strategy for groundwater management, the emergence of new water management bodies, their roles, functions, responsibilities and issues of capacity must be a focal point.

5.2.2 CMAs in the study area

The CMAs in the study area include (see Map A2):

- Crocodile West-Mariko (managed through the DWAF Gauteng and North West regional offices[20])
- Middle Vaal (managed through the DWAF Free State regional office)
- Lower Vaal (managed through the DWAF Northern Cape regional office)

The implications of this impending management structure and its institutional boundaries for the groundwater in the region, is that management of the aquifer will be divided among three catchment management agencies, in different stages of establishment, possibly adopting in different management policies and practises, and different pricing structures for users of the same aquifer. For practical purposes, an agreement has been made between the regional offices of DWAF that the North West regional office will be responsible for the management of the portion of the dolomite that falls into the Northern Cape regional area around Lichtenburg (van Dyk, 2001). This reduces the number

[20] In this CMA, responsibilities for geohydrology and catchment management functions are shared between the North West and Gauteng regional offices.

of regional offices of DWAF involved in direct management of the aquifer from three to two and effectively shifts the Crocodile West-Marico CMA boundary to the southern boundary of the aquifer.

It is clearly vital that this groundwater project proceed in conjunction with the CMA process, in order to foster early integration of management approaches for the CMA and groundwater within its area, and to draw attention to the specific management needs of the aquifer and its users.

The Crocodile West-Marico CMA process was initiated in January 2000[21]. The first major institutional step in its evolution will be the establishment of the governing board by the end of 2001/early 2002, from which the CMA will then grow. Much emphasis in this CMA process has been placed on the establishment of water management forums across the water management area[22].

These forums are multi-stakeholder organisations, which essentially act as umbrella organisations within which water users can participate in catchment management, with other stakeholders in the area. One aim of establishing forums is that they will remain in place to encourage public participation, once the CMA has been established and external agents withdraw. The Molopo Forum has been established in the section of the study area which falls into the Crocodile West-Marico CMA. Interaction with this structure, particularly in terms of developing management arrangements with the WUAs to be established in the area (see section 5.2.3), is therefore essential.

Of concern is that groundwater management, and transboundary management issues have not been resolved in the developing Crocodile West-Marico CMA[23]. It is therefore imperative that this project and the CMA process operate in conjunction. One means of integration would be through the CMA forums, which have been established in the portion of the study area that falls within the Crocodile West-Marico CMA (see Map A2).

The following challenges, of relevance to the management of groundwater, have been identified in the Crocodile West-Marico CMA:

- water quality (both surface and groundwater)
- the allocation and equitable use of water
- the effect of individual user demands on a resource that needs to be managed in an integrated and holistic manner
- the need to prioritise water conservation and demand management in water resource management
- the implications of management practices in one area, for adjacent areas
- the development and implementation of water use charges

[21] Hart, T. 2001. personal communication, Johannesburg, July.
[22] Further information on the specific function and role of forums will be included in the next report.
[23] Hart, T. 2001. personal communication, Johannesburg, July.

5.2.3 WUAs in the study area

In terms of the new water legislation, water users can be required by the Minister to register their water usage and form water user associations. Alternatively, interested persons can apply to establish a WUA with the submission of a proposal for the WUA to the Minister. This particularly applies to the existing irrigation boards and subterranean water control boards which will ultimately be restructured as WUAs.

A need was identified to manage the dolomite as a single water resource at a local scale. To facilitate this, the option of establishing one WUA for all users of dolomitic groundwater was mooted, but generally discarded, owing to the vast area of the dolomite, the numerous stakeholders and complexity of management issues. Five WUAs, broadly defined according to internal boundaries of compartments within the aquifer, have thus been proposed for users of the dolomitic groundwater (see Map A2). These include:

- Lichtenburg-Itsoseng
- Grootfontein
- Grootpan
- Ventersdorp
- Zeerust

These WUAs are in different stages of establishment, some well organised and waiting to operate, others barely conceived. Further discussion around the WUAs will take place in section 6.2, however it is worth noting here, that in most cases, an urgent need has been expressed by WUA representatives for DWAF to intervene and assist with the establishment of the WUAs. Of particular concern to representatives from WUAs are:

- defining the optimal boundaries of the WUAs
- the organisational capacity to begin the process of establishing the WUA
- the need for accurate information on water supply and allocations to effectively manage the resources.

5.3 Dept of Water Affairs and Forestry (Regional Offices)

The regional offices of DWAF are decentralised national offices, acting as the regional implementing agents for policy made at a national level. Although the study area falls within the North West province, the establishment of three CMAs across the dolomitic area has involved the regional offices responsible for each CMA in the management of the dolomitic aquifer (see Map A2). To some extent, the regional offices currently fulfil the role of CMAs and will continue to do so until the CMAs are established and functional[24]. Once the CMAs are established, the regional offices will most likely continue to exist, although in a reduced, and largely supportive, capacity[25].

The regional offices of DWAF involved in managing the dolomite, through the CMAs, are:

- North West Regional Office
- Gauteng Regional office
- Free State Regional Office
- Northern Cape Regional Office[26]

In terms of groundwater management, the primary function of the regional offices is monitoring of groundwater and liaison with the National Office of DWAF[27]. The type of data collected during monitoring is water levels, with very little attention paid to collecting data on the quality of groundwater[28]. Information on rainfall to determine recharge is gathered from weather bureau offices.

Regional management of groundwater seems beset with problems. Claims are made that groundwater management is not well organised at this level, and indeed, no clear and integrated management structure seems obvious. Issues of institutional capacity together with the inheritance of a legacy of neglect of groundwater due to its status as private water under previous legislation, appear to lie at the root of these problems. The following problems affecting groundwater management at a regional level were identified:

- the neglect of groundwater in overall management systems
- a lack of knowledge on the functioning of the aquifer, cross-flows between compartments and how the aquifer is reacting to current levels of abstraction[29]
- the failure to implement the results and recommendations from recent research on groundwater management[30]
- the perceived lack of control of the use of irrigation systems[31]

Regional offices currently, and in the future, occupy pivotal roles in decentralised water resources management, as implementing agents of policy. Therefore, at this level, issues of capacity, clarity of management functions, roles and responsibilities, and interaction with CMAs will have to be clearly addressed in a groundwater management system.

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[24] Bredenkamp, Mr. 2001, personal communication, telephonic, May.
[25] Botha, R. 2001. personal communication, telephonic, July.
[26] See section 4.2.2
[27] van der Merwe, P. 2001. personal communication, telephonic, July; Botha, R. 2001. personal communication, telephonic, July.
[28] van der Merwe, P. 2001. personal communication, telephonic, July.
[29] Botha, R. 2001. personal communication, telephonic, July.
[30] Botha, R. 2001. personal communication, telephonic, July.
[31] Van der Merwe, P. 2001. personal communication, telephonic, July.

5.4 Water boards

Water boards are organs of state established to provide water services to other water services institutions within its services area (Water Services Act, 1997). The water board in operation in the greater part of the study area is North West Water Supply Authority (NWWSA), originally established under the old Bophuthatswana government to supply water to the Bophuthatswana districts (see Map A5). There is currently no water board serving the southern portion of the study area in the Southern District Council. The existing arrangements of services and functions supplied by NWWSA to various towns in the study area are provided in table 6 below, in section 5.5.1.

Beyond infrastructure and water services, the groundwater management functions that NWWSA currently undertake include data collection and monitoring (of water levels and quality), testing borehole sites and the design of appropriate installations according to the geohydrological specifications[32]. Monitoring is also undertaken around particularly sensitive aquifers, and points of pollution.

The future role of water boards is very much up for debate. Issues that need to be resolved concern the economic viability of either water boards or local and district councils in providing water services. In some instances there are the perceptions that local municipalities could provide these services more economically and would prefer independence from water boards[33]. Currently however, NWWSA has the knowledge and experience of managing water supplies in the area, has instituted regular monitoring and data collection systems, as well as the equipment and capacity to undertake water supply functions. Problems of institutional capacity within local and district councils need to be thoroughly assessed and addressed.

A related issue is the transfer of operation and maintenance responsibilities from NWWSA to district and local councils. The lack of qualified staff within these structures again raises questions regarding capacity and the future operation of these schemes under local councils. Staff in district offices are frequently new to the area and lack the detailed knowledge of local conditions to enable them to alert authorities early enough, should problems or warning signs emerge[34].

Perceived threats and challenges to groundwater management, identified by NWWSA, include:

- the impact of pesticides on water quality, particularly in sensitive areas
- the lack of control of sewage treatment and dumping into water courses
- the lack of capacity and clarity in terms of roles and functions, at the local government level, to enable district and local municipalities to fulfil their roles as water service authorities

[32] Van Rensburg, S. 2001. personal communication, telephonic, 13 July.

[33] strongly argued by ward councillors from the Ditsobotla Municipality (21 June 2001).

[34] Van Rensburg, S. 2001. personal communication, telephonic, 13 July.

NWWSA proposes a framework for groundwater management which includes representatives from CMAs, water boards as well as local and district councils. There should be a formalised structure and a clear division of functions between the tiers of government, with a clear delegation of functions from national to local government, in line with the institutional capacity available to undertake these functions.

5.5 District and Local Municipalities

In terms of the Water Services Act (Act 108 of 1997) local authorities (including district or local councils) have been tasked with the responsibilities of water service authorities, and are responsible for the planning and implementation of water services and infrastructure to ensure acceptable minimum levels of provision to their constituents (DWAF, 2000a). While not tasked with any specific groundwater management functions, these agencies are important agents in water management, in terms of provision, and their level of capacity and resources are critical factors in the efficiency of service delivery and local management.

District councils are new structures (or built on the old Regional Services Councils and Joint Services Boards), following the local government transition and the demarcation process, that have a key role to play in the provision and management of local water services (Murray and Dindar, 1998). District councils are responsible for the bulk service functions of old regional service councils, and in some cases, they provide municipal services directly to the public. In general, local municipalities are responsible for the planning, implementation, operation and maintenance of the water services infrastructure within their municipal area. However, there is a lack of clarity and considerable confusion around the division of roles and functions between local and district councils, following the local government elections and municipal demarcations in 2000[35].

In terms of the Water Services Act and as part of the integrated development planning process, local authorities are responsible for preparing and adopting water service development plans (WSDPs) to ensure the basic minimum standards for access to basic water supply and sanitation are met (Water Services Act, 1997). However, where WSDPs have been prepared, many are now outdated following the demarcation process[36].

As water managers, the district and local councils fulfil a key role in the institutional structure for the management and supply of water. In addition, their role as major users of water must not be overlooked. Municipalities therefore need representation in water management structures, in terms of their own local management and use practises, and as representatives of their constituents.

[35] This issue was raised in almost every interview with municipal managers.

[36] Khumoeng, I. 2001. personal communication, Mmabatho, 19 June.

5.5.1 District Councils

At a district level, the study includes portions of two district councils (see Map A4):

- the Central District Council
- the Southern District Council.

Although they currently do not use water from the dolomite, should the towns of Koster and Swartruggens (situated north of the dolomite boundary) require water from this source in future, the Rustenburg District Council would be included as part of the study area. However, in terms of current planning, the expense of supplying these towns with dolomitic groundwater precludes this option, as they are some distance from the dolomite[37].

At a district council level, the following arrangements (see Table 6) for water supply, operation and maintenance have been identified in DWAF[38] (2000a).

[37] Harmse, Mr. 2001. personal communication, telephonic, July; Bester, Mr. 2001. personal communication, telephonic, July. However, there appear to be conflicting perceptions on the feasibility of supplying these areas with water from the dolomite.

[38] Labauschagne, F. 2001. 2001. personal communication, telephonic. July.

Table 6: Water supply, operation and maintenance in district councils and local municipalities (DWAF, 2000a; Ventersdorp WSDP, 2001)

District Councils	Settlement	Water Board	Bulk Water Supply		Municipal O&M
			Ownership	***O&M***	
Central	Coligny	Goudveld Water	Central District Council	Own	Own
Central	Lichtenburg	NWWSA	Central District Council	Own	Own
Central	Itsoseng	NWWSA	DWAF	NWWSA	Own
Central	Zeerust	NWWSA	Own	Own	Own
Central	Lehurutse	NWWSA	DWAF	NWWSA	Own
Central	Mafikeng	NWWSA	DWAF	NWWSA	Own
Central	Mmabatho villages	NWWSA	DWAF	NWWSA	CDC
Southern	Ventersdorp	None	DWAF	Own	Own
Southern	Villages	None	?	?	?
Rustenburg	*Koster*[®]	*None*	*Rustenburg District*	*Own*	*Own*
Rustenburg	*Swartruggens*[®]	*None*	*Rustenburg District*	*Own*	*Own*

[®] these towns do not currently use and are not intending to augment their water supply using dolomitic groundwater.

In terms of institutional capacity, the central and southern district councils appear confident that they are addressing issues of delivery within their service areas, and that they have the institutional and financial resources to continue this function[39]. These views would have to be validated with research in communities served by the district councils to determine the overall levels of service and needs in their management areas, and the capacity for local management of water supplies.

5.5.2 Local Municipalities

The study area includes the following municipal and district councils[40] (see table 7 and Map A5):

Municipalities	District Councils
Lichtenburg (NW384)	Central District Council (DC 38)
Mafikeng (NW383)	Central District Council (DC 38)
Zeerust (NW385)	Central District Council (DC 38)
Ventersdorp (NW401)	Southern District Council (DC 40)
NW 383 (Koster/Swartruggens)	*Rustenburg District Council (DC 37)*

Table 7: Municipalities and district councils in the study area

In general, the focus of local municipalities is the urban areas within their municipal boundaries. As with district councils, they are responsible for water service provision, and infrastructure operation and maintenance within these areas. Again, an issue raised by several municipal managers, is the lack of clarity in terms of divisions of roles and functions between local and district councils, particularly with respect to rural settlements within municipal areas following the demarcation process (e.g. Grasfontein near Lichtenburg)[41].

5.5.3 Ward councillors and ward committees

The election of ward councillors and ward committees is the lowest tier of governance. These committees are responsible for the representation of the community's needs and, depending on the circumstances in the area, may have key roles in the management of a local water supply and service delivery. There however are several obstacles that have lead to a decline in participation amongst committee members (Ralo, 2000). These problems include:

- a difficulty in attracting new members
- insufficient training leading to inadequate skills

[39] Mokhele, J. 2001 personal communication, Mafikeng, July; Labauschagne, F. 2001, personal communication, telephonic, July.

[40] Post 2000 municipal demarcations

[41] Harde, M. 2001. personal communication. Lichtenburg, 18 June; Dandashe, B. 2001. personal communication. Zeerust, 20 June; Smit, H. 2001. personal communication, telephonic, 4 July.

- the voluntary nature of committee, resulting in a lack of incentive for members to remain involved
- lack of powers to enable them to take effective action to enforce payment for water services

In some communities (e.g. Sheila), a water committee is well established and functional, performing tasks such as the collection of payments, conveying problems to the councillor and undertaking repairs to pipes and pumps in the water supply system. In other communities, water committees do not exist or play a major role in the management of water where local water is managed by the tribal authority which interacts with the ward councillor (e.g. Dinokana).

What is relevant in this context is that at a local level, particular systems of managing a water source/supply may be in existence, and cognisance must be taken to identify these structures before instituting external systems in an area. Care must also be taken to work with tribal customs and systems of water management. If appropriate, existing local structures should be incorporated into a broader management structure. Particular tasks for committee members tasked with water management might include:

- pump attendant
- undertaking repairs to pump/pipes where possible
- reporting faults
- payment collection
- local monitoring and transfer of data to district council/DWAF
- conveying information on water issues to the community
- community education and awareness about water, sanitation and health issues

5.6 *International water management arrangements*

The SADC Water Sector Unit describe the dolomitic resource in the study area as a "small but very important transboundary aquifer in the dolomites of the Transvaal Group, which is used on both sides of the border. ... The aquifers are mentioned in general terms by South Africa as part of shared water resources of the transboundary Limpopo basin..."[42] The issue of aquifers of the Limpopo basin and the relationship with the rivers will form part of a SADC project on "Protection and strategic use of groundwater in the transboundary Limpopo basin and drought prone areas of the SADC region".

[42] Púyoo, S. 2001. correspondence via email. 21 June.

Although we are not able to identify any current (formal) international arrangements between Botswana and South Africa for the use or management of transboundary dolomitic aquifers in the study area, this is clearly an important issue that needs clarification[43].

Issues related to internationally shared aquifers that need to be considered in groundwater management include:

- the use and management of transboundary aquifers and how practises on one side of the border affect the resource as a whole, for other users
- the interaction between ground and surface water systems across international borders, for example, how surface water developments (e.g. dam-building) affect transboundary groundwater resources

Existing international arrangements regarding surface water, in proximity to the study area, include the supply of water to Botswana from the Molatedi Dam on the Marico River in South Africa. In this respect, the relationship between these surface water resources and groundwater, particularly from the dolomitic area, needs to be clearly understood. One particular example of surface/groundwater interaction is that the building of dams may cause negative long-term impacts on groundwater recharge and in this respect, transboundary activities and water resources management need to be fully assessed in their regional context.

In addition, the hydrological interaction between the dolomitic aquifer in this study, and groundwater in Botswana also needs to be understood. Geological information shows that the dolomites do extend into Botswana. Clarification is therefore needed on whether abstraction on either side of the border has any impact on cross-border groundwater levels, and what implications this holds for groundwater management and institutional arrangements for dolomite.

[43] The Karoo aquifer between Botswana, Namibia and South Africa is being used as a starting point for the development of transboundary aquifer management – an initiative being promoted by the Internationally Shared Aquifer Resource Management (ISARM).

6 USER PROFILE

6.1 Water use and demand in the study area

The key factors regarding water use and demand, which lay the context for the user profile analysis include:

- Water users in the study area are dependent on groundwater – whether it is water pumped from boreholes or outflow from springs. Surface water resources in the dolomitic area are limited and those that exist are integrally connected with the groundwater system.
- In most areas, current water supplies are able to meet *existing* demands, but any increase in water demand will exceed local supplies in addition, many rural areas and villages within the study area of this project do not have adequate water supplies to meet even basic needs at RDP standards. The implications of implementing the 'free basic water' policy also need to be fully understood in terms of an increase in water demand, although the provision of basic water is a non-negotiable priority.
- A study commissioned by DWAF and completed in 1999[44] established that there is not enough bulk water in the region available to meet the projected future demands of *all* consumers, including towns and villages, irrigated agriculture and mining enterprises (DWAF, 2000a:1). To meet the future demands of the towns[45] in its study area it was noted that water would have to be supplied from external sources such as the Molatedi dam (situated in South Africa near the Botswana border and supplying water to Botswana) or the Vaal River – both at substantial cost (DWAF, 2000a).
- Conclusions from a more recent DWAF study[46] established the following factors of relevance to water use and demand to this study (DWAF, 2000a):
    - the major areas of growth are domestic water use (residential development and associated institutional and commercial activity)
    - mining and cement production are not expecting any growth
    - agriculture is a major factor in water consumption and recent years have witnessed significant growth in irrigated agriculture

[44] The North West Water Supply and Sanitation First Order Strategy

[45] The area covered by the study included the towns of Swartruggens and Koster in the east, Mafikeng in the west, Lichtenburg in the south and the Lehurutse district in the north.

[46] commissioned following the North West Water Supply and Sanitation First Order Strategy to investigate the augmentation of the primary water to Zeerust, Swartruggens and Mafikeng

- most settlements will require additional bulk water in the next 30 years, with priorities being Swartruggens, Lehurutse (including Sehujwane and Dinokana), Zeerust, and the southern Madikwe district)
- following on from the 1999 DWAF study, it was found that future bulk water demands *for primary consumers* can be met from local resources. However in doing so, DWAF (2000a) identified that a reallocation of a portion of the water resources from irrigation to primary use will be needed.

The main users of groundwater in the study area include:

- agriculture
- domestic/urban
- industry
- conservation/environment
- recreational
- small-scale/emerging activities – despite their involvement in most user groups, small-scale and emerging users are discussed separately as these users face similar constraints and need particular attention in terms of representation and involvement in management structures

The following issues are presented in order to better understand the needs and concerns of each group and to highlight points of tension/conflict between groups, as well as issues that require further research.

After some contextual information on the user group, the following issues are used as the basis for analysis of the user profile:

- key concerns regarding water availability, use and management
- increasing or decreasing water needs
- perceived threats to water quality or quantity
- desired future management scenarios for groundwater
- problems with current groundwater management and institutional arrangements
- primary challenges for groundwater management

Information was gathered during a series of semi-structured telephonic interviews with key informants from each group. This information presents the views and opinions of stakeholders and as such, may therefore not be regarded as factual. However, it provides valuable insight into the perceptions of different groups, indicating at an early stage in the process, sensitive or conflictual issues, as well as where support or opposition for different management scenarios may lie.

6.2 Water User Associations

Although WUAs should represent all water user groups using a particular resource, commercial farmers, who have had to register their water use in terms of the National Water Act, are driving the establishment of WUAs in the study area. In some cases (Grootfontein), existing irrigation boards are converting to WUAs. Across the area, WUAs are thus in various stages of establishment – some ready to operate (Lichtenburg-Itsoseng), others having stalled for various reasons (Grootfontein), and others have not started at all (Zeerust).

While representatives of WUAs acknowledge the need to involve all water users in the area[47], attempts to involve groups, outside municipalities and the commercial farming sector, in establishing WUAs have proven futile. In order to understand the social dynamics and the causes for poor participation and representation, this issue needs to be addressed in further research in this project.

WUAs are thus dominated by commercial farmers and issues of ownership and buy-in from other groups (e.g. emerging farmers) will arise as they realise the need to become involved in a process which started without them. If this situation is not addressed, despite the best intentions and sound policy, existing patterns of imbalance and inequity in the use and management of water, and resulting development opportunities (including health, socio-economic and gender issues), are likely to be entrenched in these processes.

The membership and voting systems of the management committees of WUAs is a crucial issue that needs to be examined. Questions of representivity need to be addressed, for example. Should representation be on the basis of the amount of water used, or the number of water users?

Key concerns raised by WUA representatives include:

- the lack of knowledge about groundwater (how much water is there, how much is safe to use, flow patterns etc.) and the problems this raises for managing water sustainably and equitably[48].
- the optimal boundaries for WUAs, which may run through a farm, placing the farmer in two WUA areas[49].
- the need for clarity or assistance from DWAF on the membership and mandates of WUAs, details on boundaries, and around Zeerust, to initiate the process of establishing the WUA.
- how to involve other water users and small-scale farmers in establishing WUAs[50]

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[47] Beyers, A. 2001. personal communication, Lichtenburg, 21 June.

[48] Beyers, A. 2001. personal communication, Lichtenburg, 21 June; Lohann, M. 2001. personal communication, telephonic, July.

[49] Lohann, M. 2001. personal communication, telephonic, July.

[50] Kruger, D. 2001. personal communication, telephonic, 10 July; Lohann, M. 2001. personal communication, telephonic, July.

- the need for interaction between surface water users and groundwater users, particularly around the Schoonspruit eye.
- the levying of uniform water charges where farmers in one area have had greater costs in developing their water supply (e.g. borehole users vs. surface water users around Schoonspruit)[51]
- the impact of water levies on the economic viability of farming.
- pollution was not perceived to be a major issue, despite the use of fertilizers and pesticides in farming.

6.3 Agriculture

Agriculture uses an estimated 90% of the 1.8 million m^3 groundwater abstracted in South Africa (CSIR, 1999). Farmers are therefore most at risk from groundwater contamination, and have an important role in groundwater management.

Agriculture is a major economic activity in the study area and many of the towns and industries in the area have developed around this sector. The contribution of agriculture to the local formal and informal economy, particularly in terms of employment, livelihoods and supporting rural communities, is significant. In addition, agriculture has been identified as a key sector for future economic growth in the region.

However, alongside this important role in providing livelihoods and economic growth, there are disparities associated with the agricultural sector. Agriculture is the greatest consumer of water and the linking of land and water rights under previous legislation has had significant socio-economic implications. Water for basic needs and domestic use now gains priority over water for agriculture, with the result that agriculture is likely to be the sector most affected by the implementation of the new water law, although the allocations of existing lawful users remain protected. However, redressing imbalances must take into consideration the vital role that agriculture plays in the local formal and informal economy.

While agriculture is dominated by a minority involved in well-organised commercial operations, the growth of emerging and small-scale farmers, as well as subsistence farming, all largely without formal representation in agricultural structures, needs to be considered in the management of water resources. The development of water management strategies, particularly in an agricultural context, is likely to be highly contentious, and these issues need to be clearly understood and addressed. In the

[51] Van Zyl, H. 2001, personal communication, telephonic, 19 July.

drive to "mainstream the marginalized", the revitalisation of "agricultural crop water use"[52] is one part of a broader integrated sustainable rural development policy.

The Department of Agriculture (DoA) in the North West does not play a role in groundwater management, however, their activities in agriculture, particularly with respect to irrigation and their involvement in the agriculture community (both commercial and emerging), places them as stakeholders in the use of groundwater. In areas such as Dinokana, the DoA is involved in the drilling of boreholes for applicants, after the application has been approved through the tribal office and the district council[53]. (Although currently lacking, there should be some coordination in this regard with DWAF.) DoA also assist (either through resources or funding) in developing facilities such as reservoirs for stock watering.

The DoA sees that the primary challenge for groundwater management will be the implementation of an accurate metering and monitoring system, particularly for borehole water used for agricultural activities[54].

Issues of payment are controversial amongst both commercial farmers, whose access to water has been protected and free, allowing them considerable advantage in developing their activities, and amongst emerging farmers, who have been denied access to land and water, and are entering the agricultural sector needing support, and often with perceptions that water was and is free. This debate includes positions where farmers have personally placed large financial investments in developing water supplies on their farms[55]. This matter needs to be carefully addressed.

Issues of representivity and organisation need to be addressed in the agricultural sector. Commercial farmers are well represented through organised agriculture and agricultural unions. The National African Farmers' Union (NAFU) is a membership-based organisation for black farmers but, in the study area, was not seen to be active in terms of organising and developing capacity amongst emerging farmers and representing their needs at a local level[56]. Although invited to meetings, NAFU has not played a role in the establishment of WUAs in the area and was not able to provide contact details for their members[57]. In contrast, the commercial agricultural unions have been actively involved in this process.

[52] Agricultural crop water user encompasses more than irrigated agriculture, but also the use of water through rainwater harvesting and other conservation techniques to improve agricultural productivity.

[53] Thubise, D. 2001. personal communication, Dinokana, 20 June.

[54] Swanepoel, Mr. 2001. personal communication, telephonic, 19 July; Viljoen, W. 2001. personal communication, telephonic, June.

[55] Swanepoel, Mr. 2001. personal communication, telephonic, 19 July.

[56] Thubise, D. 2001. personal communication, Dinokana, 20 June.

[57] Beyers, A. 2001. personal communication, Lichtenburg, 21 June.

The Transvaal Agricultural Union and the North West Agricultural Union have both been actively involved in the establishment of WUAs in their respective areas, in terms of representing their members and the interests of the commercial farming community. Although the National Water Act will impact on farmers, Union representatives believe that while farmers were initially concerned about its impact on their activities, as users under the new Act, farmers have a voice in the management of water, and with the correct information, they will be able to manage water and minimise negative impacts[58]. Despite this view, there is uncertainty over water management in the agriculture sector. Farmers do feel vulnerable and realise that water levies will decrease their income and probably the scale of their operations[59].

The key concerns voiced by Unions include:

- the lack of information and understanding of groundwater, in terms of safe water yield,
- the impact of pesticides and overabstraction on groundwater
- the growth of urban areas, particularly Mmabatho, and the impact of increased domestic demands on groundwater and the implications for agricultural users[60].
- Issues of payment were also raised by the unions, with the perception that when WUAs are established, farmers will be able to manage water more efficiently and with lower administrative costs than current structures, ultimately resulting in lower payment charges for water use[61].
- In terms of management, it was also noted that the degree of representation should be proportional to the amount of water used – in other words, as large users of water, farmers should be well-represented on management structures[62]. This is evident in the membership of the management committee of the Lichtenburg-Itsoseng WUA[63].

In terms of managing the dolomite at a local level, through years of experience in the area, and with water central to their livelihoods, farmers see that they have a central role to play, provided they receive the accurate information on safe water yields and aquifer boundaries from DWAF[64].

[58] Beyers, A. 2001. personal communication, Lichtenburg, 21 June; Greyling, P. 2001. personal communication, telephonic, 10 July.
[59] Kruger, D. 2001. personal communication, telephonic, 10 July; van Zyl, H. 2001. personal communication, telephonic, 19 July.
[60] Greyling, P. 2001. personal communication, telephonic, 10 July.
[61] Greyling, P. 2001. personal communication, telephonic, 10 July.
[62] Beyers, A. 2001. personal communication, Lichtenburg, 21 June.
[63] From the Proposal to DWAF for the Establishment of the Lichtenburg-Itsoseng Water User Assocation
[64] Beyers, A. 2001. personal communication, Lichtenburg, 21 June, van Zyl, H. 2001. personal communication, telephonic, 19 July.

6.4 *Domestic use*

The availability, use and management of water resources and services at a local level has profound implications for health and development opportunities, particularly among marginalized groups. Analysis of water use and decision-making at this level must be seen within this context of inequity and uneven development.

6.4.1 District councils

Key considerations in the provision of water and sanitation services in district council areas, are the many rural settlements – some once part of the former homeland state of Bophuthatswana, others recent settlements of the result of land reform initiatives[65]. Rural communities within the district councils rely primarily on groundwater. These settlements generally lack a formal institutional infrastructure and thus fall under the responsibility of the district councils in terms of service provision, operation and maintenance (DWAF, 2000a). Water supplies in rural settlements are generally managed at a local level by the community (through village water committees, where they exist) and maintained by water boards for the district councils, or by the district councils themselves (DWAF, 2000a).

The level of service provision within rural settlements in district council areas varies enormously, from areas with no local water supply and no services, to those with basic RDP standards, others with a nearby water source (e.g. spring) and then those with household supplies and services. Addressing standards of water supply and sanitation services are immediate challenges for the new district councils.

The Rural Water Supply Programme, being implemented in collaboration between NWWSA and the district councils, is assisting in the development of services in rural areas[66]. In both the Central and Southern Districts, several projects are in progress to develop water and sanitation services to RDP standards[67] in rural settlements[68]. However, there are still many communities in desperate need of water and service provision. Some communities are happy with RDP service standards[69], while others would prefer standards to be upgraded to yard connections to facilitate payment and better

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[65] District councils include many small settlements, each with particular problems, ways of addressing them, internal community structures, water supply systems and so on, which management systems must take care to consider. However, to provide an understanding of the types of problems that groundwater management needs to address, I will provide an overview of some of the more representative issues and problems that communities in district councils experience regarding their water and sanitation systems.

[66] Van Rensburg, S. 2001, personal communication, telephonic, July.

[67] RDP standards of service refer to the basic minimum level of service required in the Water Supply and Sanitation Policy White Paper of 25 litres per person per day of potable water within 200m of any household (Cain, Ravenscroft and Palmer, 2000)

[68] Mokhele, 2001; Labauschagne, 2001

[69] Labauschagne, F. 2001, personal communication, telephonic, July.

management of the water supply[70]. This shows consistence with other studies, which found that there is dissatisfaction with the system of communal taps, where there is no control of individual use and a flat rate is charged for consumption (Dreyer, 1998; Ralo, 2000).

Addressing concerns around payment for water services is a major issue at the district level. Charging for water is highly varied. In some cases, such as Sheila, the community pays the municipality a flat rate on a monthly basis for the energy used to pump the water, while in other cases households with meters (e.g. households in Dinokana) pay on an individual basis. In other areas, such as Grasfontein, where the supply is locally managed, there are private internal systems of paying an attendant a levy for pumping the water, or for delivering water. In other areas (e.g. Bodibe), municipal water has been switched off due to non-payment, however, local sources (e.g. springs, wells, hand pumps) provide a reliable supply of water to the village.

Attempts by local authorities to institute payment systems for water services have been met with resistance, resulting in heated debate and conflict between those with meters and private borehole users[71]. A thorough understanding of local systems, as well as education and capacity building are necessary to develop an appreciation of the value of water and the need to pay. However where this understanding exists, communities are not prepared to pay for an inadequate or non-existent service[72]. In other cases, people do not see the need to pay for water when it is perceived as a free service, coming to them naturally (e.g. Dinokana, where water flows from a local spring through village). Sparse information on the government's 'free basic water' policy has further complicated attempts to encourage payment for water services. In addition, conflicts and tensions between tribal authorities with their own systems, and local municipalities instituting municipal systems, compound problems around payment[73].

One of the significant threats to groundwater quality and the health of local communities is the location of pit latrines in close proximity to underground water supplies[74]. Upgrading these facilities and siting new boreholes away from villages (which raises issues of access) are two approaches being used to address this enormous problem. Pollution to groundwater from cattle kraals is a further problem that needs attention in local groundwater management[75].

Groundwater quality requires regular monitoring and data collection, and is an important component of groundwater management. Although there is generally quarterly monitoring at the source of

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[70] Sheila Water Committee, 2001.

[71] Thubise, 2001

[72] Sheila Water Committee, 2001.

[73] Thubise, D. 2001. personal communication, Dinokana, June.

[74] Mokhele, J. 2001 personal communication, Mafikeng, July; Labauschagne, F. 2001. personal communication, telephonic, July.

[75] Labauschagne, F. 2001. personal communication, telephonic, July.

municipal supplies (see table 8), the monitoring of groundwater quality around the municipal area (particularly to monitor the quality of water used by rural communities) is not a norm. Very few institutions seem to be undertaking this function or ensuring that systems are in place to collect this data. As an exception, the Southern District Council monitors water quality twice yearly[76].

6.4.2 Local Municipalities

Overall, the level of service provision and water supply within local municipalities is satisfactory. However, certain areas now included in these municipalities following the demarcation process have not yet received adequate attention from local authorities in terms of addressing their needs and improving service levels. Most municipal managers were quick to point out that they were unfamiliar with conditions in the areas newly included in their boundaries. In many cases, these areas are still served by district councils.

The primary concerns from local authority managers across the study area were:

- pollution to groundwater from pit latrines in informal areas,
- the quality of water being used for domestic purposes within informal areas,
- their lack of knowledge on the impact of pollution on groundwater quality, and
- their lack of capacity (currently and in the foreseeable future) to address these concerns through regular monitoring of water quality[77].
- issues of urban growth, and the impact of water demand on the existing supplies were raised in some municipal areas. Particular growth nodes include Mafikeng, Zeerust and Lichtenburg.

The high levels of unaccounted for water due to leakage and unauthorised connections are issues of particular concern that affect water use and predicted future demand in Mafikeng, and Lehurutse and Dinokana near Zeerust (DWAF, 2000a). Concerns about overabstraction by municipalities was raised by water users and managers across the study area. The need for better control of unaccounted for water and more accurate metering systems is one means of addressing this problem and an important component of local water management.

The implementation of the government's free basic water policy is a further factor of concern within local municipalities. The full implications of this policy require research, particularly in terms of understanding the implications for increased demand, and the infrastructure requirements needed to provide this service[78]. In Zeerust, for example, the local authority has considered implementing a 3000l per household per month free quota to determine the effect on water demand, before instituting

[76] Labauschagne, F. 2001. personal communication, telephonic, July.
[77] Harde, M. 2001. personal communication, Lichtenburg, 18 June.
[78] Dandashe, B. 2001. personal communication, Zeerust, 20 June.

the full policy. This however raises issues related to prioritisation of water usage within municipalities, which should be investigated in further research. In addition, implementing water demand management and decreasing unaccounted for water would increase the amount of water available for meeting basic needs within the existing supply.

In terms of domestic (primary) water use and demand, it has been established that there is sufficient bulk water supply in the region to meet future demands until 2030 for primary consumers (DWAF, 2000a). However, this study noted that reallocation of a portion of the supply (including both ground and surface water) from irrigation to primary use, will be required to meet demands within this period (DWAF, 2000a).

From discussions with municipal managers responsible for water services, the following details on supply and demand for their municipalities were provided:

- Zeerust[79]: supply currently meets demand (but any increase in demand will exceed supply)
- Lichtenburg[80] & Ventersdorp[81]: no supply problems (current or future)
- Mafikeng[82]: there is currently sufficient water to meet demands for the next ten years, thereafter augmentation will be necessary

The following table provides information related to consumption patterns, unaccounted for water and monitoring within municipal areas (see Table 9). This information is sourced from existing data and reports which have not been updated following the municipal demarcation process.

[79] Dandashe, B. 2001. personal communication. Zeerust. 20 June.
[80] Lombard, D. 2001. personal communication. Lichtenburg. 21 June.
[81] Boschoff, Mr. 2001. personal communication. telephonic. 4 July.
[82] Smit, H. 2001. personal communication, telephonic, 4 July.

Table 9: Figures relating to water consumption for towns in study area

Data was taken from DWAF 2000a and Water Service Development Plans (where available). Data is useful only as an indication of trends and of the quality of data currently available from municipalities. Figures have not been updated following the municipal demarcation process in 2000. Outside urban boundaries, the rural areas included in these figures are variable (e.g. Dinokana is included in some of the data for Zeerust). N/d = no data

Area	Water source	Present demand (2000)[⊕]	Estimated demand (2030)[⊕]	Growth rate[⊕, 83]	Consumption patterns[◊]	Demand centre[⊕]	Water balance[84] (excess/deficit)[⊕] 2000	2030	Unaccounted for water[⊕,85]	Monitoring (quality at source)[◊]
Mafikeng	Grootfontein compartment (pumping), Molopo compartment (overflow), Setumo dam	13.27 Mm^3/yr	41.25 Mm^3/yr	7.8%	Growth is three times higher than normal	1st largest	18.216 Mm^3/yr	**-10.553** Mm^3/yr	28%	?
Zeerust	Zeerust compartment (well field)	2.117 Mm^3/yr	5.36 Mm^3/yr	4.08%	Negative growth over past years	2nd largest	0.037 Mm^3/yr	**-3.688** Mm^3/yr	9.1%	Yes (monthly)
Lehurutse[86]	Zeerust compartment (Dinokana eye)	0.829 Mm^3/yr	N/d	34.35%[87]	N/d	2nd largest	0.976 Mm^3/yr	**-1.062** Mm^3/yr	Unknown	?
Lichtenburg	Lichtenburg-Itsoseng compartment	3.752 Mm^3/yr	13.3 Mm^3/yr	1.85%	Less than theoretical demand	3rd largest	2.402 Mm^3/yr	**-6.642** Mm^3/yr	10%	Yes (quarterly)
Itsoseng	Lichtenburg-Itsoseng compartment	1.784 Mm^3/yr	3.4 Mm^3/yr	4.3%	Equivalent to theoretical demand	3rd largest	1.197 Mm^3/yr	**-1.054** Mm^3/yr	77.8%[88]	Yes (quarterly)
Ventersdorp[◊]	Schoonspruit eye (Ventersdorp comp.)	0.928 Mm^3/yr	N/d	N/d	N/d	?	?	?	?	Yes (quarterly)

[⊕] Source: DWAF, 2000a (except data for Ventersdorp which is from the Water Service Development Plan).

[83] Growth in water consumption, (DWAF, 2000a)

[84] within existing resources

[85] figures within 10% are generally regarding as well within acceptable limits of unaccounted for water

[◊] Source: Municipal Water Service Development Plans

[86] including Dinokana and environs

[87] high growth rate due to high number of illegal yard connections in area

[88] contributing factors to the high figures for Mafikeng and Itsoseng are not so much water lost, but water not properly metered and billed

[◊] Source: Municipal Water Service Development Plans

Information has been collected for towns that currently use water from the dolomitic series. Other towns in the area that currently do not use dolomitic water, but whose needs will need augmentation in future include Koster, Swartruggens and Coligny[89]. However, following discussions with municipal managers[90], it is unlikely that these towns will consider augmenting their supply using water from the dolomite due to the distance from the dolomite and the costs involved in pumping water to the town[91]. Again, there are conflicting perceptions here.

6.5 *Industry*

Although there are no short term plans for the expansion of existing industry in the study area, migration from rural areas to urban settlements and the growth of Zeerust and Mafikeng, are creating an increased demand for employment in the area that needs to be addressed, possibly through industrial development. The North West Spatial Development Initiative (discussed in section 4.6) is a longer term planning proposal for the region that specifically aims to address job creation through industrial and economic growth.

However, availability and access to water resources are key factors determining economic and industrial growth. Major plans for the expansion of the industrial sector will have a significant impact on water use and demand in the province, particularly if the implementation of water demand management is not included in the planning process. Growth in a particular sector may also lead to increased competition between water users for the limited water resources in the area. Perceptions exist that irrigation users are overabstracting[92], thus impacting on the amount of water available to other users[93]. Future industrial development initiatives will therefore have to be carefully planned in line with the availability and capacity of water resources, as well as employment needs in the area.

The existing formal industrial operations include:

- cement factories and lime quarries
- small scale alluvial diamond mining operations, primarily in the broader Lichtenburg/Mafikeng area[94]
- other small industrial mining operations (peat, chrome, fluorite, slate, etc.)

[89] I was unable to contact the town engineer at Coligny for information on their water supplies.

[90] Others may view this differently.

[91] Bester, Mr. 2001, personal communication, telephonic, 3 July.

[92] When looking at issues of overabstraction, it is important to distinguish between exceeding existing allocations, and exceeding the sustainable yield of the resource.

[93] Meyer, P. 2001, personal communication, telephonic, 5 July.

[94] The Lichtenburg area was the sight of the world's largest diamond rush during the early 1900s. The landscape bears witness to this history of activity and digging (e.g. Malan's Pothole) and small operators still sieve the soils looking for remnants of this past wealth.

- small-scale and emerging industrial operations (e.g. brick making) are discussed separately in section 6.8 below.

None of the existing industries are planning any expansion of their operations, and some of the smaller mining operations are in the process of rehabilitation. In addition, the water needs of these industries (cement, diamond digging and dairy) are limited and no industry contacted was expecting their water consumptions to increase in time[95]. The water use of Clover dairies is in fact decreasing[96].

None of the industries experience any problems in accessing a regular and sufficient water supply. All of the industries undertake some form of regular monitoring of water levels, and in the case of Clover dairies and Alpha cement, microbiological quality testing. PPC, for example, has monitoring data from when they started producing cement at Slurry in 1915.

Indications from industry (environmental/risk) managers are that there is very limited environmental impact occurring as a result of their operations, with the exception being aesthetic scarring due to mining. However this is not on a scale significant enough to alter catchment patterns. While there is wastewater discharge from most of the industries, this is first treated and monitored for quality. Most plants use recycled water to some extent in their operations. Where water is not treated (e.g. Clover dairies), it is returned through the municipal sewage system. A closer analysis of the environmental impact of mining and industrial operations, particularly those in close proximity to sensitive systems, for example mining around springs, is required.

A concern amongst industrial water users is the recent increase in large-scale irrigation, leading to declining groundwater levels, to the detriment of other user groups[97].

Industrial representation on WUAs is limited, with the only positive response coming from Alpha cement, which is represented on the Lichtenburg-Itsoseng WUA.

6.6 Conservation

The water needs of conservation, and conservation-related activities should not be overlooked, and need to be considered in managing groundwater and related systems. As an example, the springs in the study area provide unique habitats which have developed in isolation, many sustaining endemic species, which would be threatened should the groundwater levels drop due to overabstraction, as in the case of the Grootfontein eye. The North West Department of Agriculture, Conservation and Environmental

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[95] Edgar, D. 2001. personal communication, telephonic, 3 July; Wolmarans, D. 2001. personal communication, telephonic, 5 July; Meyer, P. 2001. personal communication, telephonic, 5 July; Wessels, F. 2001. personal communication, email, 24 July.

[96] Wessels, F. 2001. personal communication, email, 24 July.

[97] Meyer, P. 2001. personal communication, telephonic, 5 July.

Affairs is involved in monitoring environmental impacts which might affect groundwater quality (e.g. the oil spill at the Eskom substation near Lichtenburg).

Of particular concern to environmental managers in the area is the fact that only one of the eyes (the Malmane eye) has any formal conservation status[98]. As unique and threatened ecosystems, the springs in the area require careful management and protection, but this has to be done in a broad sense, understanding the impacts on these habitats should water levels or water quality deteriorate.

Other challenges, from an environmental perspective, in managing groundwater, include[99]:

- high levels of water abstraction and its impact in the broader ecological context, as well as the sensitive ecosystems and habitats of springs
- the impact of large scale irrigation on water levels and soils
- the introduction of alien fauna (e.g. bass) in water systems
- the impact of alien vegetation species on the aquifer in terms of increasing water use[100]
- water quality issues, particularly relating to the high use of pesticides and fertilizers, and the lack of knowledge of the long term effects of these pollutants on water quality in the aquifer – for example, is water quality deteriorating or stabilising over time?
- the impact of mining operations around springs (e.g. peat mining near Schoonspruit and brick making around the Polfontein eye at Bodibe)
- the impact of seasonal holiday-makers at recreational sites around the eyes, particularly in terms of increased impacts on septic tanks and resultant pollution (e.g. Molopo Eye).

The North West Department of Agriculture, Conservation and Environmental Affairs currently has no active role in groundwater management, although they have sufficient capacity and would like to play a limited role in functions such as groundwater monitoring[101]. This raises the question of departmental mandates with respect to the policy of cooperative governance, which needs to be practically addressed, considering issues of capacity and resources. As an example, at least three provincial or regional departments, as well as local government, have some role to play in water quality monitoring, however, very little is currently done in this regard. These matters need to be resolved in defining the activities and resources needed for sustainable and equitable groundwater management.

Environment and conservation managers are stakeholders in groundwater use and management, and their needs, concerns and roles need to be included in a management framework.

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[98] Mangold, S. 2001, personal communication, telephonic, 26 July.

[99] Mangold, S. 2001, personal communication, telephonic, 26 July.

[100] Blue gum trees, for example, are know to use up to 220l of water per day – comparing this to basic water needs raises questions about the overall impact of alien vegetation on the aquifer and the need to increase alien clearing programmes.

[101] Mangold, S. 2001, personal communication, telephonic, 26 July.

6.7 Recreational use

Groundwater also has an important role in various recreational and tourism activities in the study area, and the needs of these users must be considered, as well as impacts resulting from these activities.

Recreational uses include:

- diving and swimming
- fishing
- camping
- bird watching, etc

The deeper springs in the area are regularly used by divers for both sport and training (particularly Wondergat and Groot Marico Eye). Small infrastructural developments have occurred around the eyes to support these activities, particularly at Wondergat, where a campsite has been established. Clearly, if water levels deteriorate, these activities will be threatened, whilst at the same time, they impact on groundwater in terms of pollution through increased sewage, run off from campsites, etc.

6.8 Emerging and small-scale water users

Discussion around the water use of small-scale and emerging water users has been separated from the sectoral discussions above. Specific attention needs to be given to involving emerging/small-scale users in water management structures. In some cases, the needs and problems characterising emerging users, across sectors, have generic trends.

The water uses of emerging and small-scale groups, for income or subsistence purposes include, amongst others:

- vegetable gardening
- stock watering
- brick making
- diamond digging
- small-scale commercial farming operations

Involving small-scale and emerging water users in the management of groundwater is a major challenge, given the lack of organisation and formal representation of these groups, but is an essential component in developing equitable management systems. In some communities, the DoA has agricultural extension offices that offer assistance and representation to emerging farmers, but they nonetheless remain a marginalized and excluded group that faces significant constraints and challenges in their activities and access to water, particularly in the context of the history of inequity and imbalances in access to water resources.

Given their lack of representation on water management structures, current patterns of inequity are likely to be perpetuated, as emerging groups' needs will not be adequately represented, for example, in terms of water allocations. The impacts of overabstraction are real threats to users whose access to water is primarily from spring flow. Overabstraction ultimately results in springs drying up, either seasonally or completely, as in the case of the Grootfontein eye. For small-scale farmers who do not have the resources that commercial users do, to pump water during dry periods, this will effectively block access to this water resource, limiting the livelihoods opportunities. However, commercial farmers do see the need to involve emerging groups, and do not believe that their usage is significant enough to pose a threat to commercial operations.

In many cases, representation of small-scale water users is through local government structures (e.g. ward councillors). However, internal politics prevent the concerns of small-scale water users from being heard, and often causes small operations to grind to a halt, through the sabotage of equipment for example (e.g. Grasfontein)[102]. Although these are internal issues, the lack of alternative representation for small-scale water users, as well as gender issues, reinforces the problem in communities.

Amongst small-scale and emerging groups, gender issues are particularly relevant in the context of access to water and levels of representation. In many cases, rural women become involved in vegetable gardening, for example, to provide food security for their households, and if possible, a small, but critical income. Access to water is vital for these activities, but particularly vulnerable when resources are limited (e.g. the ability to pump water) and women are not empowered to vocalise their needs and concerns. The important role of women in food security and providing or supplementing household incomes, and their access to water and representation, is disproportionate and needs to be addressed through groundwater management. The knock-on effects, in terms of health, empowerment, livelihoods and opportunity are considerable.

In addition, the needs and customs of tribal cultures are important in managing and accessing water, particularly with respect to the role of women in society, and the significance of cattle. The lack of access to water for stock watering in rural communities leads to conflicts with local farmers, when cattle wander into their property in search for water (e.g. Grasfontein)[103]. In some cases, cattle are confiscated, in other cases, owners have to pay a heavy fine to get their animals back. This again affects livelihoods and security.

Small-scale brick making operations are also highly dependent on access to a reliable source of water, the lack of which affects livelihoods and income, particularly when compared to the valuable and low cost opportunity for a person to take responsibility for meeting their own housing needs. There are several small groups of brick makers in Bodibe, for example. They use only locally available natural

[102] Mahlaba, F. 2001, personal communication, Grasfontein, 19 June.

[103] Milton, 2001, personal communication, Grasfontein, 19 June.

resources in making the bricks (water, clay-soil and sun), which they use to build their own structures or sell to others wanting to build or extend on their houses. Internal politics has prevented these groups from forming a co-operative organisation and thus representing their interests and needs (e.g. water).

7 MANAGEMENT CHALLENGES

The following challenges to the equitable and sustainable management of groundwater have been identified and need to be addressed in developing a management framework for groundwater.

Institutional capacity

Addressing issues of institutional capacity at every level in the management structure, from local government through regional/provincial levels to the national level, is a central factor that affects sustainable and equitable management. This is currently a significant problem and an issue that has been repeatedly raised as a challenge to groundwater management, in both existing and emerging institutions.

Questions related to cooperative governance and departmental mandates need to be practically resolved, in line with the management needs of the resource (e.g. monitoring), and the capacity and resources available to undertake these functions. Definitions of roles, functions and responsibilities need to be clarified, in the context of the available capacities and resources, and strong channels of communication for data, information and recommendations need to be established within and between the institutions.

Small-scale and emerging user groups

The lack of organisation and representation within small-scale and emerging user groups, to enable these users to articulate their needs and concerns with respect to the access to and use of water (including resources, services and benefits) and thus to participate in decision-making and management is a critical issue that needs to be considered in developing the institutional arrangements for the management of groundwater.

Compounding factors related to the capacity of this group include internal power relations, the role of women, cultural traditions and the integration of formal and informal systems. Access to water, and the ability to participate in decision-making are significant factors that affect livelihoods and development opportunities. Without the appropriate interventions, the lack of capacity within this group and the lack of involvement in formalised management structures will entrench existing patterns of imbalance, inequity and poverty.

Representation

An issue related to both of the above points, is the strength and representivity of local structures. This is particularly relevant in the context of internal conflict, where local politics and unbalanced power relations prevents the needs of marginalized groups from being articulated and addressed. Issues of culture, empowerment and vested interests prevent these groups from gaining access to resources (e.g. water) that would contribute to their livelihoods and levels of empowerment, and possibly upsetting existing power relations. Where these matters cannot be resolved internally, groups need access to representation, other than via local political structures, to enable them to address their needs, develop capacity and build empowerment.

Issues of representivity also relate to the establishment of local management structures, such as water user associations, being dominated by certain user groups. Although mention is made of the need to involve previously disadvantaged groups, and provision made in management structures for a representative, establishing these organisations without facilitating proper participation through building capacity and awareness, will simply lead to the entrenchment of existing patterns of unbalanced use and inequity. It also relates to issues of buy-in and ownership, without which excluded groups may feel their needs will be sidelined. This matter needs attention, and cannot be left as a responsibility of local users. In addition, arguing that local government representatives can serve as representatives for user groups in disadvantaged areas relates to issues of intuitional capacity and representivity, above.

Competition between water users

Competition and tensions between different user groups have been articulated, particularly between agricultural, domestic and industrial water users, and between more powerful and weaker users. Agricultural users feel municipalities over abstract, while domestic and industrial users feel the recent increase in irrigated agriculture threatens the availability of water in the aquifer. These matters need to be resolved through allocations and local management of the resource, and again, dominance of certain groups in the process, must be addressed.

Formal and informal systems of water management

In some areas, particularly in rural communities where there have not been formalised institutional structures operating, informal systems of local water management have developed. In some cases, these systems serve all members of the community adequately and equitably, while in others, they entrench unbalanced power relations to the detriment of certain groups. Often, these informal structures contain valuable resources in knowledge and skills necessary for local water management. When developing and implementing formal systems of management, due consideration must be given to identifying informal systems, and where appropriate, integrating them into the management structure of the resource.

Information about the resource

A further challenge to the management of groundwater is the lack of accurate information about the supply and functioning of the aquifer. Managers and users simply do not have the information needed to make informed decisions about groundwater, or the ability to develop this information base through monitoring. This information is essential to enable the appropriate management interventions to be made, particularly with respect to defining the reserve and the allocations available for users.

Information is also needed to understand how the aquifer will function under stress. This information is needed by managers at all levels, and should be disseminated to users, to enable them to understand the consequences of certain actions and the extent of impacts.

8 CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

Several gaps in the existing knowledge base on the users and institutions involved in groundwater have emerged. These gaps pose significant problems in developing sound institutional arrangements for the management of groundwater, which will effectively address its sustainable and equitable management. In addition, these institutions need to both bring about and accommodate change, focussing particularly on "mainstreaming the marginalized". In order to develop this institutional framework, several issues need to be resolved.

A deeper understanding of the needs and internal/informal structures of small-scale/emerging groups is needed, with particular emphasis on:

- the role and importance of water in their operations,
- problems they experience in accessing water
- how this affects their activities and livelihoods,
- the nature and structure of any management systems they employ, internal systems of organisation and channels of representation,
- internal power relations and traditions.

In addition, the relationship between access to water, livelihoods and development opportunities needs to be clearly understood in the context of the study area to inform the development of institutional arrangements and promote equity. Where are the critical areas where there are problems with access to a reliable and sufficient water supply and services to meet basic needs, and how can these be addressed through the management of groundwater? What is needed in management of groundwater address these problems?

One of the most significant knowledge gaps affecting groundwater management is the lack of information on the supply and availability of water from the aquifer. Where this information exists in research, it needs to be effectively disseminated to users/managers to enable informed decision-making and negotiations, while gaps in the scientific knowledge that affect management, must be addressed in further research. Gaps in knowledge relate particularly to the definition of the two components of the reserve of this resource, and the amount of water available for allocation to users.

There is also a lack of information on the impacts of pollution on the aquifer. The relationship between sanitation systems (e.g. pit latrines), water quality and health, is one issue, while the impact of fertilisers and pesticides on water quality, both in the short and long term, are issues that need clarification. A better understanding of the long term impacts of pollution on the aquifer is essential to informed decision-making – is the quality of the aquifer deteriorating or stabilising over time?

The implications of planning initiatives, such as the North West Spatial Development Initiative, for water demand in the area need to be clarified and addressed in the planning process. Water is a key factoring in determining economic growth in region, and development planning must take place within the context of the availability and capacity of existing water resources, while balancing the urgent need for job creation.

There is currently a lack of information on the international issues related to the dolomitic aquifer. Clarity is needed on the interaction between ground and surface water systems where international arrangements may exist, as well as the relationship between the dolomitic groundwater in South Africa, and any groundwater in Botswana.

8.2 Recommendations and research needed

There are several key issues that need to be clarified before proceeding into the field research components in Phase 2 of this project. These broadly relate to the scope of the project and the integration of this project with other water management projects underway in the study area.

In terms of scope, clarity is needed on the extent of socio-economic impacts and institutional arrangements, particularly in the context of ground/surface water interactions in this project. While the geohydrological boundaries may be clear, the socio-economic influences extend well beyond these perimeters.

This issue also relates to the need for integrated planning processes – to what extent and how should this research relate to other development planning initiatives in the area, and other water management planning processes? In terms of development planning, the preparation of water service development plans (WSDPs) form part of integrated development planning of district councils, and in this context, the local management of water resources, such as groundwater, is an issue.

Integration with other water management planning processes currently underway needs clarity. Interaction with establishment of catchment management agencies is important, but again how, and to what extent is necessary? The integration of this project with two CMA processes, at different stages of establishment, and following different approaches needs thought.

In addition, stakeholder involvement is an issue relating to the integration with other studies that needs attention. The various water management studies currently underway have lead to a degree of confusion and stakeholder fatigue. How does this groundwater project, which depends on a broad and participative process in the development and ultimate implementation of a management framework, proceed in this context?

Before proceeding with further research, these issues need to be resolved.

Thereafter, issues that require further research in the social/institutional components of this groundwater project, include:

- detailed research and analysis into the social, cultural, political and institutional interactions taking place with respect to groundwater use and management in the study area, looking particularly at:
  - issues that would facilitate or hinder the implementation of groundwater management in the area,
  - the type of groundwater management systems that would both gain support from users and managers, and promote issues of equity and sustainability
  - stakeholders' vision for groundwater use/management – whether there is a common vision, or where points of conflict may exist
- further research into the use patterns, representation, management arrangements and concerns of small-scale/emerging user groups
- how to address issues of capacity, organisation, representation, education/awareness, empowerment, etc., particularly within marginalized groups through groundwater management
- capacity building, education and awareness about the important role of groundwater in the area, and developing an understanding of the responsibilities of users in terms of new legislation
- a thorough investigation into issues of institutional capacity and resources, the roles, functions and responsibilities of different lines and levels of government, as well as departmental mandates and issues of cooperative governance, communication channels, technical assistance and information sharing between departments with respect to groundwater management
- the integration of existing formal and informal systems of groundwater management, the consideration/adaption of management arrangements proposed in other studies, with a framework appropriate in this context, that promotes sustainability and equity
- an analysis of the economic implications of proposed institutional arrangements on various user groups and economic activities
- clarification on the scope in terms of international issues

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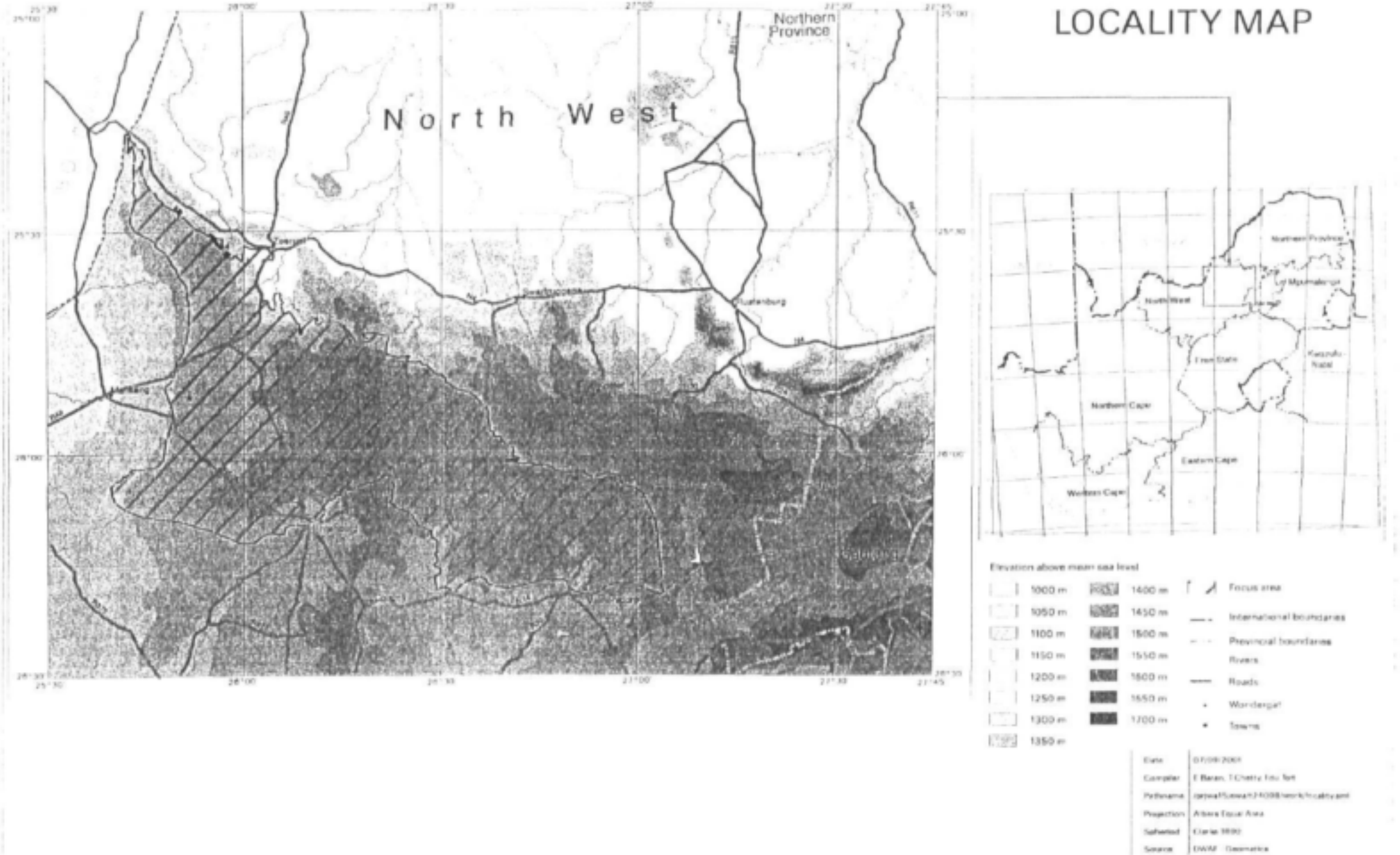
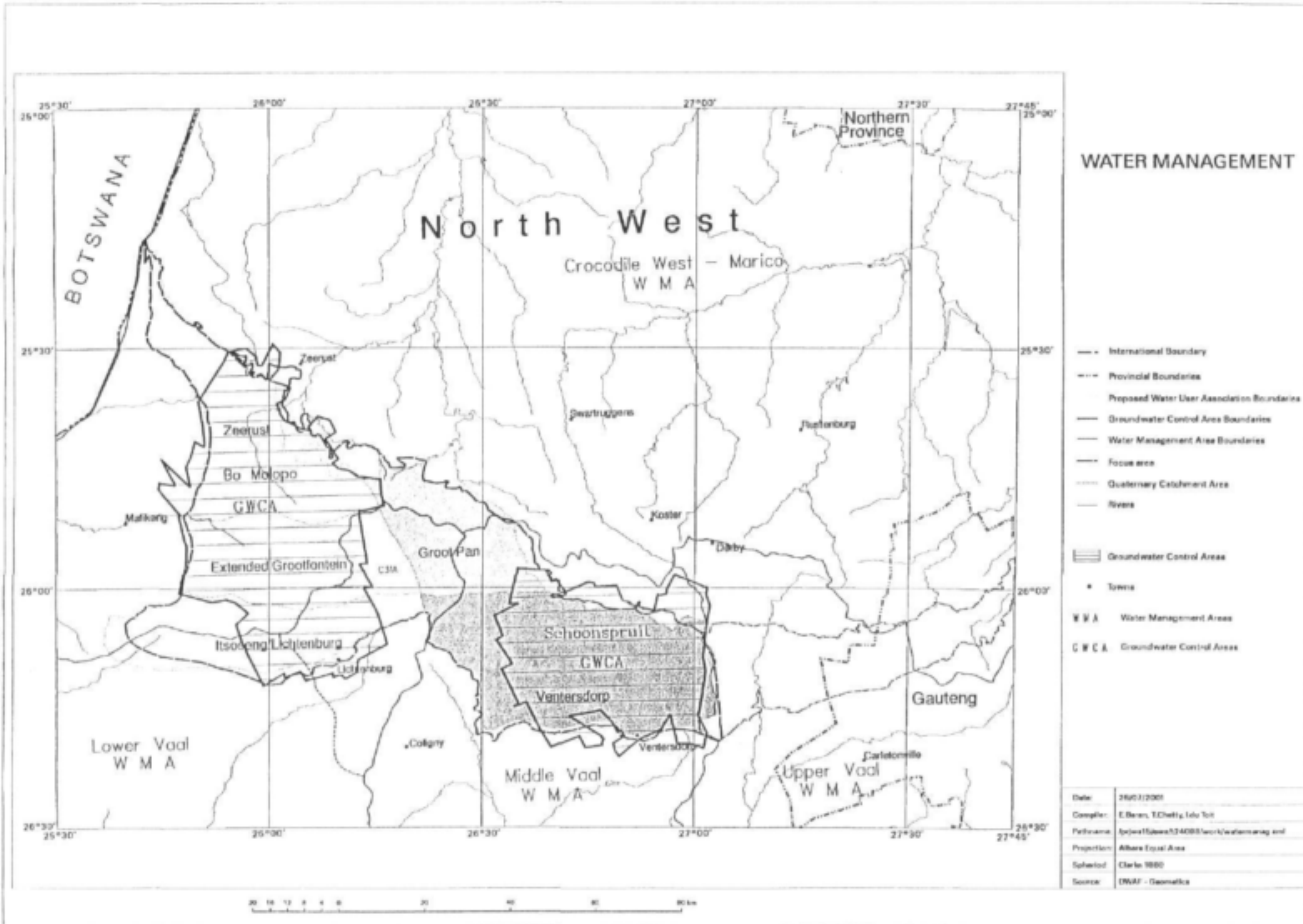
ANNEXURE A:

List of Maps

LOCALITY MAP





WATER MANAGEMENT
BOTSWANA
Northern Province
North West
Crocodile West – Marico W M A
Zeerust
Swartruggens
Rustenburg
Zeerust
Bo Molopo
GWCA
Mafikeng
Koster
Derby
Groot Pan
Extended Grootfontein
Schoonspruit
GWCA
Itsoseng/Lichtenburg
Lichtenburg
Ventersdorp
Ventersdorp
Gauteng
Coligny
Carletonville
Lower Vaal W M A
Middle Vaal W M A
Upper Vaal W M A
International Boundary
Provincial Boundaries
Proposed Water User Association Boundaries
Groundwater Control Area Boundaries
Water Management Area Boundaries
Focus area
Quaternary Catchment Area
Rivers
Groundwater Control Areas
Towns
W M A Water Management Areas
G W C A Groundwater Control Areas
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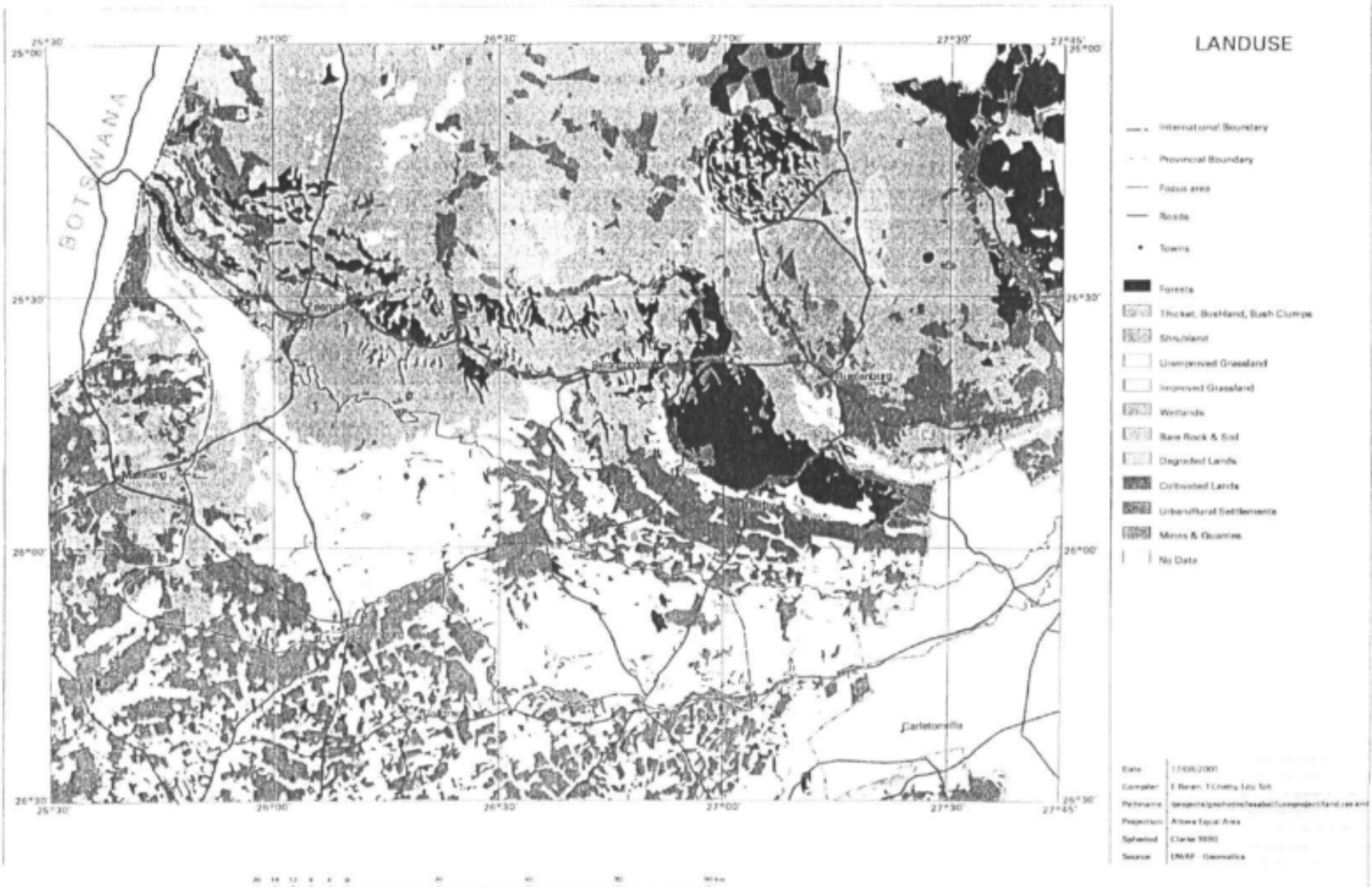
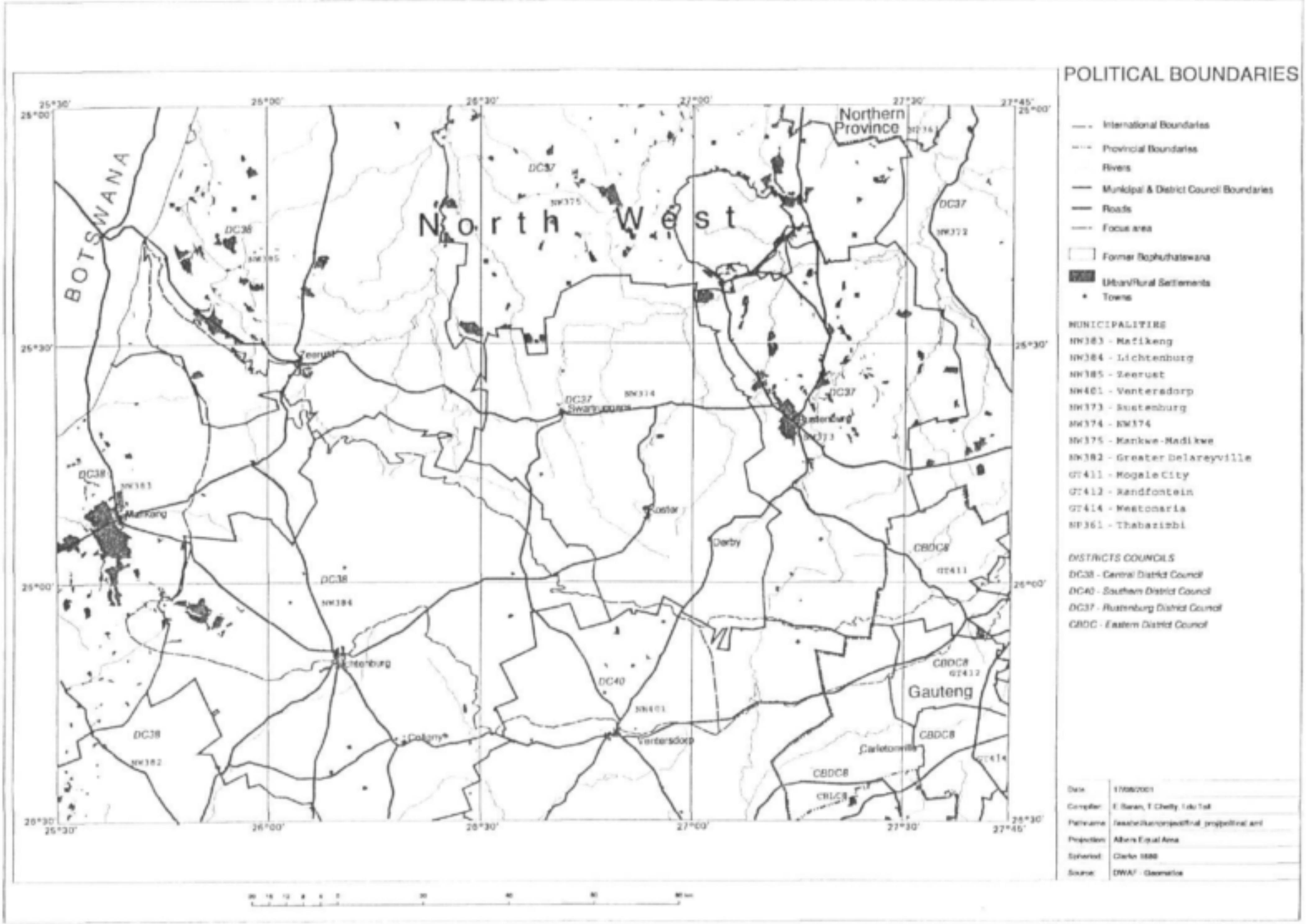
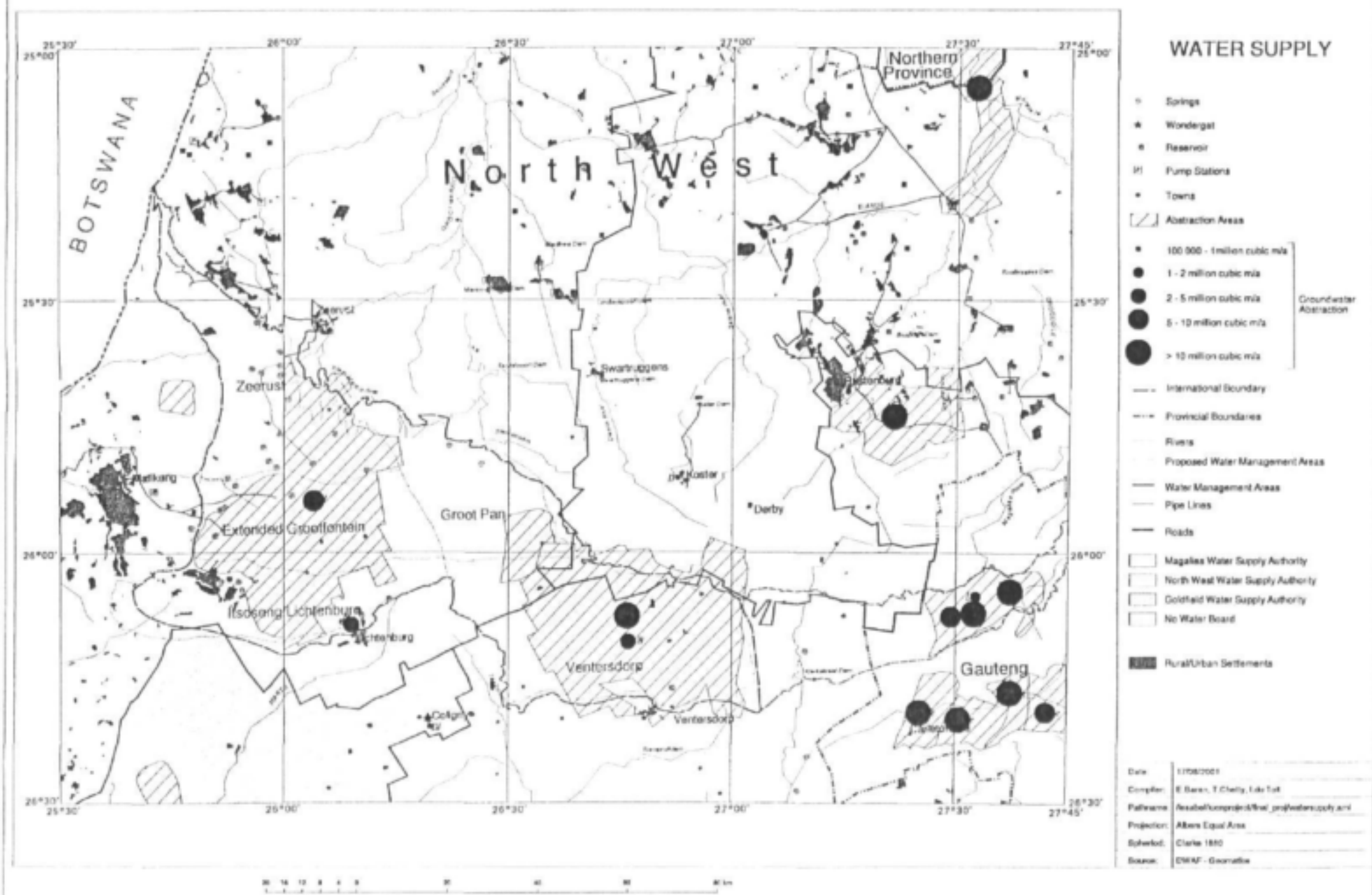
Source: DWAF - Geomatics



LANDUSE
International Boundary
Provincial Boundary
Focus area
Roads
Towns
Forests
Thicket, Bushland, Bush Clumps
Shrubland
Unimproved Grassland
Improved Grassland
Wetlands
Bare Rock & Soil
Degraded Lands
Cultivated Lands
Urban/Rural Settlements
Mines & Quarries
No Data
BOTSWANA
Carletonville
Date 17/08/2001
Projection Albers Equal Area
Spheroid Clarke 1880
Source DWAF - Geomatics


POLITICAL BOUNDARIES
International Boundaries
Provincial Boundaries
Rivers
Municipal & District Council Boundaries
Roads
Focus area
Former Bophuthatswana
Urban/Rural Settlements
Towns
MUNICIPALITIES
NW383 - Mafikeng
NW384 - Lichtenburg
NW385 - Zeerust
NW401 - Ventersdorp
NW373 - Rustenburg
NW374 - NW374
NW375 - Mankwe-Madikwe
NW382 - Greater Delareyville
GT411 - Mogale City
GT412 - Randfontein
GT414 - Westonaria
NP361 - Thabazimbi
DISTRICTS COUNCILS
DC38 - Central District Council
DC40 - Southern District Council
DC37 - Rustenburg District Council
CBDC - Eastern District Council
North West
Northern Province
BOTSWANA
Gauteng
Mafikeng
Lichtenburg
Ventersdorp
Swartruggens
Koster
Derby
Carletonville
Coligny
Date 17/08/2001
Projection Albers Equal Area
Source DWAF - Geomatics



WATER SUPPLY
Springs
Wondergat
Reservoir
Pump Stations
Towns
Abstraction Areas
100 000 - 1 million cubic m/a
1 - 2 million cubic m/a
2 - 5 million cubic m/a
5 - 10 million cubic m/a
> 10 million cubic m/a
Groundwater Abstraction
International Boundary
Provincial Boundaries
Rivers
Proposed Water Management Areas
Water Management Areas
Pipe Lines
Roads
Magalies Water Supply Authority
North West Water Supply Authority
Goldfield Water Supply Authority
No Water Board
Rural/Urban Settlements
BOTSWANA
North West
Northern Province
Gauteng
Zeerust
Mafikeng
Extended Grootfontein
Groot Pan
Itsoseng Lichtenburg
Lichtenburg
Coligny
Ventersdorp
Swartruggens
Koster
Derby
Rustenburg
Date: 17/08/2001
Compiler: E Baron, T Chetty, Lds Toit
Projection: Albers Equal Area
Spheroid: Clarke 1880
Source: DWAF - Geomatics

ANNEXURE B:

KEY INFORMANT INTERVIEWS

Phase 1: Groundwater Project – Social Assessment

CONTACT	ORGANISATION/ROLE	INTERVIEW
	Water User Associations (WUA)	
Andries Beyers	Lichtenburg/Itsoseng WUA	Yes, 21/6/01
Manfred Lohann	Grootpan WUA	Yes, 5/07/01
Dawid Kruger Hurter van Zyl	Ventersdorp WUA	Yes, 10/07/01 Yes, 19/07/01
Mr Cordier	Zeerust WUA	Yes
Theuns du Plessis	Grootfontein WUA (Bo Molopo Water Board)	No
Hendrik Smit	Grootfontein WUA (Bo Molopo Water Board)	Yes, 5/07/01
	Water Supply Authorities	
Faan van Rensburg	North West Water Supply Authority (NWWSA)	Yes, 13/07/01
	Agricultural Unions	
Andries Beyers	North West Agricultural Union	Yes, 21/6/01
Paul Greyling	Transvaal Agricultural Union	Yes, 11/07/01
?	National African Farmers' Union (NAFU)	No contact
	Consultants/research organisations	
Reinhard Meyer	Environmentek, CSIR	Yes, 10/07/01
Prof. B. de Villiers	Geology dept, Potchefstroom University	Yes, 2/07/01
Tim Hart	Resource Development Consultants	Yes, 12/07/01
Max Jordaan	Ernst and Potnes, Rustenburg	Yes, 4/07/01
	DWAF – Regional offices	
Ismaël Khumoeng	DWAF – North West	Yes, 19/06/01
Paul van der Merwe	DWAF – North West	Yes, 14/07/01
Dr Johan van der Merwe	DWAF – Free State	Yes, 20/07/01
Rens Botha	DWAF – Gauteng	Yes, 15/07/01
	NW Province	
Kelebogile Sethibelo	Dept of Economic Development and Tourism	Yes, 17/01/01
Batlang Lekalake	Dept of Land Affairs, North West	Yes, 22/07/01
Stuart Mangold	Dept of Agriculture, Conservation and Environment	Yes, 26/07/01
	DWAF Head Office	
Eddy van Wyk	Directorate: Geohydrology	Yes, 20/07/01
Eberhard Braune	Directorate: Geohydrology	Yes, 20/07/01
	Local Government	
John Mokhele	Central District Municipality	Yes, 20/06/01
Felix Labuschagne	Southern District Municipality	Yes, 4/07/01
Dirk Lombard	Engineer, Ditsobotla (Lichtenburg/Itsoseng) Local Municipality	Yes, 21/06/01
Manfred Harde	Health Inspector, Ditsobotla (Lichtenburg/Itsoseng) Local Municipality	Yes, 18/06/01
Hendrik Smit	Mafikeng Local Municipality	Yes, 4/07/01
Mr Dandashe	Engineer, Zeerust Local Municipality	Yes, 20/06/01
Mr van Niekerk	Head of Health Services, Ventersdorp Local Municipality	Yes, 3/07/01
Mr Boshoff	Treasurer, Ventersdorp Local Municipality	Yes, by fax

Mr Bester/Mr van Staden	Koster Local Municipality	Yes, 2/07/01
Mr Harmse	Town clerk, Swartruggens Local Municipality	Yes, 2/07/01
Tommy Pienaar	Coligny Local Municipality	Messages
Department of Agriculture		
Walter Viljoen	North West, Dept of Agriculture	Yes.
Priscilla Kgosi	North West, Dept of Agriculture	Fax, awaiting info.
Mr Swanepoel	North West, Dept of Agriculture	Yes, 19/07/01
Dan Thubise	North West, Dept of Agriculture (Dinokana)	Yes, 20/6/01
Industry		
Dennis Edgar	Lafarge Cement (Lichtenburg)	Yes, 3/07/07
Peter Meyer	PPC Cement (Slurry)	Yes, 5/07/01
Kostas & Dimitri Synodinos	Diamond mining operations, small scale (Grasfontein)	Yes, 19/06/01
Flip Wessels	Clover Dairy	Yes, 24/07/01
Derek Wolmarans	Alpha Cement	Yes, 5/07/01
Ward Councillors		
Councillors	Ditsobotla Municipality	Yes, 21/06/01
Other		
Charles Steyn	Grasfontein Community	Yes, 18/06/01
Irene Wapad	Grasfontein Community	Yes, 18/06/01
Setch Malebo	Grasfontein Community, pump attendant	Yes, 18/06/01
Ruth Celishane	Grasfontein Community	Yes, 19/06/01
Milton Manenza	Ward councillor, Grasfontein Community	Yes, 19/06/01
Flora Mahlaba	Grasfontein Community, women's group	Yes, 19/06/01
Alex Nqabasa	Bodibe Community	Yes, 19/06/01
Agnes Sepharaqatlha	Bodibe Community	Yes, 19/06/01
Petrus Mhlapo Petrus Matsolo	Sheila Community	Yes, 19/06/01
Sheila Water Committee	Sheila Community – water committee	Yes, 19/06/01

INSTITUTIONAL ARRANGEMENTS FOR GROUNDWATER MANAGEMENT IN DOLOMITIC TERRAINS

PHASE 1: SITUATION ANALYSIS

TECHNICAL ASSESSMENT

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Abstract:

The groundwater of the dolomitic deposits in the North–West region with an average annual recharge of about 300.10^6 m^3 and an estimated underground storage of 5000. 10^6 m^3 is a valuable natural resource supplying water to several towns, factories, villages, rural areas and agricultural activities. It also sustains the flow of several springs, wetland, river channels and is the lifeline of the associated water ecology of these water bodies. Large scale irrigation in the area has put the aquifer under additional stress to that imposed by natural fluctuations of rainfall and periodic droughts. The main objective of the investigation is to assess all the natural and antropogenic impacts on the resource within the legal requirements of a more equitable allocation of water to all consumers. Reliable assessment of the groundwater reserve is addressed that requires the integrity of the aquifer with regard to utilization and water quality to be examined. The identification of constraints and setting of resource quality objectives to be obtained , especially with regard to the ecological impact of over-exploitation of the aquifer, has also been put under scrutiny. Methodologies that could be applied to determine aquifer characteristics, recharge and simulation of impacts by means of different simulation models have been discussed. Available data from previous studies have been identified and would have to be organized and checked for reliability and stored in an appropriate database. The delineation of logical boundaries to groundwater units as areas to instigate Water User's Associations to take control of the water resource, has been addressed, as have problems that are foreseen with regard to incompatabilites between geohydrological and catchment boundaries.

1. INTRODUCTION

Resumé

Groundwater is increasingly being recognized as a national asset and strategic resource that has to be utilized, managed and controlled in accordance with the new Constitution and water rights defined in the different water acts. The main goal of water management is to obtain a balance between protection, conservation (also of ecosystems) and utilization in a sustainable manner. The development and utilization of groundwater must be addressed in a scientific, structured and controlled manner. It also requires a sound understanding of the concepts of sustainable development and integrated resource management within the legal framework.

The Water Services Act - WSA (DWAF, 1997) - and National Water Act - NWA (DWAF, 1998) - provide a combination of legal obligations, rights, responsibilities and constraints for sustainable development and management of water resources of South Africa. The aims of the NWA are directed at the protection of the resource, its effective use, development, conservation, management and control of water utilization in a sustainable manner.

The effective management and control of groundwater resources within sustainable limits, which is the ultimate objective of the study, also requires a clear understanding of the interactions and impacts induced both naturally and artificially on the groundwater systems. The reaction of the groundwater levels to the different stresses, and determination of the 'groundwater reserve', are key factors in the assessment of these impacts. A comprehensive report dealing with concepts and the assessment of the reserve of both surface and groundwater has been compiled by Braune et al. (2000) and a condensed version relating only to groundwater has been prepared by Van Tonder and Dennis (2001) (see Section 6). According to the National Water Act (1998), there are three things that rank as important when considering the amount of water that can be allocated:

- the reserve
- international obligations
- the integrity of the resource.

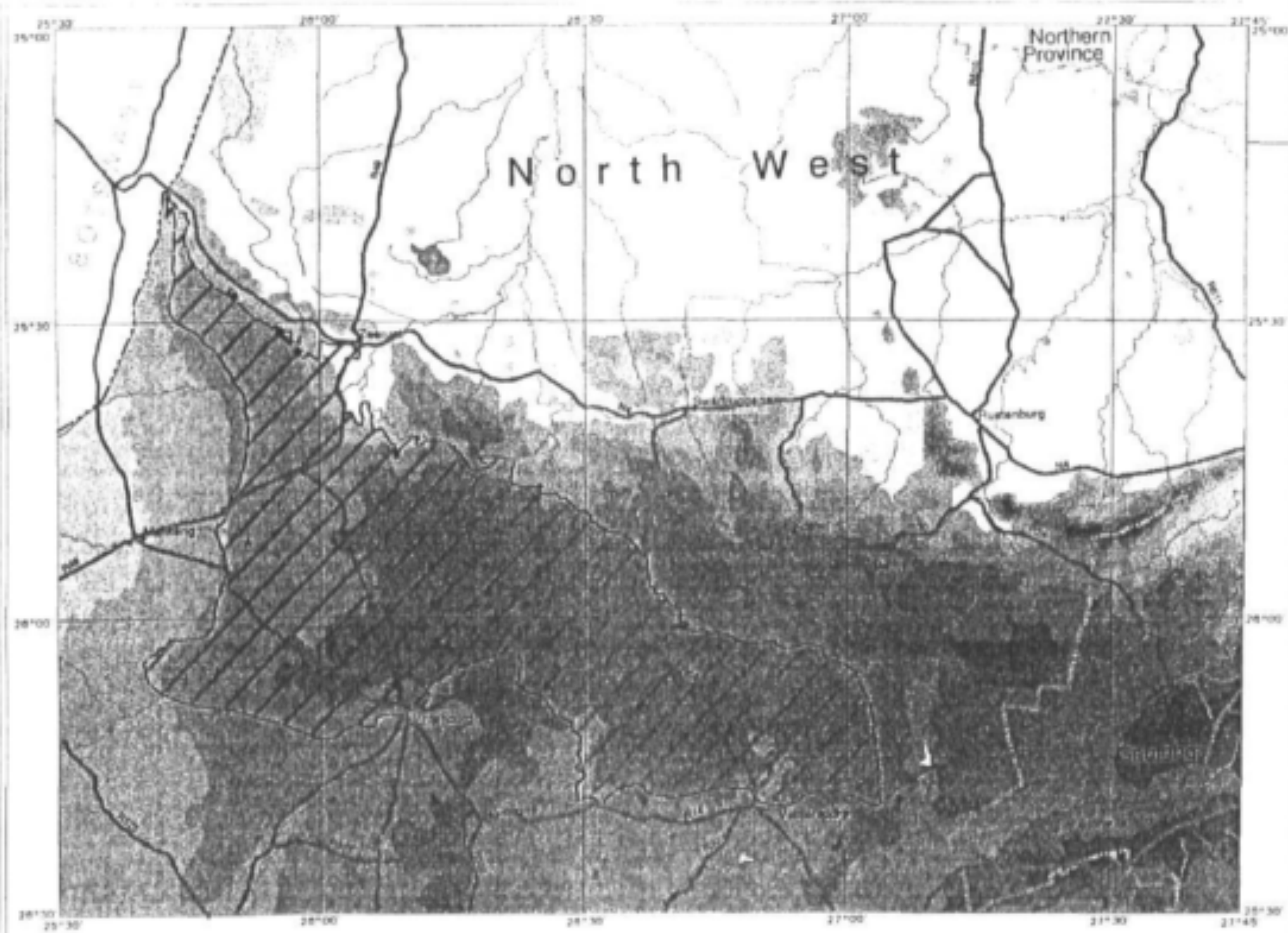
Only water which is still available after taking the above points into account can then be allocated to users.

The present project has been initiated in the light of the new legislation and constitutional responsibility of the National Government to support and augment the functions of local authorities, so as to enable them to perform their tasks effectively. This has led to a contract being awarded to the World Conservation Union (IUCN) South Africa by the Water Research Commission (WRC), in collaboration with the Department of Water Affairs and Forestry. The object is to explore the options and approaches for managing the groundwater of dolomitic aquifers of the North-West Region (see Fig. 1.1). This area has been identified as one of the most important groundwater resources supplying many towns, local communities, industries and farming activities with water.

The focus of this report is to examine the technical issues and perspectives related to effective management of groundwater resources in the region, i.e.

- the occurrence and utilization of groundwater, as well as special features and sensitivities specific to the different groundwater units;
- hydrogeological conditions, also environmental and social aspects;
- determination of excess water available for permit allocations;.
- integrated mapping of different features and aspects;
- institutional structures, arrangements and technical responsibilities to control and manage groundwater exploitation;
- identification and synthesising of technical information and methods to be used for the assessment and control of groundwater utilization; e.g.
    1. profiling of essential characteristics of groundwater aquifers e.g. aquifer recharge, storativity and transmissivity, and assessments to sustain the yields of boreholes and the utilization of the aquifers;
    2. data and technical requirements of methods that could be used to manage exploitation of groundwater resources;
    3. availability of appropriate data, and possibilities of obtaining additional data by monitoring and assessing of the impacts of groundwater exploitation on water levels, spring flows, ecological impacts, etc.;
    4. water use patterns in relation to the demographics of the area;
    5. storage of all relevant data on a suitable database, retrieval of essential administrative and technical information, and graphical displays etc.

LOCALITY MAP



Elevation above mean sea level

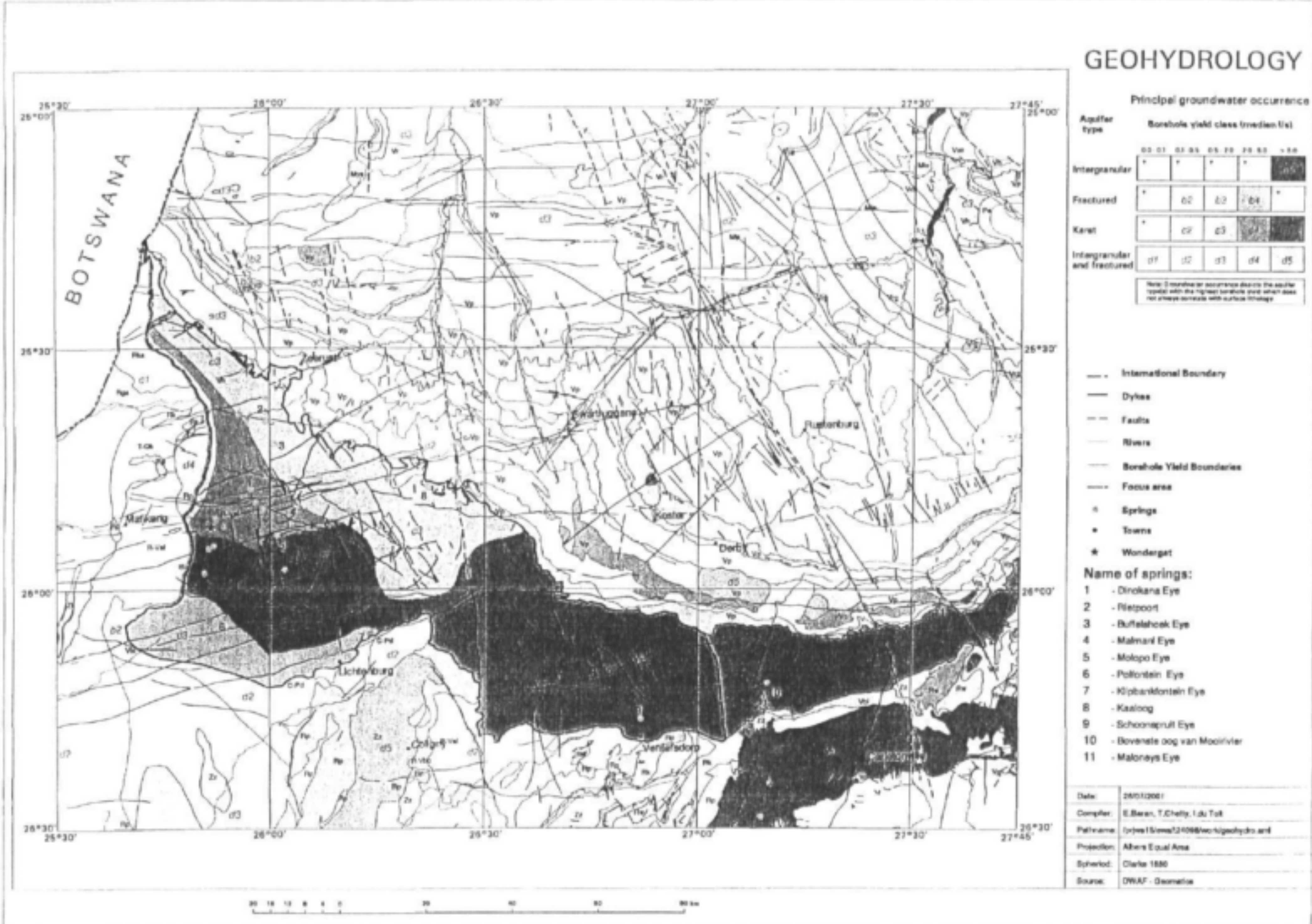
1000 m	1400 m	Focus area
1050 m	1450 m	International boundaries
1100 m	1500 m	Provincial boundaries
1150 m	1550 m	Rivers
1200 m	1600 m	Roads
1250 m	1650 m	Wondergat
1300 m	1700 m	Towns
1350 m		

Date	07/08/2001
Compiler	E Bezan, T Chetty, Mu Tot
Pathname	[illegible]
Projection	Albers Equal Area
Spheroid	Clarke 1880
Source	DWAF - Geomatics

The dolomitic formations generate little surface runoff but are capable of storing large volumes of water underground. With regard to the North-west Region included in the investigation and covering an area of about 5000 km^2, the water resources comsist almost exclusively of groundwater. Based on an estimate that 10% of the rainfall constitutes groundwater recharge, 300.10^6 m^3 is annually available in the dolomitic region. The volume of water stored within the aquifer, assuming an average aquifer thickness of 30 m and a storativity of 0,03, is 5000. 10^6 m^3 representing a capacity equivalent to 2 Vaal Dams.

The dolomite also sustains several springs that have been the only water supply for many towns and irrigation developments (see Fig. 1.2). With the introduction of more effective drilling machines and technology, high-yielding boreholes have been established and used for irrigation. Provision of electricity to farms and sprinkler systems has stimulated the expansion of irrigation, especially in the dolomitic areas of the North-west Region, to the extent that it has threatened water supplies to municipalities from springs as in the case of Mafikeng, Lichtenburg, Zeerust and Ventersdorp; all these towns depend on groundwater supplies from the dolomite.

The uncontrolled escalation of irrigation from the dolomitic aquifers could largely be attributed to the previously inadequate legislation and regulations to enforce control over groundwater development. The Bo Molopo Subterranean Groundwater Control Area has been proclaimed in phases; in each period intervening between proclamations there was an escalation of drilling activities by farmers to establish their water rights. Instigation of groundwater control, intended initially to protect the water rights of small irrigation boards, also included the water supply areas of towns such as Mafikeng, Lichtenburg and Zeerust. However in the Grootpan and Ventersdorp areas irrigation then mushroomed as indicated by the survey by Polivka of the Schoonspruit and Marico dolomitic areas (Polivka 1987a and b; Schoeman 1996). Clear evidence that the flow of the Schoonspruit eye has declined (in comparison to the natural water levels of the Wondergat) due to the irrigation expansion (see Fig.1.3) led to the proclamation of the Schoonspruit Groundwater Control Area in 1995.



GEOHYDROLOGY
Principal groundwater occurrence
Aquifer type
Borehole yield class (median l/s)
Intergranular
Fractured
Karst
Intergranular and fractured
d1
d2
d3
d4
d5
BOTSWANA
Zeerust
Mafikeng
Lichtenburg
Swartruggens
Rustenburg
Koster
Derby
Coligny
Ventersdorp
25°30'
26°00'
26°30'
27°00'
27°30'
27°45'
International Boundary
Dykes
Faults
Rivers
Borehole Yield Boundaries
Focus area
Springs
Towns
Wondergat
Name of springs:
1 - Dinokana Eye
2 - Rietpoort
3 - Buffelshoek Eye
4 - Malmani Eye
5 - Molopo Eye
6 - Polfontein Eye
7 - Klipbankfontein Eye
8 - Kaalooog
9 - Schoonspruit Eye
10 - Bovenste oog van Mooirivier
11 - Maloneys Eye
Date:
Compiler: E.Baran, T.Chetty, I.du Toit
Projection: Albers Equal Area
Spheroid: Clarke 1880
Source: DWAF - Geomatics

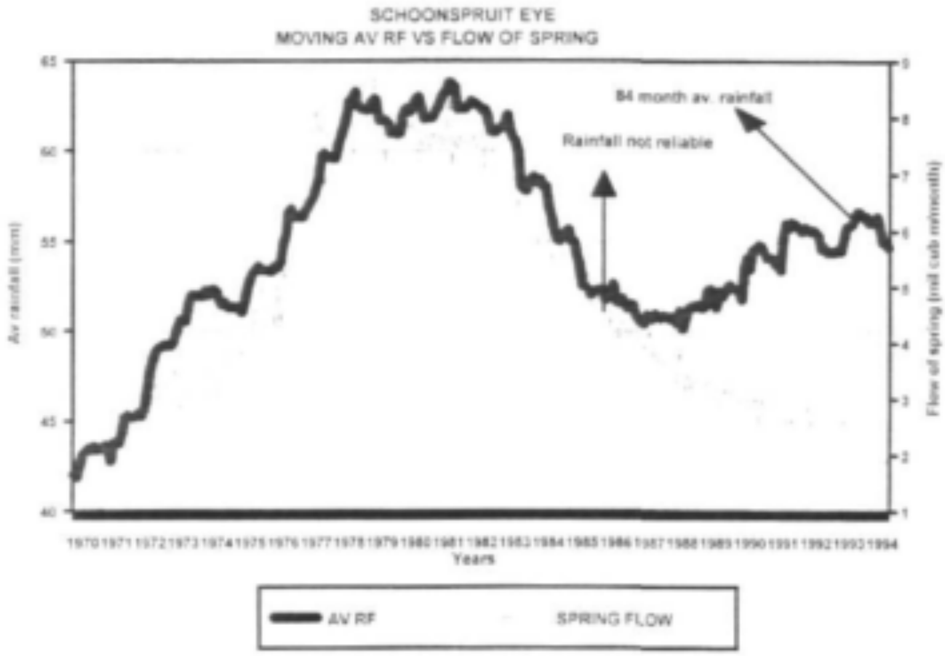


Fig. 1.3 Flow of the Schoonspruit eye relative to the moving average rainfall over 84 months, representing the natural conditions.

New legislation on water rights to secure a more equitable allocation and utilization of groundwater, came into effect in 1988 (Pietersen, 2001), changing private ownership of groundwater to public water. This has shifted the focus to the redistribution of water allocations, protection of the resources and effective management within the constraints of preferential rights to the use of water, and devolution of controlling responsibilities to the users of the water. The importance of integrated quality and quantity management of groundwater resources is widely recognized. The distinctive character of groundwater is such that a greater level of uncertainty is attached to management of these resources than is encountered in surface water.

To be specifically covered in this report are

- the sustainable development of the resource in relation to the groundwater reserve;
- the ecological importance of groundwater to springs, wetlands and aquatic fauna which are natural assets dependent on the status and management of the groundwater resources;
- threats that will affect sustainable use, and the impact of adverse changes in groundwater on the environment, e.g. deterioration of water quality.

2. INSTITUTIONAL STRUCTURES AND RESPONSIBILITIES

2.1 Introduction

In terms of the WSA the regulatory framework, institutions, their roles and responsibilities within which water services are to be provided, are specified (Pietersen, 2001) and are discussed in greater detail in the report by Stephens (2001). Control over abstractions and management of groundwater and water rights is to become the responsibility of the local communities i.e. the people utilizing the water. The methodology for the comprehensive determination of the groundwater component of the reserve of all identified areas has been targeted to be ready by January 2001 and, after verification, to be gazetted in January 2004 (Braune et al., 2000). As part of the Resource Directed Measures (RDM), the research findings of the programme K5/1007/0/1 entitled "Groundwater Reserve Determination" sponsored by the Water Research Commission (WRC) is incorporated. The Programme started on January 1st, 1999 and is due to be completed by the end of 2001.

2.2 Groundwater and management responsibilities

Delineating water management areas

The 19 catchment management areas (CMAs) proposed for the country have already been delineated by the Department of Water Affairs and Forestry (see Fig. 2.2.1). For the present study three areas are of significance i.e. Crocodile West /Marico, and the Middle and Lower Vaal. Control of the North-west dolomitic groundwater resources is to become the responsibility of Water Users Associations (WUA), and will involve groundwater matters and the management of water allocations. These WUAs are to operate within Catchment Management Agency areas (CMAs).

The WUA and CMA boundaries will not always coincide with the natural boundaries of an aquifer. However, it is still possible in most cases to compile a water balance on a catchment or subcatchment.

Fig. 2.2.1 Delineated catchment management areas (after Van Tonder and Dennis, 2001)

The area investigated falls in three main CMAs (see Fig. 2.2.2). They are

- the Middle Vaal, receiving water from the Mooi River which is fed by the Schoonspruit,
- the Lower Vaal which is fed by the Upper Hartz River;
- Crocodile West & Marico which drains water to the north, and derives some water from the headwaters of the Malmani spring.

Based on geohydrological information the study area has provisionally been subdivided into five groundwater units for which Water Users Associations may be instigated according to the Water Act (see Fig. 2.2.2). The units are the

1) Ventersdorp groundwater unit feeding the Schoonspruit eye which is the main water supply of Ventersdorp and of irrigation lower down. Large irrigation from boreholes has caused the flow of the Schoonspruit eye to diminish drastically (Bredenkamp et al. 1995, and Schoeman, 1996);
2) Grootpan unit where irrigation from groundwater has significantly expanded over the last 8-10 years, increasing concerns that it will deplete the groundwater resources of the area;
3) extended Grootfontein unit supplies Mafikeng with water from a pumping scheme at the Grootfontein eye and overflow from the Molopo eye. At the same time large abstractions for irrigation occur in this compartment. Several more

springs ooze from this unit, sustaining wetlands at the springs and down the Molopo riverbed. In this compartment a prominent sinkhole, the Wondergat occurs (see Fig. 1.2). Water level fluctuations of the sinkhole dating back to 1923 proved invaluable for assessing of the characteristics of the dolomitic aquifers and deriving reliable records of spring flows (see Section 4);

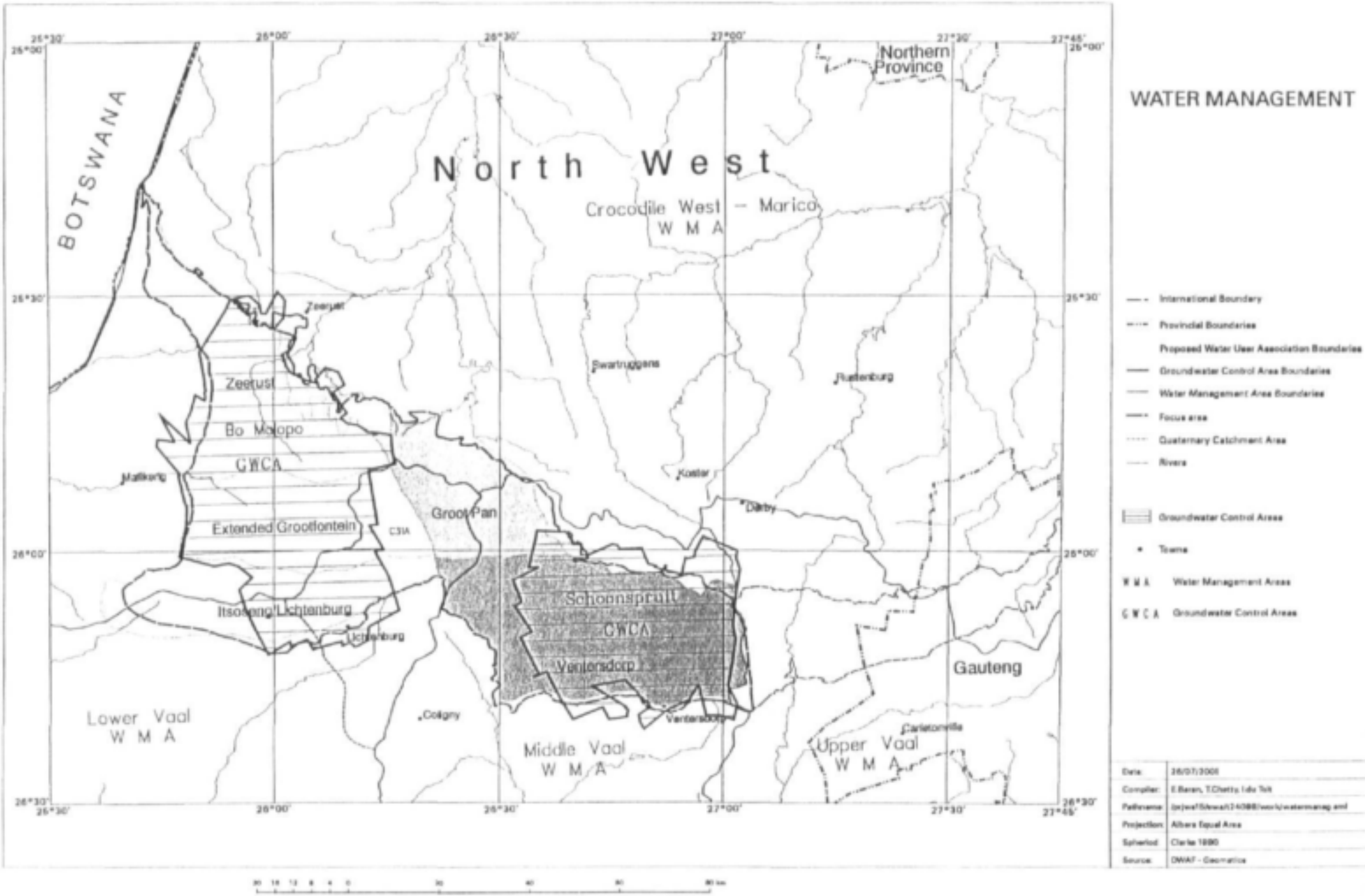
4) Zeerust groundwater unit, from which water is supplied from the Rietpoort and Doornfontein pumping schemes to the town of Zeerust; and from Dinokana eyes and a few boreholes to settlements at Dinokana-Lehurutse;

5) Lichtenburg-Itsoseng unit which supplies Lichtenburg with water, originally from springs but presently only from boreholes drilled in the dolomite. Irrigation from groundwater resources has increased over the past 10 years, but in 1983 about 580 ha had already been irrigated from boreholes. In the Itsoseng part of the unit water is supplied to the local villages, namely Sheila, Itsoseng and Polfontein informal settlements.

At this stage it is envisaged to have WUAs for each of the units, but the possibility of two or more groundwater units residing under one WUA is an option to be considered, and depends on the outcome of the present investigation.

According to the present boundaries the Grootpan unit overlaps into three CMA areas (see Fig. 2.2.2) which is undesirable as it would complicate administration, divide jurisdiction and complicate decision making. The boundaries may have to be reviewed depending on the outcome of the present investigation and should be addressed as a matter of urgency in the light of the establishment of WUAs.

A draft constitution (refer Document, 2001) for the establishment of the Lichtenburg/Itsoseng Water Users Association, the first in the area, has been prepared and is awaiting ratification. The structures within which this WUA should operate have been outlined, but need to be critically examined before the constitution is adopted for the other groundwater units e.g. the Schoonspruit Subterranean Water Control area which was proclaimed in 1995, and urgently awaits the establishment of a WUA.


WATER MANAGEMENT
BOTSWANA
North West
Northern Province
Crocodile West - Marico W M A
Zeerust
Bo Malopo CWCA
Mafikeng
Extended Grootfontein
C31A
Groot Pan
Itsoseng/Lichtenburg
Lichtenburg
Swartruggens
Rustenburg
Koster
Derby
Schoonspruit CWCA
Ventersdorp
Coligny
Gauteng
Carletonville
Lower Vaal W M A
Middle Vaal W M A
Upper Vaal W M A
International Boundary
Provincial Boundaries
Proposed Water User Association Boundaries
Groundwater Control Area Boundaries
Water Management Area Boundaries
Focus area
Quaternary Catchment Area
Rivers
Groundwater Control Areas
Towns
W M A Water Management Areas
G W C A Groundwater Control Areas
Date: 26/07/2001
Compiler:
Pathname:
Projection: Albers Equal Area
Spheroid: Clarke 1880
Source: DWAF - Geomatics

2.3 Functions and responsibilities of Water Users Associations

The functions and responsibilities of the WUAs have been examined and can be defined as follows:

1) *Setting up a comprehensive, hands-on Data Base*, that will collate all relevant geohydrological information. Large volumes of data are being stored in the National Groundwater Database (NGDB) operated and managed by the Directorate Geohydrology of DWAF. The NGDB is not sufficiently dynamic to support the functions of WUAs, especially with regard to eventual management of the aquifers. Information to be stored in the new database should be transferable to the NGDB and vice versa. A database that appears to comply with the requirements is WISH (Windows Information System for Hydrologists), which has been developed by the Institute for Groundwater Studies at the University of the Free State (IGS) with support from the WRC. Special features of the database are that it can

- accommodate all and more of the data inputs required;
- import data from and to various formats,
- store and retrieve data on project-related information;
- produce quick graphs and sophisticated charting functions;
- be integrated with GIS to produce maps of boreholes, water levels, borehole yields, abstractions, discharge of springs;
- be linked to and support a variety of Database Management Systems of which the NGDB is one which is compatible with ARC-VIEW mapping used by the DWAF.

The following are examples of information that could be produced

(i) Maps of basic information of farmland viz.

- delineated boundaries of the WUA area
- farms and registered property owners
- groundwater abstraction points
- springs and wetlands
- areas irrigated indicated by circle diameter size
- volumes of water abstracted per farm, indicated by circle area sizes.

(ii) Data base information per registered property and owner

- boreholes with details of depth, water strikes
- tested sustainable yield and date
- water levels, date of measurement
- water use, pumping installations and
- if used for irrigation the sprinkler systems, areas and crops being irrigated and seasonal plantings.

iii) Permit details and allocations are to be structured in such a way as to differentiate between the priority categories of water use, namely

- basic requirements i.e. drinking water and cattle farming, being Category 1 in the order of preference;
- municipal and industrial use, being Category 2;
- water needed to sustain the ecology and aqua-ecosystems, would probably be rated a Category 3 water use in view of the fact that basic human needs will probably always be of higher priority;
- water for irrigation is rated as Category 4 in terms of the new water legislation; However these consumers would be entitled to continue with abstractions as at the time of proclamation, but allocations would be subject to revision in terms of the bulk allocation and new priorities. It is anticipated that reviewing and issuing of new permits could be a sensitive matter if allocations are not based on a reliable estimate of the resource.
- maintaining an inventory of levies that have been paid.

All of this information along with an inventory of levies paid could be accommodated in the WISH mini database to be used by all WUAs in all areas where groundwater control and management are to be introduced.

2) *Decision-making regarding permit allocations*

Decisions concerning the division of the resource, will probably ultimately be made by a local governing authority, with due regard for the overall 'Reserve' set by the Minister on the advice of a panel of experts

In view of the control function at the CMA levels WUAs would have to be responsible for the following:

i) Consideration and adjudication of all applications for permits, which will have to be based on hydrological assessments of the exploitation potential of the resource. In this respect WUAs would have to be provided with data on the total supply for allocation as well as the groundwater reserve that is to be provided at all times. The reserve represents the water required to provide in the basic needs of all people in the area, and to sustain the ecology (see Section 6). Quantifying the reserve is still a very uncertain process and its determination is still in the research phase but certain concepts are discussed in Section 6 – specific reference being made to an excellent treatise of the reserve determination by Van Tonder and Dennis (2001).

ii) Both CMAs and WUAs would have to be well-informed of natural fluctuations in the groundwater supply due to variable rainfall, abstractions, and interactions between compartments where diabase dykes act as partial boundaries or under certain conditions as full boundaries. Understanding the groundwater interactions, and assessment of critical parameters, are crucial to the success of groundwater management, and will be discussed in more detail in Section 6 dealing with methods to assess recharge, aquifer storativity and techniques of simulating impacts on the groundwater resource.

iii) Periodic reassessment of the groundwater situation will be necessary in view of

- deterioration of the aquifer system due to droughts or over-exploitation of the resource that would occur if certain assigned limits (water levels) were to be exceeded and therefore require adjustment of permits;
- the need to verify that there is sufficient water to increase allocations, in which case permit applications should be considered according to set priorities;
- new applications for permits.

iv) Inspection and enforcement of policies and controlling measures will be needed in respect of

- drilling activities;
- testing of new boreholes and assessment of the sustainable yield;

- measurement of water abstractions and checking that meters function properly;
- monitoring of water levels and spring flows.

It is as part of all the abovementioned responsibilities and tasks that monitoring of hydrological parameters must be carried out to accumulate information on rainfall, water level fluctuations, water quality and abstraction.

3) *Liaison with Water Authorities and Stakeholders*

From time to time the WUA would have to report to and liaise with the water authorities and local interested parties regarding policy matters, the groundwater status, complaints and management issues that require a higher level of consultation. A structure within which the WUA could operate is depicted in Table 2.3.1.

Table 2.3.1 Proposed Structure within which Water Users Association will function.

WUA Steering Committee	Purpose
This committee should have restricted membership so as to be effective and should consist of representatives/delegates from - Dept. of Water Affairs Management - Catchment Management Agencies within the area. - Established Water Users Associations (WUA) - Technical Advisory Committees The members or delegates could co-opt persons acting on sub-committees of the community water supply organization and representing the demographic profile and various interests vested in the community.	- to provide a forum for discussion - to ensure consistency of policy - to deal with equitable allocations of water - to delegate authority - to ensure uniformity in the structure of levies - to be accountable to the Management of DWAF - to enforce penalties in case of non-compliance or violation of policy
WUA Management Committee Oversees and controls the management of water in each WUA area. The task and responsibilities of the WUA management has been defined in a document dealing with the establishment of the first WUA in the Bo Molopo area. (Proposal for the establishment of the Lichtenburg/Itsoseng Water Users Area)	Summary of tasks of WUA - to prevent water from being wasted - to protect the water resource - to prevent its unlawful use - to protect the water quality from deteriorating - to manage and regulate abstraction of water - to investigate and record water levels, quantities abstracted, pumping installations, and records of owners entitled to the use of groundwater - to apply penalties in cases of users not complying with permits
	Continue -

Technical Advisory Committee	Tasks
The technical aspects will form an integral part of the scientific assessment of the groundwater potential of an aquifer so as to ensure an equitable allocation of the water supply and periodic reassessment of the resource. Representation of professional staff of the Directorate Geohydrology, or an appointed consultant, is essential. In the present project IUCN will probably be assigned the task of evaluating groundwater resources, environmental impacts, sustainability of resources. This will be performed under guidance of the Project Steering Committee to be established by the WRC after approval of the inception report.	- to guide the evaluation of all geohydrological aspects related to the assessment of the aquifer characteristics, and determination of the exploitation potential taking full cognizance of the environmental and other impacts. A consultant could be appointed to carry out a full geohydrological study; - to resolve technical issues in disputes over water allocation and adjustments; - to provide professional guidance on the assessment of the water resources and control measures to be implemented.

2.4 Geohydrological information

Irrespective of the institutional set-up that is to be established, all interested groups require a good understanding of the physical nature of the resource, its general characteristics, and constraints limiting effective utilization of the resource.

Previous geohydrological and supplementary geophysical investigations supported by monitoring activities have provided much information on the dolomitic aquifers of the North-west Region. The Grootfontein and surrounding area has been the main focus of several groundwater studies (see references [1-2, 4-13, 15-18., 23, 28-30, 32-35, 38, 44-47]) aimed at refining techniques and developing new methods for reliable assessment of a groundwater resource. In addition, dynamic modelling has been applied to the Grootfontein aquifer with the view to simulating different management options that incorporate assessments of:

- recharge, which could be highly variable;
- rates of abstraction if not already measured;
- drawdown of water levels and ascertaining if water levels have been affected by pumping;
- the role of dykes acting as partial boundaries to groundwater flow, that could result in parts of the aquifer becoming hydraulically isolated from regional flow. Such isolation is rather theoretical and would have to be investigated by modelling and a certain degree of over-exploitation of the aquifer.

With the view to modelling the resource to test different scenarios of recharge and abstraction, the flow dynamics of the entire dolomitic regions under investigation is to be incorporated in an overall model in Phase 2 of the project. Although a model on such a large scale would sacrifice resolution within smaller compartments, the main objective would be to reduce uncertainties regarding the flow between sub-units and to address the total water balance. If necessary the selected groundwater units could at a later stage be simulated individually.

3. DOLOMITIC GROUNDWATER RESOURCES OF THE NORTH-WEST REGION

As indicated the dolomitic aquifers of the North-west Region contain large volumes of groundwater and constitute valuable natural assets that have to be utilized and managed responsibly.

3.1 Location of the study area

The area covered by the project comprises dolomitic depositions extending from Ventersdorp in the east, past Lichtenburg and Zeerust to the boundary of Botswana in the west (see Fig. 1.2). It covers an area of about 5000 km^2. Due to the virtual absence of surface water in the area, the dolomitic groundwater is the sole supply of water to most municipalities as well as to cement factories, local industries and large-scale irrigation. It also provides drinking water to inhabitants of rural areas and livestock farmers. Some of the springs/wetlands are ecologically sensitive areas where unique aqua-ecological habitats for fish and plants have been established.

3.2 Topography and drainage

The project area forms part of the highlands of the North-west Region with elevations ranging from 1600 mamsl in the north-east to less than 1430 mamsl in the west. The terrain is generally flat, with inconspicuous drainage valleys. Topographical lows next to diabase dyke or formation contacts often form points of outflow of springs. From the east westwards the topography rises gently to the top of the drainage areas where the three CMA boundaries meet in the central area of the Grootpan unit (see Fig. 1.2). The transition from the dolomite to the Black Reef Formation constitutes a flat relief but coincides with large deposits of limestone.

A major N-S fault also runs though the CMA intersection point, from where the topographical drainage is south-westwards to in the direction of Lichtenburg, northwards as part of the Marico catchment and south-eastwards towards Ventersdorp. The extended Grootfontein compartment falls largely in the Crocodile-West catchment but part of it extends into the proposed Lichtenburg/Itsoseng unit which is part of the Lower Vaal CMA. The Zeerust groundwater unit slopes to the north until reaching the hilly banded-ironstone formations bordering the dolomite in the region of Dinokana; further to the east the escarp marks the presence of formations of the Transvaal Sequence. Over the rest of the dolomite south of Dinokana the topography is almost flat and featureless up to the Botswana border. In the central area between Ventersdorp – Grootpan and Lichtenburg the flat relief is occasionally broken by shallow circular and linear depressions with broad hillocks. Some depressions form pans that occasionally fill with water.

The area is virtually devoid of surface drainage channels except

- in the upper reaches of the Marico River where the valley extends into the dolomite to form a swampy vlei area that is the natural outflow of the Marico (Kaaloog) spring;
- in the central area where the riverbed of the Molopo drains to the west; it is fed from springs, as well as by runoff during periods of high rainfall;
- east of the Molopo where the Malmani River drains to the north. It has perennial flow supplied from springs and base flow seepage. During the period 1978-1981 large volumes of water were contributed to the Marico River and the Crocodile River, mainly as base flow contributions from the groundwater reservoirs;
- for the dry Molopo riverbed which during recent times has only carried water in 1980-81 after the exceptional high rainfall of 1975-1980;
- for the Polfontein spruit which drains excess water from the Polfontein eye to the west.

The boundaries of the surface drainage catchments of the central dolomitic region have been drawn according to topographical elevations on an essentially flat terrain. As is indicated by Fig. 2.2.2 the boundaries in the central area do not correspond to the geohydrological boundaries of the groundwater units, which coincide with diabase dykes. A decision is pending as to whether the surface catchment boundaries should be depicted as coinciding with the dykes that form the subsurface boundaries. A decision can only be reached once the present study has been completed and the different flow patterns have been established by reliable groundwater contours, which will enable the subsurface drainage to be compared with the surface topography. By means of a dynamic flow model the impact of abstraction on the flow regimes would be revealed; only then can decisions on the boundaries be made.

Several perennial springs and others with intermittent flow issue from the dolomitic rock (see Fig. 1.2). The larger springs such as the Grootfontein eye, Molopo eye, Rietpoort eye, Lichtenburg eye, Polfontein and Schoonspruit eye, supply water to local townships. The springs and wetlands in the vicinity of the discharge points are environmentally sensitive and vulnerable to exploitation of dolomitic water. The relationship between rainfall, the flow of springs and groundwater levels will be examined in Section 6.2.

3.3 Climate and vegetation

The area of investigation falls within the northern steppe of Southern Africa. Precipitation occurs principally from thunderstorms in summer and autumn. The mean annual rainfall of the western area is about 560 mm while the eastern area receives on average 600 mm. The seasonal and annual variability of the rainfall is manifested by corresponding fluctuations of the groundwater levels, as is revealed by the Wondergat, a prominent sinkhole in the area (see Fig. 3.3.1).

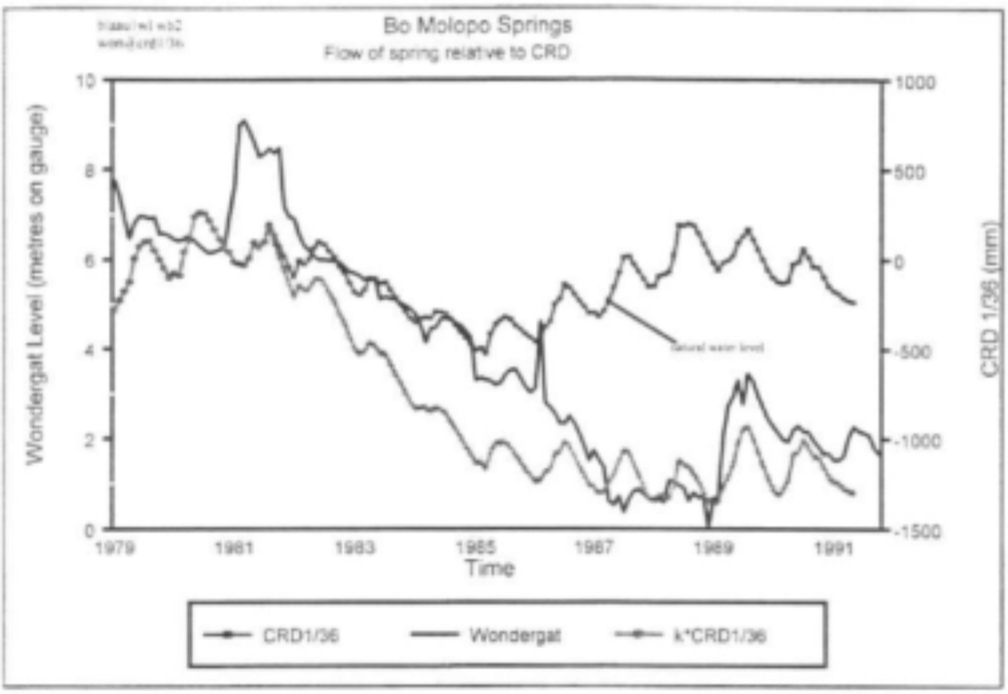


Fig. 3.3.1 Fluctuations of the water levels of the Wondergat showing measured values and corrected values after removal of the effect of abstraction.

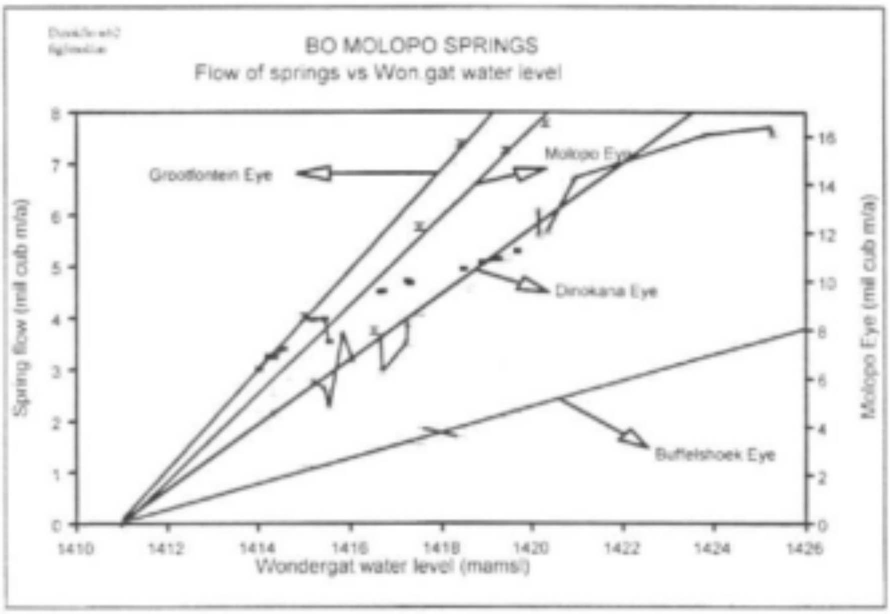
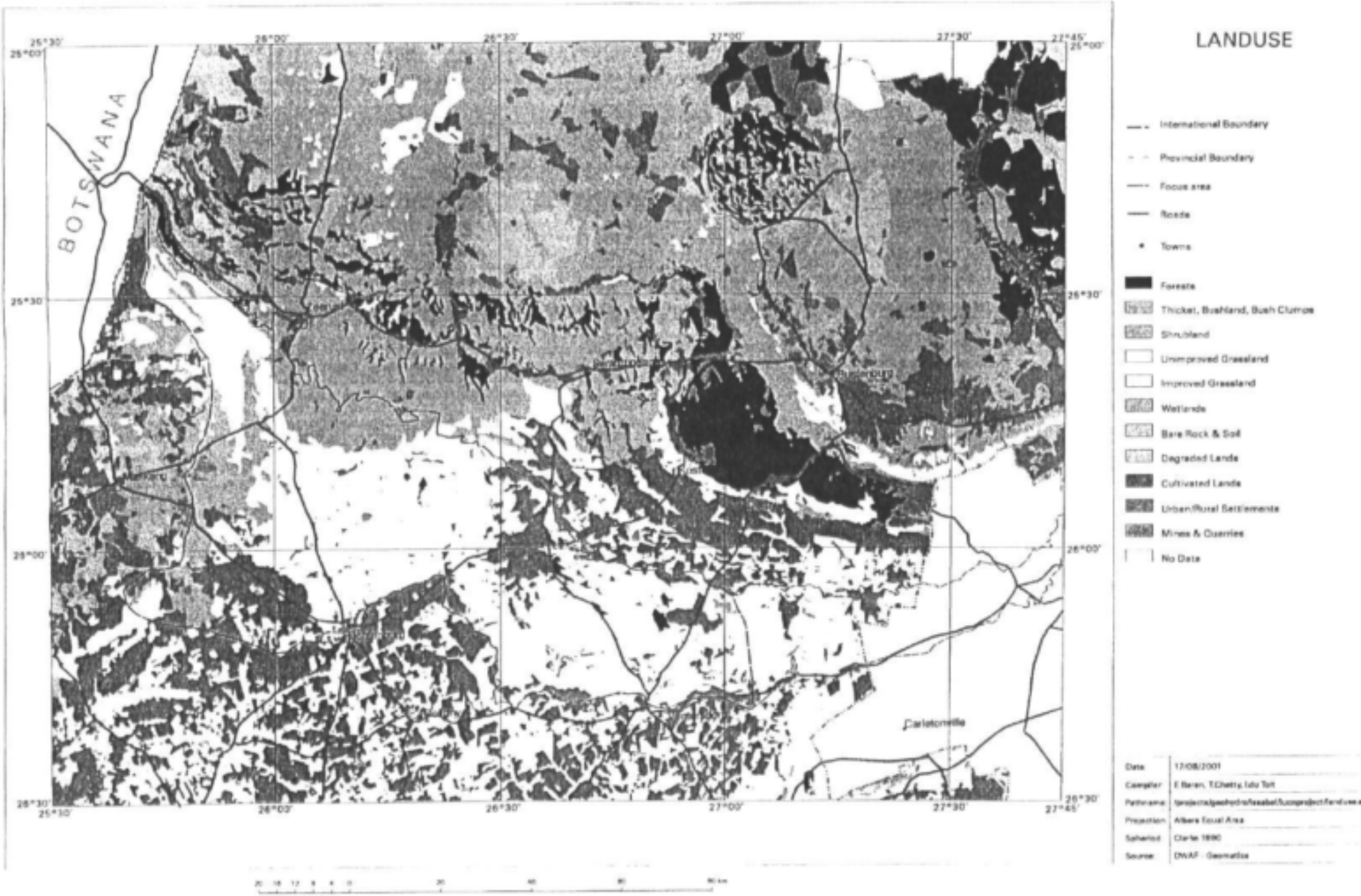


Fig. 3.3.2 Flow of springs in the Bo Molopo dolomitic area relative to the water levels of the Wondergat.

As will be indicated in Section 6.2 the cumulative departures of rainfall from the long-term average (CRD) mimic the groundwater levels quite well. Similarly the moving average rainfall over several years (MA) also corresponds to the groundwater level fluctuations. Both relationships provide a method to simulate from rainfall data the natural response of the groundwater levels. These relationships representing a simple conceptual approach have proved to be of great value in assessing the impact of pumping on groundwater levels, which in turn affects the flow of springs and causes wetlands to dry up (Bredenkamp et al., 1995). In this respect a useful relationship between the flow of springs and the water level of the Wondergat has been established, indicating that all springs in the area would stop flowing if the water level of the Wondergat were to decline to a level of 1411 mamsl (see Fig. 3.3.2). As is indicated in Section 6 this could provide a basis to help determine the reserve and to quantify the impact of diminishing water levels on the wetland ecology and the flow of springs.

The potential evapotranspiration in the area is about 2100 mm/annum and exceeds the average annual precipitation by a factor 3,5. However the actual evapotranspiration is much lower as the shallow soil cover limits availability of moisture to the plants. This at times causes excess soil water to infiltrate below the root zone, and recharge the groundwater reservoir. An analysis of the chloride profiles has revealed that recharge could still be significant even in areas covered by thick layers of clayey soils, (Bredenkamp, 1993).

The natural vegetation in large parts of the area is grassveld reasonably covered by trees in some areas in the vicinity of the Upper Molopo and Malmani Rivers. Lineations of trees are often associated with geological dykes. In large areas where good soils of reasonable depth cover the dolomite, cultivated crops such as maize, sorghum and sunflower have replaced the natural vegetation. With the advent of electricity, irrigation from groundwater has escalated appreciably. Water from springs is used to irrigate smaller patches of arable land to grow maize, wheat and occasionally also vegetables and lucerne. Areas with natural vegetation and arable land are shown in Fig. 3.3.3. The full extent of irrigation still has to be established from agricultural surveys or by remote sensing, although fairly good estimates have been obtained from previous geohydrological studies e.g. of the Grootfontein area, and the Grootpan and Ventersdorp units, conducted after the proclamation of groundwater control areas. For all groundwater units except the Ventersdorp one, these surveys have to be updated as new irrigation has been established. In the Zeerust area the irrigation from boreholes is rather small. For most of the groundwater units a reasonable estimate of the volumes of water abstracted for irrigation could be inferred from data on the electricity consumption of



LANDUSE
International Boundary
Provincial Boundary
Focus area
Roads
Towns
Forests
Thicket, Bushland, Bush Clumps
Shrubland
Unimproved Grassland
Improved Grassland
Wetlands
Bare Rock & Soil
Degraded Lands
Cultivated Lands
Urban/Rural Settlements
Mines & Quarries
No Data
BOTSWANA
Carletonville
25°30'
26°00'
26°30'
27°00'
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27°45'
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Date
17/08/2001
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Projection
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Spheroid
Clarke 1880
Source
DWAF - Geomatics

installations, obtainable from ESCOM with approval of the owners, as had been done for the Grootfontein compartment (Van Rensburg, 1987).

3.4 Geology

The geology of the area under investigation is the key to the occurrence/flow of groundwater and has been the basis of the subdivision into compartments, as well as the delineation of groundwater units that are to be managed and controlled. Fig 3.4.1 shows the geology of the area of investigation.

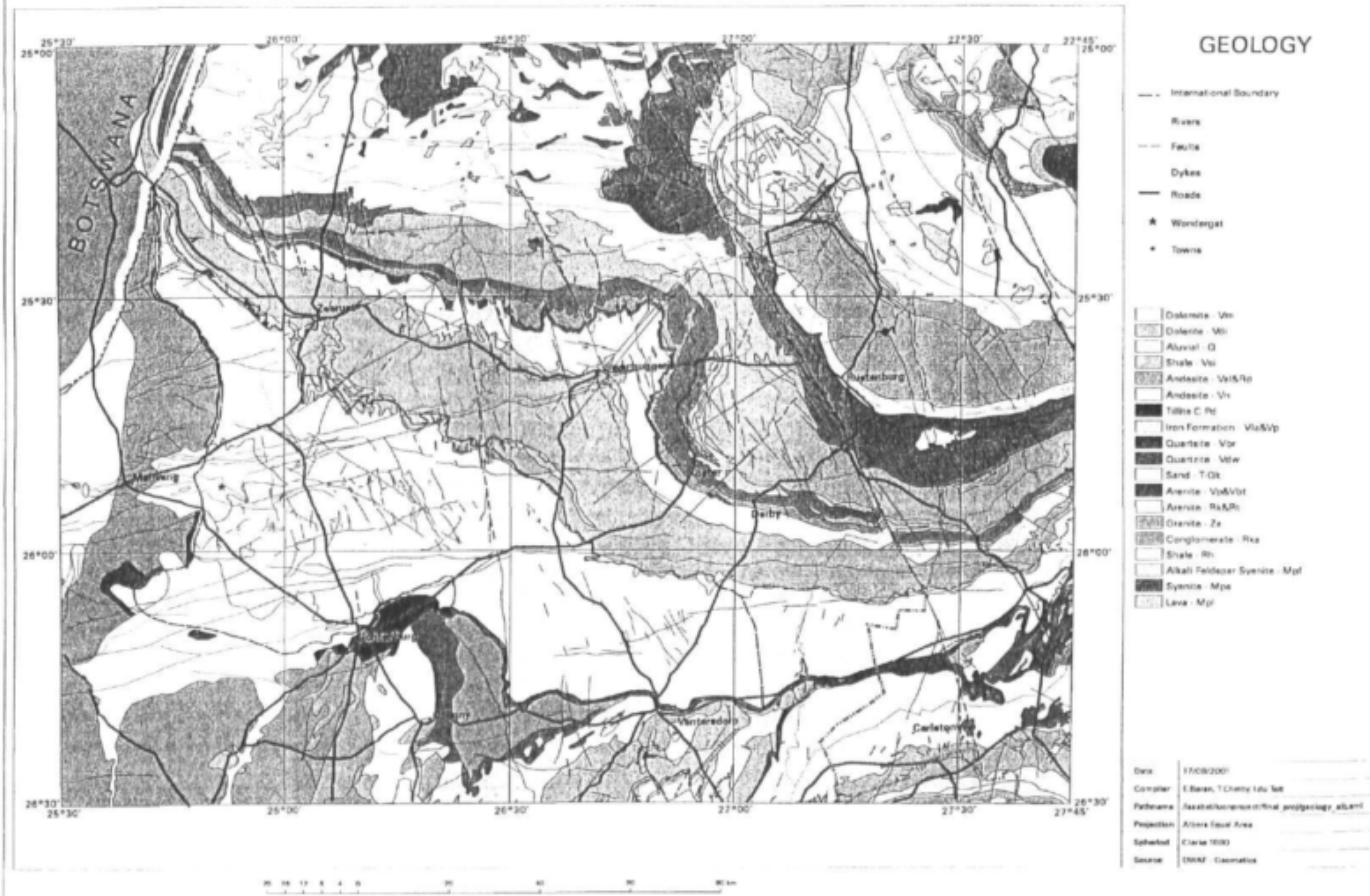
Dolomite Formations

Dolomite is the product of depositioning of calcium and magnesium carbonate in a vast basin on the Kaap–Vaal granite craton about 2300 million years ago. The lithostratigraphy of the geological sequence shown in Fig. 3.4.2 indicates that the dolomite is first of all a member of the Chuniespoort group, which in turn is part of the Transvaal Sequence.

System/ Erathem	SEQUENCE	GROUP	FORMATION		LITHOLOGY AND MEMBER	THICKNESS (m)
PERMO-CARBONIFEROUS	KAROO	ECCA			Sandstone Mudstone Carbonaceous shale, coal	
			DWYKA		Diamictite	
PROTEROZOIC	TRANSVAAL	PRETORIA	TIMEBALL HILL		Shale Diamictite Klapperkop Quartzite Mb wacke and ferruginous quartzite Graphitic and silty shale	270 - 660
			ROOIHOOGTE		Quartzite Shale Bevets Conglomerate Member Breccia	10 - 150
		CHUNIESPOORT	ECCLES		Chert-rich dolomite with large and small stromatolites	380
			LYTTELTON		Dark chert-free dolomite with large elongated stromatolitic mounds	150
			MONTE CHRISTO		Light coloured recrystallised dolomite with abundant chert, stromatolitic, basal part oolitic	700
			OAKTREE		Dolomite, becoming darker upwards Chocolate-coloured weathering	200
			BLACK REEF QUARTZITE		Shale Quartzite Arkosic grit	25 - 30

Fig. 3.4.2 Lithostratigraphy of the geology of the area of investigation in the North-west Region

The dolomite rests on the Black Reef (quartzite and shale) that forms the base, upon which alternating layers of dolomite of different chert content have been deposited in the course of geological times. The succession of dolomitic formations from the Black Reef upwards



GEOLOGY
BOTSWANA
Rustenburg
Derby
Ventersdorp
Carletonville
International Boundary
Rivers
Faults
Dykes
Roads
Wondergat
Towns
Dolomite - Vm
Dolerite - Vdi
Alluvial - Q
Shale - Vsi
Andesite - Val&Rd
Andesite - Vn
Tillite C Pd
Iron Formation - Vla&Vp
Quartzite - Vbr
Quartzite - Vdw
Sand - T-Qk
Arenite - Vp&Vbt
Arenite - Rs&Rh
Granite - Za
Conglomerate - Rka
Shale - Rh
Alkali Feldspar Syenite - Mpf
Syenite - Mps
Lava - Mpl
Date 17/08/2001
Projection Albers Equal Area
Spheroid Clarke 1880
Source DWAF - Geomatics

comprises 1) the Oaktree Formation (chert-poor) followed by the Monte Christo Formation (chert-rich), which is overlain by the Lyttelton Formation (chert-poor) followed the Eccles Formation (chert-rich). In the Zeerust area two more formations lie on top of the Eccles, viz. the Penge and Frisco Formations which are transitional to the Transvaal Sequence that has been deposited on top of the dolomite. Clays and mudstone of the Karoo Sequence occur south of the dolomite outcrop, and in some deep depressions in the dolomite kaolinitic clay and mudstones have been deposited, e.g. in the Pienaar's Pothole near Lichtenburg and one close to the northern border of the farm Grootfontein. These potholes are probably large depressions or sinkholes similar to the Wondergat, which have been infilled over geological times.

Tertiary deposits

Superficial deposits, over 20 m thick in places, overlie much of the dolomite and cover the underlying formations. The major deposits are

- alluvial gravel – usually very clayey and where it is thick it is usually ascribed to solution of the dolomite underneath (after Taylor 1983);
- calcrete over 20 m thick, which occurs largely on the southern and western rim of the dolomite, and is used in the manufacture of cement;
- alluvium consisting of black organic clay derived from decomposed reed beds, often compressed to peat, and occurring near springs and seepage along stream courses. These areas would be vulnerable in cases of depletion of groundwater by excessive pumping;
- residual chert and red soil which cover large parts of the area and has been mapped in some areas as part of previous geohydrological studies. The areas of good soil are presently cultivated, a relatively small portion being irrigated thus far (see Fig. 3.3.3).

The Black Reef Formation outcrops along the southern and western boundary of the dolomite and dips with the rest of the dolomite to the north and east, causing the different dolomitic formations to outcrop over large areas, as is indicated by Fig. 3.4.1. The thickness of the layers of dolomite increases to the north, reaching a maximum under the Transvaal Sequence (as shown in Fig. 3.4.2).

Dykes

A distinctive feature of the dolomite formations of the RSA, and differing from similar formations elsewhere in the world, is the network of diabase dykes which has intruded the dolomite during different periods of intrusion of magma from the deeper layers of the earth. These dykes subdivide the dolomite into smaller compartments and because of their lower permeability the dykes act as partial barriers to groundwater drainage from areas of higher water levels. According to fairly extensive drilling carried out in the Lichtenburg area (Taylor, 1983), the dykes are mostly vertical and between 8 – 30 m wide.

The extent of the dyke intrusions can also be seen in Fig. 3.5.1, likewise the network of compartments of different sizes that have been formed. Closer to the surface the dykes are weathered and allow groundwater to overflow from higher to lower-lying compartments. Although at greater depths the dykes are essentially impermeable, they could still be fractured in places due to dislocation and tectonic movement. Therefore the dykes impede rather than stop trans-compartmental flow of groundwater that otherwise would have been large through highly transmissive cavernous dolomite. In the light of these features the flow characteristics within the main dolomitic aquifer needs to be addressed in more detail by means of a conceptual model, as it would have a strong influence on the management of the water resource. This will be addressed later.

Often a zone close to the contact between the dolomite and an igneous dyke is a preferential area of water infiltration and high permeability. Boreholes of high yields could be drilled in these zones (Taylor, 1983). The dykes also play a prominent role in the occurrence of springs, being points of overflow of surplus water from one compartment to lower-lying ones. The occurrence of some springs is also associated with the contact zone between different dolomite formations (Oaktree - Monte Christo e.g. Grootfontein eye and Lyttelton – Eccles e.g. Buffelshoek, Molopo and Doornfontein eyes). A large number of springs also emanate along the perimeter of the dolomite, where the thickness tapers out, causing the transmissivity to decrease and water levels to rise until outflow in the form of a spring occurs. Typical examples of the latter type are the Grootfontein, Polfontein, Lichtenburg and Schoonspruit eyes.

3.5 Geohydrology

General

Dissolution of the calcium and magnesium carbonate by rain over many years has transformed the dolomite into aquifers capable of storing large quantities of groundwater. The occurrence of groundwater in relation to the geology is very similar in all five of the groundwater units. The dissolution process in the dolomite, called karstification, has been more active in the chert-rich dolomite because of more frequent infiltration of rainfall to deeper levels along chert fissures and facies. Along the dykes the contacts represent zones of high transmissivity that act as zones of preferential flow often feeding the springs e.g. Doornfontein in the Zeerust dolomite. For this reason the Monte Christo and Eccles Formations are the most productive aquifers because of high recharge, large storage and their capability of sustaining high rates of abstraction from boreholes drilled into deep cavernous or fractured dolomite.

The geohydrology of the area has been derived from several studies and surveys that have been carried out in the area (see Annexure 1). Components that are important to the effective management of the groundwater are

- the occurrence of groundwater and yields of boreholes in the different formations, and in relation to dykes, and subdivision of the dolomite into different compartments;
- recharge to the aquifer and the flow of springs in relation to rainfall;
- the sustainability of pumping rates from boreholes that are critical to the supply of water to local communities;
- determination of the reserve and the impact of abstraction on aquatic ecosystems.

Boreholes with high yields are usually found in the chert-rich Monte Christo and Eccles formations

Groundwater recharge and aquifer storativity

Recharge of the groundwater is of critical importance to the long-term exploitation of the resource in compliance with the reserve, but is difficult to determine reliably because the variability of recharge, abstraction, evapotranspiration and lateral flow all simultaneously affect the groundwater level response.

An EXCEL-spreadsheet program RECHARGE (Van Tonder and Xu, 2000) can be used to determine the nett groundwater recharge. RECHARGE can be used for different methods including the Chloride method, Saturated Volume Fluctuation method (Van Tonder, 1989), Cumulative Rainfall Departure method (Wenzel, 1936; Temperley, 1980; Bredenkamp et al., 1995), Isotopes method, and Series of qualified guess methods.

To derive lumped estimates of recharge from water balance studies, simplifying assumptions must be made. For example, recharge is equal to the abstraction during periods of equal volume and could be related to the corresponding rainfall. Storativity is usually determined by means of pumping tests that have proved not to be representative of a fractured/cavernous aquifer such as the dolomite (Bredenkamp et al., 1991). Special interpretations of the groundwater balance, however, allow the storativity of the aquifer to be determined.

Recharge has also been derived from the chloride concentrations of the rainfall relative to that of the spring water (chloride method) or from the average flow of a spring in relation to the recharge area (Bredenkamp et al., 1995). By means of the linear relationship between the flow of springs in relation to the Wondergat, a complete series of monthly flows could be simulated from 1923 to the present time.

Groundwater levels

Groundwater level monitoring points were established in the course of geohydrological studies carried out in the different areas. The distribution of the monitoring stations is indicated in Fig. 3.5.1, and water level observations have been interpreted in different ways to obtain the characteristics of the aquifers.

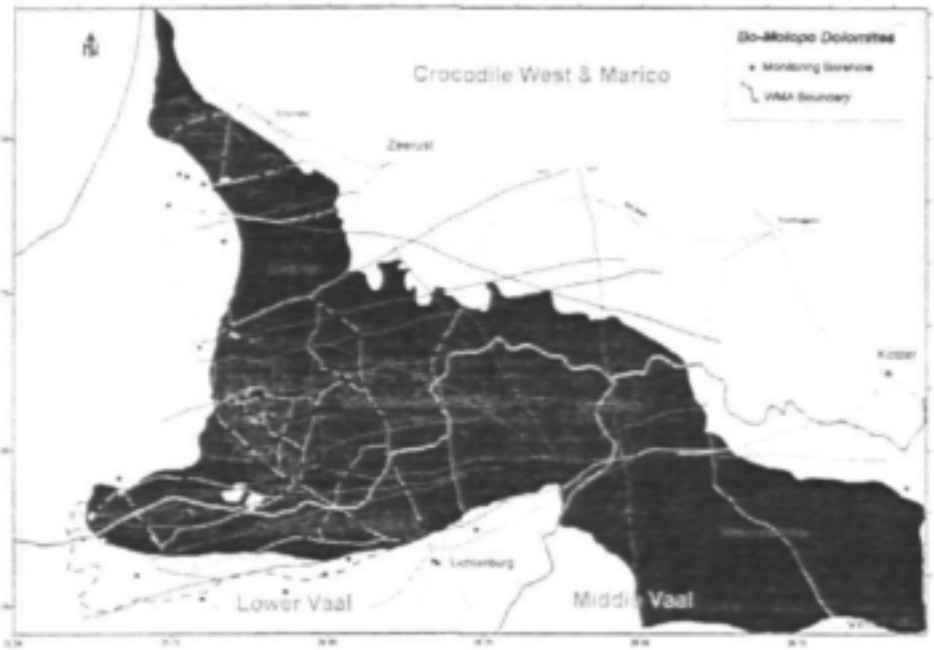


Fig. 3.5.1 Map showing the distribution of water level monitoring points in the different groundwater units.

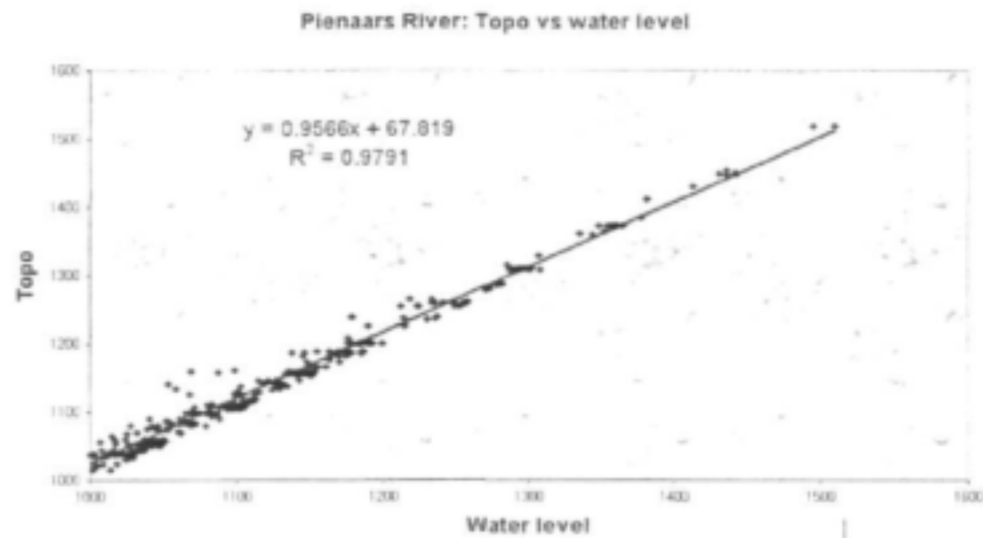


Fig. 3.5.2 Correlation between topography and groundwater levels in the Pretoria area after Van Tonder and Dennis (2001).

A graph showing the correlation between water levels and surface elevations of existing boreholes in the catchment should be plotted, as in more than 95% of aquifers studied in the RSA, the groundwater levels follow the surface topography (Van Tonder and Dennis, 2001). If the correlation is high then the topography can be used to assess regional water levels. Topography data, easily obtainable from a digital terrain data or map, can be used in a BAYESIAN estimation to plot a reliable groundwater contour map. Figure 3.5.2 indicates that there is a linear relationship between the topography and the groundwater levels of the Pretoria area; hence the groundwater contours and drainage would resemble the surface topographical relief (Van Tonder and Dennis, 2001).

However, because of the dykes, the dolomitic aquifer is not homogeneous and almost certainly for the dolomitic area of investigation a poor relationship between the groundwater levels and the topography is likely to be found.

From the groundwater contour map the areas could be identified, where groundwater enters or leaves the catchment. Usually the catchment boundary acts as a groundwater divide and it is only in low-lying areas that groundwater will enter or leave the system. This might not be the case in the area of investigation because of the flat topography and the bounding effects that the dykes and fault impose on the flow.

The recharge and transmissivity of the aquifer control the groundwater levels. The groundwater level gradient increases if the transmissivity is small and becomes flatter where transmissivities are higher. Steeper gradients also occur if the groundwater flow is obstructed e.g. by a diabase dyke or decreasing thickness of the aquifer due to wedging out of the dolomite on the edges of the basin. A sharp drop in groundwater levels over a distance of several metres normally indicates the presence of a dyke. When the water levels have been drawn down appreciably the dykes could act as impermeable boundaries, which could have a significant impact on the exploitation of water.

It is of critical importance to compile a regional drainage map for the entire area under investigation to determine the flow patterns and areas of inflow and outflow of groundwater.

4. GEOHYDROLOGICAL INFORMATION AND MONITORING

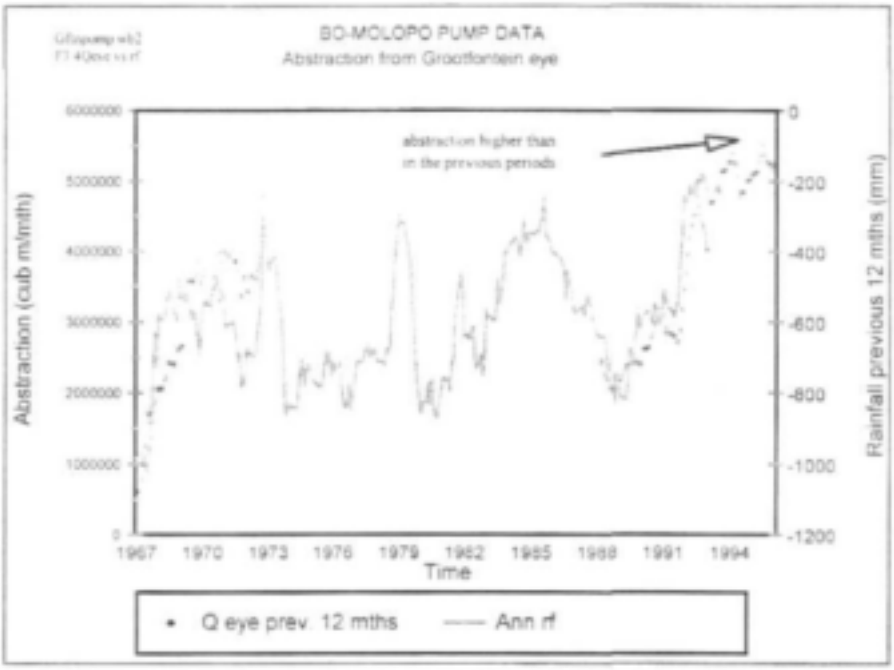


Fig. 4.1 Monthly abstraction at the Grootfontein eye supplying Mafikeng with water, in relation to the moving average rainfall of the preceding 12 months.

A groundwater monitoring programme can be defined as a system for collecting field data pertaining to the occurrence and behaviour of groundwater in a given region over a given period of time (Van Wyk, 2000). To ensure the protection of the areas, and that the ecological component and allocations have been correctly calculated, a monitoring programme must be

Table 4.1 Summary of all the data needed to determine reference conditions and potential sources over the country (after Braune et al., 2000).

Data needed	Potential data sources	Data required
Water quantity		
-groundwater levels	NGDB, field data & national groundwater maps (Vegter, 1995)	At least 2 years of monthly data from a borehole for every $2km^2$ of geohydrological region, preferably where very little or no abstraction is taking place
-surface water levels	Field data & WR90 - rainfall (Midgley *et al*, 1994)	At least 2 years of monthly data from every surface water body in geohydrological region
-abstraction	NGDB, field data	At least 2 years of monthly data for a borehole for every $2km^2$ of geohydrological region
-rainfall	WR90 - rainfall (Midgley *et al*, 1994), Weather Bureau & field data	At least 5 years of monthly data for a borehole for every $5km^2$ of geohydrological region, the last 2 years of which must be the same time period as that of the surface and groundwater level data required.
-recharge	Field data, WR90 - rainfall (Midgley *et al*, 1994), National groundwater maps - baseflow (Vegter, 1995) & various methods to calculate recharge/discharge (Bredenkamp *et al*, 1995; Kirchner *et al*, 1991; Vegter, 1995; Water Research Commission, 1990	One set of recharge values for the geohydrological region
-aquifer parameters	NGDB & field data	Information for a borehole every $2km^2$ of geohydrological region
Water quality		
-EC -pH -Cl	NGDB, field data data & national groundwater maps (Vegter, 1995)	At least 2 years of monthly data from a borehole for every $2km^2$ of geohydrological region The data should date back at least 2 years
-Sources of contamination	-Land use maps (CSIR & ARC), field data	
Aquifer structure		
-geology	NGDB, field data data & national groundwater maps (Vegter, 1995)	Geological logs for a borehole every $2km^2$ of geohydrological region; a down-the-hole camera can be used.
-blow yields	Drillers, borehole owners/managers & NGDB	Original records of at least one borehole every $2km^2$ of geohydrological region
-abstraction rates	Borehole owners/managers & NGDB	At least 2 years of monthly data for a borehole for every $2km^2$ of geohydrological region
-aquifer parameters	Field data	Information for a borehole every $2km^2$ of geohydrological region
Ecological aspects		
-all ecosystems	Land use maps (CSIR & ARC) & ecologists	The data should date back at least 2 years

implemented. Each of the monitoring components can be altered according to the results obtained. Reference conditions that describe the natural, pristine or 'unimpacted' conditions of a geohydrological region, and present a baseline from which the current conditions can be calculated. The natural series of groundwater levels and spring flow could be simulated by means of the cumulative rainfall departures from the average rainfall (CRD) and by the moving average rainfall method (MA) – see Section 8.3.

Ongoing monitoring extends the historical data that have been collected from previous studies, and all the information has to be collated in an appropriate database. Table 4.1 indicates the different parameters that have to be monitored, and relevant sources of data.

The monthly abstraction of Mafikeng appears to correspond to the moving average rainfall of the preceding 12 months rainfall (see Fig. 4.1) and the same has been observed for the irrigation abstraction (Bredenkamp, 1999). The latter correspondence seems more likely than the first, but the first implies that there is a large component of water used for gardening in Mafikeng which is portion of the water consumption varying according to the average rainfall of preceding months.

An assessment of the current status of a resource is necessary to determine the degree of modification that has occurred and hence the current risk of irreversible damage to the geohydrological region. Factors, which may collectively account for unrealistic monitoring, are summarised below:

1. Lack of government funding
2. Priority given to issuing licenses
3. Unwillingness on the part of organizations to assume and sustain the responsibility of monitoring
4. Absence of formal requirement or legal obligation
5. No experience of monitoring
6. Lack of technical resources, especially at local levels
7. Absence of an appropriate methodology
8. Benefits difficult to quantify or not immediately apparent
9. General ignorance about groundwater
10. Complacency due to apparent fluctuation of groundwater levels.

In Annexure 1 a brief summary is given of the outcome of geohydrological investigations and hydrocensus surveys that have been carried out in the area and which have yielded much information on the different sub-units in the dolomite.

5. ECOLOGY AND WATER QUALITY

5.1 Aqua-ecosystems

Fresh-water wetlands are the most seriously threatened ecosystems of Africa, and the wetlands of the dolomite of the North-West Region which sustain unique fish and faunal populations are particularly vulnerable to the increasing demand for water. As the dolomitic ecosystems form a valuable part of the natural heritage, South Africa has a responsibility to conserve, sustain and manage these systems.

A multi-disciplinary investigation to determine the value of the ecosystems was initiated by the Department of Nature and Environmental Conservation and has been funded by the Department of Environmental Affairs. The J.L.B. Smith Institute was contracted to characterize and determine the uniqueness of the indigenous fish populations (Skelton et al., 1994). The Institute also investigated an allegation by the local people at Molopo Eye that the natural fish population was threatened by the introduction of alien fish species (bass).

Five natural water bodies occurring in the dolomite of the North-West Region have been studied. A comparison of the fish populations is shown in Table 5.1.1. The water bodies are:

Molopo eye – this is a perennial spring constituting the origin of the Molopo River and is situated about 32 km NW of Lichtenburg. It presently supplies water to Mafikeng and is used as a private holiday/recreational area. The spring has an estimated long-term minimum flow of about 190 l/s and originally was used for irrigation on both sides of the river channel.

1) The diversion of the flow of the spring has been effected by the construction of a new weir about 600 m downstream from where the eye oozes. The new weir diverts the bulk of the water into a pipeline supplying Mafikeng with water, allowing the surplus flow to sustain the wetlands of the Molopo River below the weir. The maximum capacity of the pipeline to Mafikeng is 190 l/s but the flow at times could be less due to drought, thus little water except for some leakage underneath the weir would be available at such times to sustain the ecology downstream in the Molopo River. During the drought of 1993 only

about 200 m^3 of water was supplied to the wetlands below the diversion weir in the month of April, which is totally inadequate to sustain the wetlands lower down.

Table 5.1.1 Summary of indigenous aquatic biota of different springs in the dolomite of the North-west Region.

Aquatic fish fauna	Molopo eye	Wondergat	Malmani eye	Marico eye Kaaloog
Pseudocrenilabrus Philander (southern mouth brooder)	Occur in shallow area surrounding the jetties. Move from channel to lagoon - utilized by female brooders.	Breeding and migration of all species appears to be unaffected and no decline in populations has been observed.	Consistent supply of water to the wetland should be ensured. Being a nature conservation area it should maintain the environmental assets.	Dense vegetation protect Tilapia.
Banded tilapia *Tilapia sprarrmanii*	Occur in shallow area surrounding the jetties. Follows the same patterns as P Philander.		This species occurs in spring, vlei area and above and below weir.	Observed in the eye.
Large mouth bass *Speudocrenilabrus philander*		Land owners should adopt a management plan and educate visitors on the importance of sustaining the fish species.	This species occurs all over the aquatic regime.	Movement of bass during hunting limited due to thick vegetation.
Sharp-tooth catfish *Clarius gariepinus*	Large increase after culling of M salmoides. Breed successfully in Molopo. Populations have decreased.	The impact of man on the Wondergat (diving activities) should be limited.		
Straight fin barb *Barbus paludinosus*	Threatened by habitat loss – endemic species.		This eye represents a unique case of an undisturbed wetland ecosystem.	Importance of conservation of the site and management of the system (pumping from the eye not recommended).
Short fin barb *Barbus previpinnis*	Only habitat in the Orange rive system for this species – endemic.		Occurs in spring and channel and vlei area.	Only occur in the vlei area.
Micropterus salmoides	Threat to all species.		Occur in the eye.	Occur in the vlei, upstream and downstream of waterfall.
Barbus motebensis				Present in vlei and down waterfall.
Amphilius uranoscupus				Only present in vlei.
Chiloglanis pretoriae				Only present upstream of waterfall.

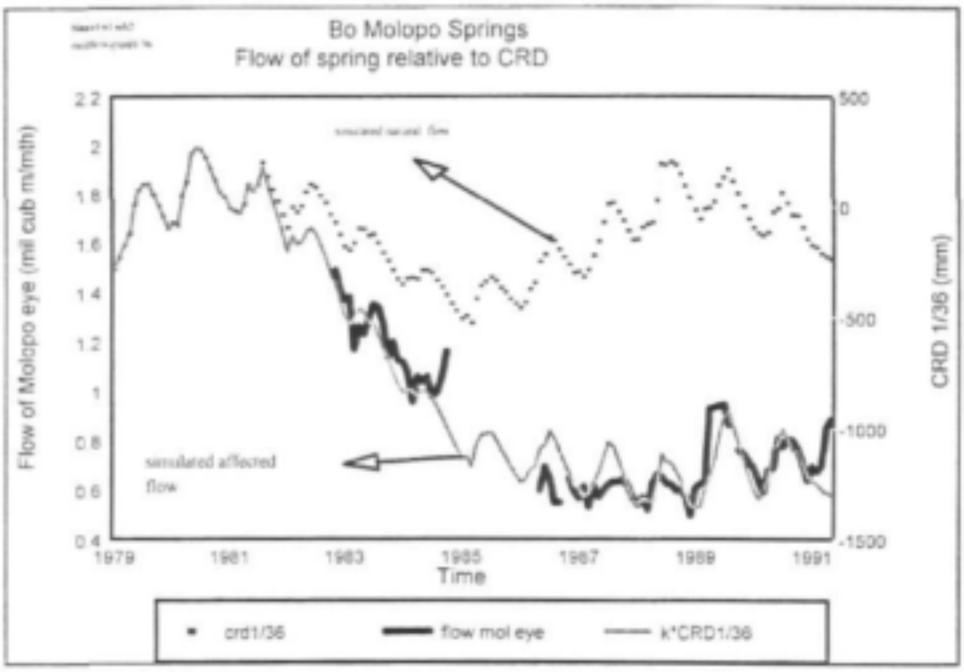


Fig. 5.1.1 Flow of Molopo eye in relation to the cumulative rainfall departures (CRD) .

The flow of the eye fluctuates according to the rainfall over the recharge area. Clear evidence that the flow of the eye has been affected by irrigation abstraction in the region has been obtained- see Fig. 5.1.1 (Bredenkamp, 1999).

A detrimental impact of human activities due to about 100 residents living during the holidays around the eye is a great concern and refuse and sewerage disposal is to be regulated. The quality of the spring water has been measured by the Department of Water Affairs and Forestry but has not shown any pollution yet.

2) The **Wondergat**, situated about 25-km east of Mafikeng near the Molopo River is a sinkhole that formed in geological times, close to the contact between the Oaktree and Monte Christo dolomitic formations. The sinkhole is about 50-60 metres deep and is one of the most popular inland training sites for scuba diving in the country. Many visitors camp around the eye and until recently there have not been adequate ablution facilities.

   Insecta: Only one of the 10 families is found at the Wondergat but crustacea is similar to that of the springs, suggesting that the crustacea populations are related to the chemistry of the water.

Fish populations: Mostly *pseudo philander* and *Tilapia sparrmanni* but the sharp-toothed catfish seems to be uniquely associated with the Wondergat. Alien species of carp and moddervis have been noticed.
Human pollution poses a potential danger and control measures should be introduced.

3) **Malmani eye**: This is also a perennial spring, emerging from an extensive wetland about 8 km east of Molopo eye. The farm was bequeathed to the Department of Nature and Environmental Conservation in 1993, and has been protected from human impact and alterations of the flow. Sustaining of this ecosystem rates a high priority, especially in view of the spring-flow having been earmarked as a potential source to augment the water supply of Mafikeng in the future (Theron, 1989).

Insecta: Three of ten families of mayflies occur at the site and 16 species have been identified, and 5 families of caddis, representing 21 species.

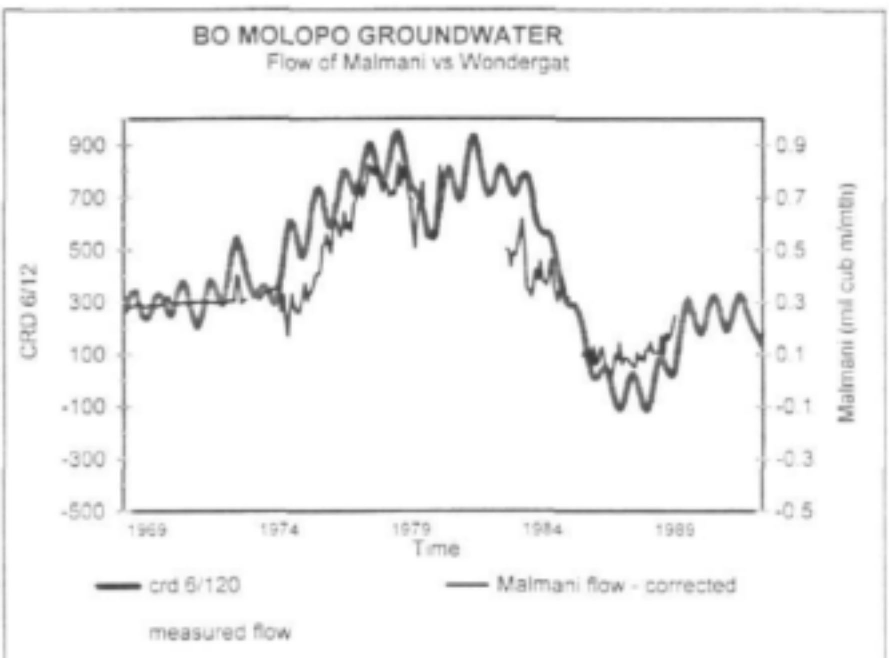


Fig. 5.1.2 Flow of Malmani eye derived from measurements that have been corrected in relation to the cumulative departures of rainfall from the average (CRD).

Human activities are at present very slight as the area is a nature reserve but cattle grazing close to the eye could pollute the wetland. It has been recommended that the flow of the eye and its water quality be measured more reliably. The flow records of the eye have been unreliable but by means of the good relationship to the CRD series the true flow could be inferred (see Fig. 5.1.2).

4) **Marico eye** – (Kaaloog): This eye forms part of the headwaters of the Groot Marico River and is increasingly being used as a training and recreational site for divers. It sustains a unique ecosystem that is being endangered by pumping to irrigate land. Although some measurements of the flow of the eye have been obtained in the past, the flow data does not correspond to the levels of the Wondergat and are therefore considered to be unreliable. Polivka (1987a) has however simulated the flows based on a simple relationship between the measured flow and the levels of the Wondergat devised by Bredenkamp and Zwarts (1987).

   Insecta: Four of ten families of mayflies, representing 14 species including four new ones have been found. Four families of caddis representing 14 species occur at the spring wetland.

   Crustacea: Eleven species of *Ostracods* occur at the site.

   Fish species: 6 Species occur with *Tilapia sparrmanni* and *Micropterus salmoides* being the most abundant. Although bass has also been introduced into the water system the dense vegetation protects the indigenous species from falling prey to the bass.

   The main conclusion regarding this aquatic ecosystem is that it should be protected against anthropogenic influences and the riparian vegetation should be preserved.

5) **Schoonspruit eye**: The spring issues as seven eyes oozing from the Monte Christo Formation not far from the contact with the Oaktree Formation. As is the case with many of the other springs the Schoonspruit eye emerges as a result of the thinning of the dolomite basin as it wedges out on the Ventersdorp lava. Apart from supplying water to the town of Ventersdorp and to irrigation lower down the Schoonspruit, the eye sustains a wetland of reeds and shallow water pools forming the habitat of several fish species. Presently 84% of the yield of the eye is used for irrigation along a canal to Rietspruit and Elandskuil dams; 16% of the water is used for domestic and industrial purposes.

Insecta: Two of ten families of mayflies are found in the area and 8 species have been identified. Six species of dragonflies occur at the site and four families of caddis. Eight species of *Ostracods* occur in the area.

Fish population: The spring is the habitat of two indigenous fish species viz. *Pseudo philander and Tilapia sparrmanni.* A comparison of the fish populations appears in Table 5.1.

Human impacts: The fact that the flow of the eye has been affected by irrigation abstraction in the recharge area is of great concern (see Fig. 1.3). If the abstraction is not controlled the water supply of Ventersdorp as well as the irrigation lower down would be seriously threatened, and the wetlands below the eye could dry up. Measures to control the irrigation abstraction should therefore be put in place. The control and management of the groundwater is thus of a high priority.

Conclusions and recommendations

The natural aquatic ecosystems of the five terrains are similar in respect of some of the fish and faunal populations that they support but each sustains a unique ecological habitat. Table 5.1 indicates the different fish and faunal populations that have established themselves in these water bodies and that would be threatened by declining water levels. For all of the five sites it has been recommended that

- management programmes in accordance with the requirements of the different consumers be formulated;
- conflicts due to the diverse water requirements be resolved through consultation with the different stakeholders;
- the flow of the eyes be monitored, the effects of abstraction by irrigation be determined, and irrigation abstraction be measured;
- the water quality of the springs be monitored to detect contamination, and informal settlements close to the eyes be limited;
- educational brochures be prepared and programmes be arranged to inform the public and stakeholders of the vulnerability of aquatic ecosystems.

5.2 Groundwater quality

Overview

Groundwater quality refers to the water chemistry and micro-organisms living in the water. The level of total dissolved substances (TDS) in groundwater determines its salinity. Water with a salinity exceeding 450 mg/l tastes salty but up to 1000 mg/l is still safe for humans to drink. Livestock can tolerate drinking water with levels up to 3000 mg/l. All the groundwater of the North-west Region is of an excellent quality except that the water is hard because of its bicarbonate content. A useful handbook on groundwater quality containing valuable general information on pollution problems has been published by Water Research Commission based on a project carried out by the Cape Water Environmentek branch of the CSIR (1999).

One of the objectives of responsible management of groundwater resources is to be aware of areas and conditions that are potentially vulnerable to pollution. Once an aquifer has been polluted it will no longer be available as a cost-effective source of water. Chemical monitoring of groundwater is important for the purpose of establishing reference concentrations for the identification of pollution. Sampling at points of abstraction or springs provides a more representative picture of the chemical characteristics and changes occurring in the groundwater, than water obtained from inactive boreholes.

Chemical data obtained during surveys and follow-up studies do not so far indicate any serious sign of pollution. In most cases the concentrations of total dissolved solids and of individual chemical components are so low that errors in the analysis could be mistaken for pollution.

As a general rule chemical analysis of groundwater should be carried out at least once a year at selected points of abstraction, where the vulnerability of the aquifer is high. In other areas representing zones of potential pollution, water sampling and analysis should be carried at least twice a year.

The chemistry of several springs has been monitored in the dolomitic area under investigation (see Table 5.2.1) and analyses should be continued.

Table 5.2.1 Comparison of the chemistry of different springs in relation to the characteristics of the recharge areas.

Dolomitic Bo Molopo springs	TDS mg/l	HCO3' mg/l	Cl mg/l	Sulphate mg/l	Comment
Dinokana Upper (some recharge from banded ironstone)	351	207	4,9	6,6	Pristine spring – low TDS and Cl indicating higher recharge
Molopo (100% dol.)	326	199	4,8	5,3	No contamination
Vergenoegd (100% dol)	399	244	4,9	6,6	Natural spring – no contamination
Skilpadfontein (100% dol)	442	272	5	6,5	Natural spring – no contamination
Rhenosterfontein (Transvaal shales and quartzites – only partially dolomitic)	395	209	25	12	The chemistry is clearly different from that of normal dolomite – spring also indicates pollution

In the case of Polfontein sporadic chemical data are available from 1981 to 1984, followed by a period of no records up to 1990 with further measurements up to 1992. The chloride concentrations indicate that the spring has not been seriously polluted yet. (Fig. 5.2.1).

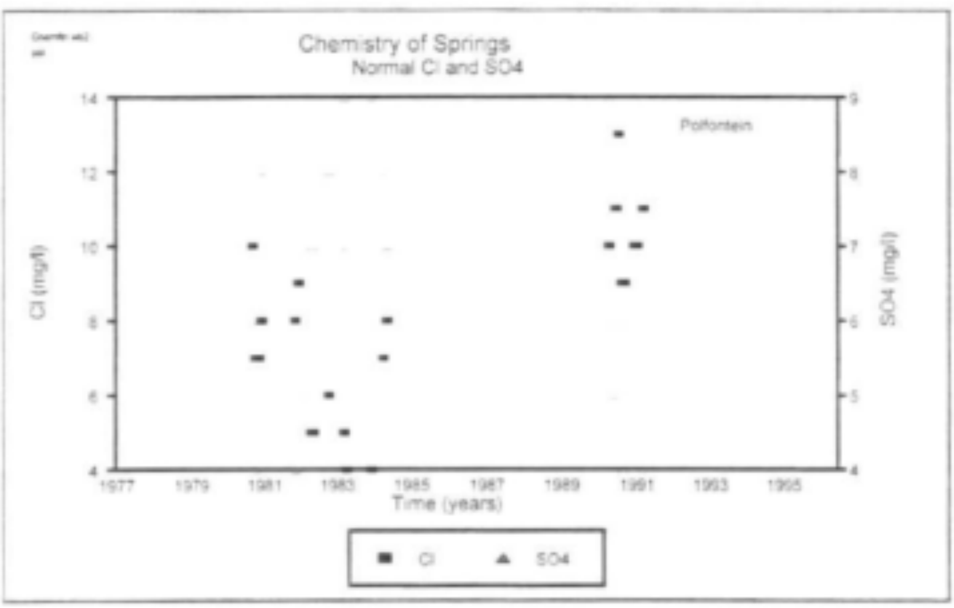


Fig. 5.2.1 Chloride and sulfate concentrations of water samples obtained from the Polfontein eye.

According to Fig. 5.2.2 the Rhenosterfontein clearly shows that contamination entered the aquifer around 1981 when concentrations started increasing and reached peak concentrations in 1982, before diminishing exponentially. This is typical of an injected pulse of pollution.

The extent of the pollution can be seen in relation to the water quality of the Buffelshoek eye, plotted as cumulative concentrations; the latter may still be in its natural state although a slight increase in chloride concentration occurred from 1989 to 1991 (Fig. 5.2.3).

A longer series of sulphate measurements is available but data on both chloride and sulphate exist only from 1989 to 1996. Because the chloride and sulphate concentrations during the latter period responded similarly and concentrations of sulphate have remained small, the aquifer is regarded as being in a fairly natural state. Hence this spring would be suitable for deriving recharge quantitatively using the chloride method.

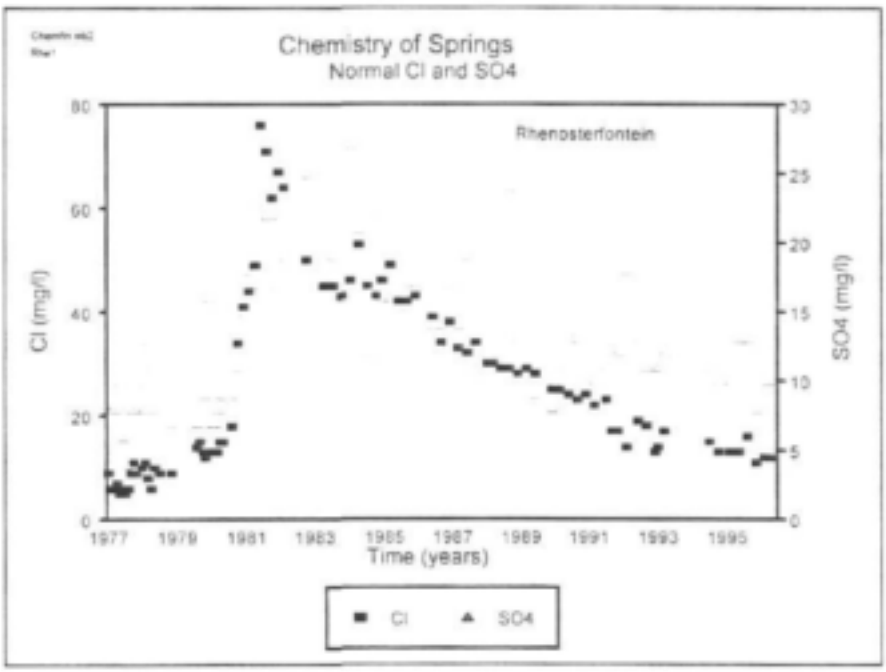


Fig. 5.2.2 Comparison of the chloride and sulphate concentrations of Renosterfontein, clearly indicating that pollution occurred around 1981.

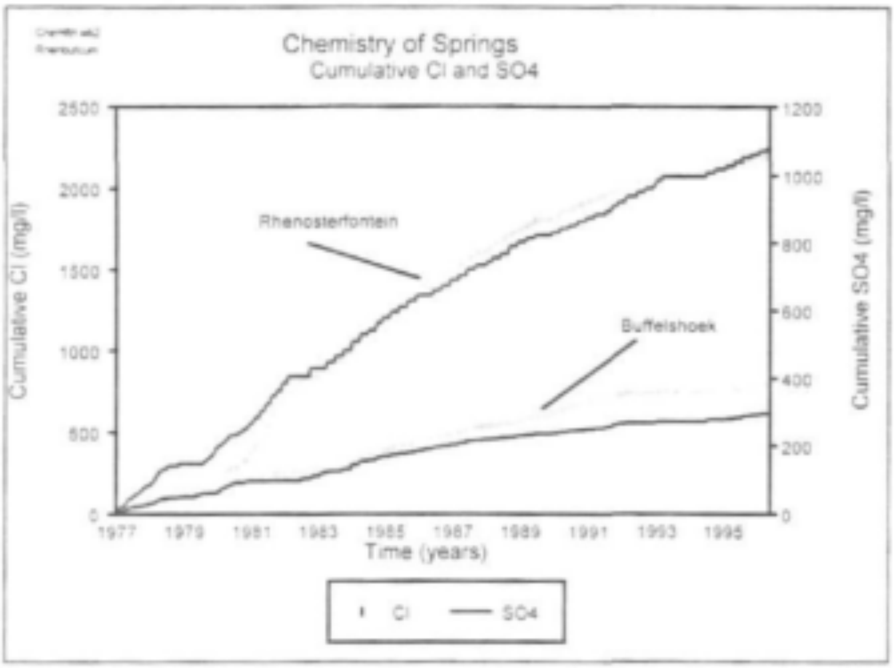


Fig. 5.2.3 Water quality of the Buffelshoek and Renosterfontein eyes - the low concentrations of chloride and sulphate of Buffelshoek eye showing no evidence of pollution.

There are too few measurements of the water quality of the Molopo eye to define a clear trend. However the low concentrations of both chloride and sulfate indicate that this aquifer is probably still in a natural state and could also be used for a reliable estimation of the recharge, using the chloride method.

Microbial contamination

All aquifers contain communities of micro-organisms. Microbial contamination occurs when micro-organisms that pose a health risk are introduced to the groundwater often from a faecal source. Dysentery, cholera and gastro-enteritis are examples of diseases transmitted by bacteria in water. Such micro-biological pollution is definitely a cause of concern in areas where informal dwellings with poor sanitary systems are built close to the source of drinking water. As a general rule boreholes should not be drilled at distances closer than 100 m to septic tanks and cattle feedlots. Drilling close to critical water supply boreholes should be prohibited.

Groundwater contamination by substances such as oil, fertilizer nitrate and other point sources of pollution does not seem to be serious in the dolomitic areas. This is probably due to the large volumes of water stored underground in relation to very localized infiltration of contaminants. The problem of contamination could be serious in those cases where the groundwater occurs at shallow depths and in small quantities. As is the case in large parts of the dolomitic area, the groundwater occurs at great depth and the unsaturated zone contains clays of low permeability, thus the vulnerability of the aquifer to contamination is low. However in many parts of the dolomitic aquifers in the area, pathways for rapid infiltration of contamination of groundwater exist.

6. IMPACTS ON GROUNDWATER RESOURCES AND DETERMINING THE RESERVE.

6.1 Introduction

The management and control of the groundwater resources being the ultimate objective of the study, require a clear understanding of the interactions induced naturally and artificially on the groundwater system. The response of the groundwater levels and their relationship to recharge and the different stress factors is the key to the assessment of the impacts and effective management of groundwater. Determination of the natural status and requirement of groundwater in relation to the different consumers of water, termed the groundwater "reserve", is pertinent to the allocation and management of the groundwater resources. Table 6.1.1 indicates the three basic consumer groups of groundwater.

According to the National Water Act (1998), there are three important considerations regarding the amount of water that can be allocated:

- The reserve
- International obligations
- The integrity of the resource with regard to the water quality, quantity and ecology.

Only water, which is still available after taking account of the three components, can then be allocated to users. Depending upon the significance of the resource in question, the determination of the reserve required may be a preliminary estimate or comprehensive evaluation.

Table 6.1.1: Brief description of 3 basic use-groups of ground water, according to availability and potential usage (Braune et al., 2000).

Name (tag)	Description
Ecological Reserve (E)	Agreed amount of water required locally and/or downstream to maintain/improve local ecology.
Basic Human Needs (B)	Agreed minimum amount of water guaranteed as a right for every South African citizen, to suit basic human needs, such as cooking and cleaning.
Allocatable (A)	Remaining quantity of water, once Reserve has been determined and subtracted from the quantified total amount of water economically available.

A preliminary estimate may be upgraded into a more comprehensive and accurate reserve assessment, as more information becomes available. The initial reserve determination will be based on whatever hydrogeological and demographic information currently available. In other words, readily obtainable hydrogeological data, which is sufficient for preliminary reserve determination (Parsons, 1999) could be insufficient for use in the comprehensive reserve determination.

The following steps are part of an initial Comprehensive Reserve Determination Methodology for groundwater to be applied in the North-west dolomitic area.

- STEP 1: DELINEATE RESOURCE
- STEP 2: DETERMINE GEOHYDROLOGICAL REGION
- STEP 3: DETERMINE REFERENCE CONDITIONS
- STEP 4: DETERMINE CURRENT STATUS (SETTING THE CURRENT MANAGEMENT CLASS FOR A GEOHYDROLOGICAL REGION)
- STEP 5: QUANTIFY THE RESERVE
- STEP 6: SET RESOURCE QUALITY OBJECTIVES
- STEP 7: FOLLOW-UP MONITORING

• STEP 8: PERIODIC REASSESSMENT OF RESERVE REQUIREMENTS

Fig. 6.1.1 Presentation of the components involved in determining the groundwater reserve (cf. Braune et al , 2000).

The Water Act takes into account two main principles: sustainability and equity. The determination of the reserve is one of the ways in which these two principles can be taken into account. Van Tonder and Dennis (2001) have prepared an excellent publication on the determination of the groundwater reserve and related matters, and several excerpts have been included in this report.

The reserve is defined as the quantity and quality of water required (Van Tonder and Dennis, 2001):

(a) to satisfy basic human needs (BHNs) by securing a basic water supply for people who are now or who will, in the reasonably near future, be relying upon and taking water from or being supplied from a certain water resource;

(b) to protect aquatic ecosystems in order to secure ecologically sustainable development; this will be referred to as the ecological component of the groundwater reserve (ER) - which is set according to instream flow requirements (IFR), riparian vegetation requirements and use of the relevant water resource.

Determination of the reserve for an aquatic ecosystem entails investigation of the relationship between major interactive components of the water cycle, namely surface water bodies and groundwater. Validation of the determined reserve would be subject to review after five years.

The total, sustainably available, groundwater in any given area, once decided upon and quantified, can be divided into two potential or actual usage groups: the 'Reserve' (already outlined) and the allocatable component.

Groundwater plays a role in the reserve determination if there is direct hydraulic connection between groundwaters and surface water bodies that jointly sustain the aquatic ecosystems. In such situations the often complex role of groundwater (in terms of volume, movement and distribution) in supporting the ecosystem and human population, has to be ascertained.

Sustainability takes into account the balance between protection and utilization. Resource Quality Objectives take this into account and can be defined as a numerical or descriptive statement of the conditions which should be met in the receiving water resource, in terms of the resource quality (and quantity), in order to ensure that the resource is protected (MacKay, 1998).

Important issues for the determination of a groundwater reserve, to be dealt with (Van Tonder and Dennis, 2001), include:

- Concept of the Reserve
- Methodology employed
- Follow-up monitoring
- Interaction with surface water bodies

The authors recommend the following approach:

The groundwater level within the system can be expressed as:

$$\text{Change in storage} = \text{Inflow} - \text{Outflow} \tag{6.1.1}$$

Equation 6.1.1 can be expressed mathematically as:

$$\frac{S\Delta V}{\Delta t} = R + I - O - Q \tag{6.1.2}$$

where

ΔV [L3]	=	change in aquifer volume within the time increment Δt
R [L3/T]	=	natural effective groundwater recharge to aquifer
I [L3/T]	=	natural groundwater inflow into the system
O [L3/T]	=	natural groundwater outflow from the system
Q [L3/T]	=	abstraction (including spring flow) from the system
S [ ]	=	specific yield
Δt[T]	=	time increment

The two entities I and O can be broken down into the following components:

$I = I_b + I_r + I_{df}$

and

$O = O_b + O_r + O_{df}$

where

I_b & O_b = lateral groundwater inflow and outflow over catchment boundaries

I_r & O_r = groundwater inflow and outflow from/to rivers

I_{df} & O_{df} = deep groundwater inflow and outflow over catchment boundaries

Under the steady-state groundwater flow condition, the change in storage is zero and Equation 6.1.2 can be rewritten as:

$$R + I - O - Q = 0 \tag{6.1.3}$$

Under steady state conditions (Equation 6.1.3), the Potential allocatable groundwater for a catchment is defined as:

Allocatable groundwater = $R + (I_b - O_b) + I_r - BHN - ER$ (6.1.4)

where

BHN = basic human needs

ER = ecological requirements

Points to consider

1. The amount of water that can be allocated under steady state conditions is required, therefore the quality/quantity and ecological condition of the resource has to be taken into account.
2. The inflow/outflow over a catchment boundary is not affected, thereby taking international obligations and adjacent catchments into account.
3. It is assumed that the maximum riparian ecological requirements are equal to the groundwater flow towards the river
4. The inflow/outflow from/to deeper aquifer systems is zero as a first approximation.

Estimating groundwater for Basic Human Needs

The amount of groundwater needed for basic human needs can be determined by multiplying the population that is dependent on groundwater by 25 l/d (Water Service Act: Act No. 108 of 1997). Future changes in the groundwater-dependent population must also be considered.

Estimating groundwater for Ecological Requirements

It is assumed that the amount of groundwater needed for aquatic ecosystems is equivalent to the amount of flow towards a surface water body, which is similar to $I_b - O_b$ in equation 6.1.4.

Discussion

After the estimation of each component, Equation 6.1.4 can be used to estimate the potential allocatable groundwater for a catchment. The term potential allocation is used because water balance components on a large scale have been estimated under steady state conditions. Local impacts due to abstraction must still be evaluated separately e.g. abstraction close to a river can cause the water level gradient to be reversed, leading to undesirable conditions. In practice, the allocable amount of groundwater will be less than the potential allocable amount.

It is evident that, depending on the priorities of the demands of consumers, it would not be possible to satisfy all consumers at all times, because the recharge from rainfall – the main input counteracting the losses – is variable and could be low in times of prolonged droughts. The groundwater 'reserve' could therefore be defined in terms of the minimum groundwater level of an aquifer that is to be sustained to provide in the needs of preferential users of groundwater. Basic guidelines, principles and approaches to effectively manage and control a groundwater system have been presented by Van Tonder and Dennis (2001), but in its entirety equitable allocation of groundwater is a complex problem requiring a good level of professional expertise.

6.2 Estimation of groundwater recharge and aquifer storativity

Recharge is one of the most important impacts on a groundwater resource and is the main component balancing the losses from the aquifer. This recharge water is stored in openings, designated storativity, in the aquifer rock. Reliable estimation of the groundwater recharge and storativity is a basic requirement for assessment of groundwater resources and their effective management. Although several estimates have been obtained in previous studies (Bredenkamp, 1996a) a reassessment of these parameters is still needed in the light of additional data that have been acquired, and refinement of methods that could be applied.

Although there are various methods of determining recharge, most estimates are subject to uncertainties but these are less critical if the following methods are used:

6.2.1 Estimation of groundwater recharge by means of the Equal Volume Method

Monitoring of groundwater levels and abstraction is important in estimating the recharge of an aquifer from the saturated water budget by balancing the input and output over a selected time interval dt according to the water balance equation:

$$Re_{tot} = Q_{abstr} + S.dV + Evt + Q_{outflow} - Q_{inflow} \quad (6.2.1)$$

Where

Re_{tot}	=	total recharge with evapotranspiration losses included
Q_{abstr}	=	pumpage from system, or spring flow
$Q_{outflow}$	=	lateral flow to lower compartments
Q_{inflow}	=	lateral inflow from higher aquifers
Evt	=	evapotranspiration losses directly from the aquifer
S	=	aquifer storativity or specific yield
dV	=	change in saturated storage volume (positive or negative)

The effective recharge Re_{eff} represents the nett recharge after evapotranspiration losses from the aquifer have been accounted for. It can be obtained more easily than Re_{tot} because of difficulties of quantifying evapotranspiration. Hence effective recharge is usually obtained by applying the following balance to a selected time interval:

$$Re_{nett} = Q_{abstr} + S.dV + Q_{outflow} - Q_{inflow} \quad (6.2.2)$$

For $dV = 0$ and $Q_{outflow} = Q_{inflow}$ the aquifer storativity does not come into play and the effective recharge is equal to the abstraction over the equal volume interval. By comparison with the rainfall during the equivalent period (in accordance with the moving average relationship) the rainfall/recharge relationship could be derived. In this way a lumped estimate of the average recharge could be obtained.

In the case of dolomitic springs of which the flows correspond linearly to the cumulative departures of rainfall from the long-term mean, the equal-volume method could be applied to periods when the flow at the beginning and end of the period is equal. Any pumping in the recharge area during the equal-volume period has to be added to the flow of the spring. It is therefore important to monitor spring flow on a regular basis. If only discontinuous measurements of flow are available a full time series could be simulated from rainfall records by means of the CRD and MA methods. Fig. 6.2.1.1 shows the relationship between rainfall and recharge for the Buffelshoek eye as determined by means of the EV method, indicating that the recharge at higher rainfall input becomes exponential.

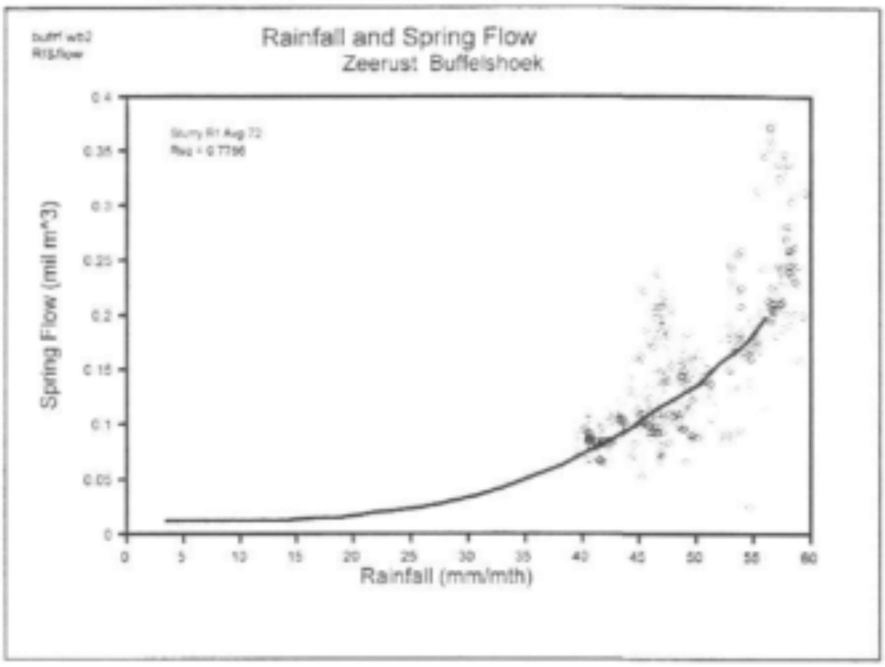


Fig. 6.2.1.1 Relationship between the recharge and rainfall derived by means of the equal–volume method applied to periods of equal flow of the Buffelshoek eye.

The recharge could be determined if the storativity is known, from the coefficient a= b/S (see eq. 8.3.2 and 8.3.3) that has been derived from a regression fit between the CRD or MA rainfall series and the natural water-level fluctuations of an individual borehole. If the water level measurements have been affected by pumping they first have to be corrected by removing the stress factor (see Section 8.3).

6.2.2 Determining recharge by means of the Chloride Ratio Method

As has been indicated by several authors in the RSA such as Kok (1992), Sami (1991), Bredenkamp et al. (1995) and Bredenkamp (1993), the percentage rainfall representing recharge can be derived from the ratio of chloride concentration in rainfall relative to that of the local groundwater. Mathematically the relationship can be expressed as:

RE (%) = $Cl_{rain}/Cl_{groundwater} * 100$ ....(6.2.3)

Although the chloride concentrations of the soil profile with depth can be used to determine recharge, the chloride-method can be applied to the chloride concentration of spring water as the springs represent the recharge integrated in time and space. A specific requirement is that no chloride should have been added by dissolution of aquifer material, or by contamination or salts contained within the aquifer matrix. The natural hydrological evaporative processes should be the only processes by which chloride injected by the rainfall is concentrated.

Values of the input chloride concentration could be derived from a relationship between precipitation and chloride concentrations, based on chloride measurements over the country. (Bredenkamp et al. 1995 and Bredenkamp, 1999). *The lack of specific data of chloride concentrations of rainfall in the area of investigation stresses the need to monitor the rainfall chloride at selected water level monitoring points.*

Recharge of several dolomitic springs determined by the chloride method is listed in Fig. 6.2.2.1.

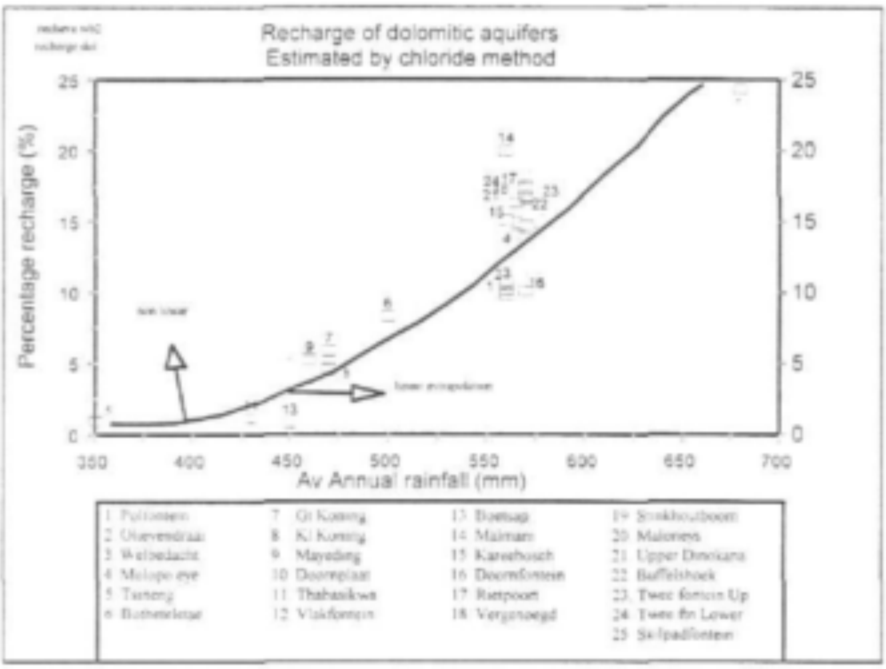


Fig. 6.2.2.1 Average recharge determined by the chloride method, for dolomitic springs, relative to the average rainfall.

6.3 Abstraction data

Current groundwater abstractions can only be obtained by investigating abstraction boreholes within the study area. Databases, such as the National Groundwater Database (NGDB), can be used. A hydrocensus would also give an indication of abstraction rates. One should be aware of the possibility that many boreholes are not registered on the database. If a useful database does not exist, other sources of information such as land use maps (for estimating irrigation) and population maps (for estimating drinking and industrial uses) can be used to determine the existing abstraction rate.

The abstraction is an essential parameter required for modelling and in water balance studies to determine recharge and the storativity of the aquifer. Although meters have been installed in the Grootfontein area to register the quantities being pumped from the main irrigation boreholes, these meters have frequently not operated well. However, by calibrating electricity consumption of the pumping installations against pumping rates, fairly reliable records have been obtained for the Grootfontein aquifer (Van Rensburg, 1987). The same method could be used to calculate the abstractions from all the groundwater units if the electricity data could be obtained from ESCOM.

The following is an overview of the availability and reliability of abstraction from the different units:

- The abstraction data of the Grootfontein unit are the most reliable and have been checked by means of a relationship with rainfall over the preceding 12 months (Bredenkamp 1996b). This relationship is probably due to the integrated soil - moisture status and relative demand for watering of crops, and of gardens in Mafikeng. Accordingly not only months with missing or incomplete records could be simulated, but for all areas this relationship could be used to construct pumping records that could be used in the models, for individual points of abstraction proportional to the areas that are being irrigated.
- Abstraction volumes from the Zeerust compartment mainly comprise water pumped by the municipality of Zeerust, and are recorded.
- In the Lichtenburg –Itsoseng compartment, except for the municipality, pumping data would have to be resurveyed as several new irrigation installations have been erected. Short flow records of springs obtained by Taylor (1983) in the Lichtenburg area would have to be extended by means of a linear regression between the measured flows and the corresponding levels of the Wondergat.
- Groundwater abstraction for irrigation has expanded in the Grootpan and Ventersdorp groundwater units since the studies by Polivka (1987a and b) were conducted. Fairly reliable interim estimates of the abstraction could be derived

from the survey carried out by Schoeman and Partners (1996), based on the areas that have been irrigated.

Table 6.3.1 summarizes the present average water requirements of the main towns.

	Water source	Present demand	Estimated demand 2030	Growth rate	Consumption Patterns
	Grootfontein compartment (pumping), Molopo compartment (overflow), Setumo dam	13.27 Mm^3/yr	41.25 Mm^3/yr	7.8%	Growth is three times higher than normal
Zeerust	Zeerust compartment (well field)	2.117 Mm^3/yr	5.36 Mm^3/yr	4.08%	Negative growth over past years
Lehurutse	Zeerust compartment (Dinokana eye)	0.829 Mm^3/yr	N/d	34.35%	N/d
Lichtenburg	Lichtenburg-Itsoseng compartment	3.752 Mm^3/yr	13.3 Mm^3/yr	1.85%	Less than theoretical demand
Itsoseng	Lichtenburg-Itsoseng compartment	1.784 Mm^3/yr	3.4 Mm^3/yr	4.3%	Equivalent to theoretical demand
Ventersdorp	Schoonspruit eye (Ventersdorp comp.)	0.928 Mm^3/yr	N/d	N/d	N/d

7. DELINEATING ECOLOGICAL REGIONS & DETERMINING THE ECOLOGICAL RESERVE

7.1 Delineating an ecological region dependent on groundwater (after Van Tonder and Dennis, 2001)

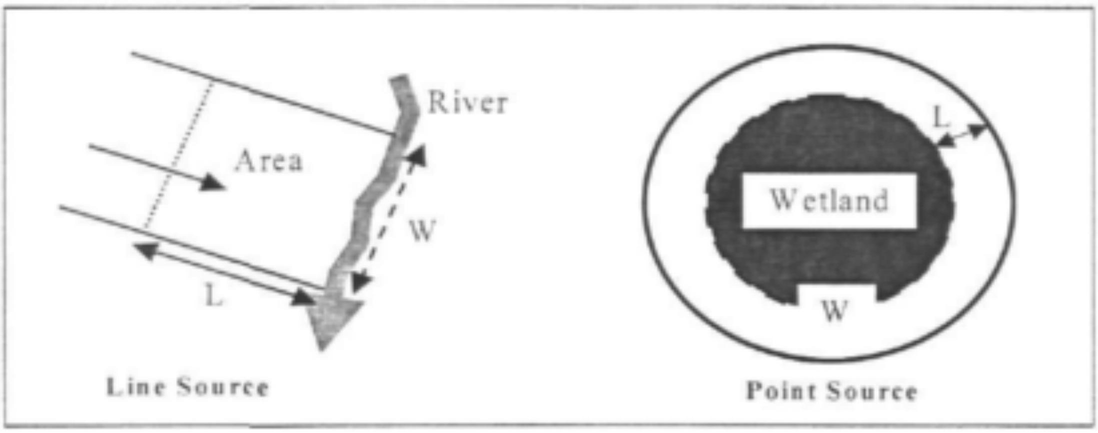


Fig. 7.1.1 Construction of a groundwater protection area A for a sensitive riparian aquatic ecological region along a river (line source) and around a wetland.

Water management areas and even quaternary catchments are still too large to be used as a basis for groundwater allocation. Therefore, for water allocation purposes sensitive ecological regions have to be delineated. These delineated regions will be referred to as protection areas.

When delineating sensitive ecological regions identify riparian vegetation along rivers and around wetlands as in the case of Molopo eye, Wondergat, Malamani, Marico eye, Schoonspruit eye and the Grootfontein eye (which is presently dry due to excessive pumping).

Terrestrial and riparian/aquatic ecosystems need to be considered separately.

- For riparian/aquatic ecosystems determine the flux towards the surface water body. To estimate the flux towards a riparian ecological region use either a numerical model or Darcy's Law. When using Darcy's Law the flux can be determined as:

$$Q_{ER}=TiW \qquad (7.1)$$

Where

ER = ecological reserve

T = transmissivity (m^2/d)

i = water level gradient and

W = length of the protection area perpendicular to flow (m)

In the case of a point ecological region (e.g. wetland) W is equivalent to the perimeter of the point source. Q_{ER} is the maximum flux that must enter the wetland in order to maintain all ecological functions and can be referred to as the ecological component of the reserve.
The protection area A for the sensitive ecological region can then be determined using Q_{ER} viz.

$$A = \frac{Q_{ER}}{R} \tag{7.2}$$

where

R = effective groundwater recharge (m/a) within the protection area

The length (L) of the protection area (refer to Figure 7.1.1) can now be estimated as

$$L = \frac{A}{W}$$

for a line source and

$$L = \sqrt{A\pi}$$

for a point region.

- When considering terrestrial vegetation it can be assumed that the vegetation is an abstraction point and can be treated as a borehole. *The amount of groundwater used by terrestrial vegetation will have to be determined by ecologists.* The protection area can be determined using equation 7.1. Depending on the shape of the terrestrial vegetation area, the same equations used to determine the length L can then once again be used to determine its length.

Taking uncertainties into account when delineating ecological regions.

Because of the uncertainties in effective recharge (R) and also in transmissivity (T), a risk-based protection area can be estimated. For example, say σRe is the standard deviation for the recharge estimate, then the effective recharge will fall in an interval: $Re+f(\sigma Re)$, where for f = 1 a 68% certainty interval is estimated and for f = 2 the 95% certainty interval is estimated.

Points to consider (after Van Tonder and Dennis, 2001) are that

- if the ecological region requires less than Q_{ER}, then the area A will decrease. The instream flow experts will set the instream flow requirement for a river, while ecologists will have to be consulted on the requirements of sensitive ecological vegetation;
- another method that can be used to estimate the ecological requirements is base flow separation. However more research concerning base flow separation is needed;
- a first estimate of Q_{ER} and L can be obtained using national maps.

7.2 Delineating borehole protection areas and allocating groundwater (including BHNS component of the reserve)

The two important parameters that should be considered for a borehole protection area are

(a) the radius of influence of the borehole (as abstraction from the borehole will have zero influence on water levels outside the radius of influence) and

(b) the capture area of the borehole which will be used to estimate the safe yield of the borehole, and to determine the impact of pollution.

Allocating groundwater in areas adjacent to ecological regions:

Manual procedure using Darcy's Law

The first step is to determine the radius of influence (r_e) for potential or existing boreholes. The size of the radius of influence will be independent of borehole abstraction and will only depend on T, S and the duration t of abstraction. The radius of influence can be estimated by:

$$r_e = 1.5\sqrt{\frac{Tt}{S}} \qquad (7.3)$$

where

T = transmissivity of the formation

S = storativity of the formation

t = time in days (=365 days)

The radius of influence for different values of T and S is shown in the next figure.

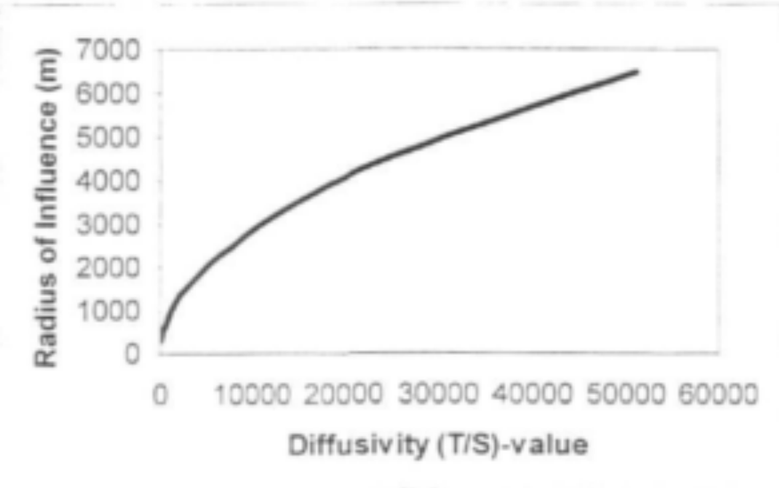


Figure 7.2.1 The one year radius of influence of a borehole for different T/S –values.

The radius of influence could be large in dolomitic aquifers that have high T values.

8. MANAGEMENT OF GROUNDWATER

8.1 Overview

Regarding the management of water, using models to simulate the response of the aquifer to different stress factors, the following questions have to be answered:

1) How much water is required and is available?
2) When is it needed and what requirements have to be satisfied?
3) What are the conditions and risks of failure that could have undesirable effects on water quality and the ecology, or cause diminution of spring flow. (A more extensive discussion of groundwater management appears in Annexure 3).

According to Van Tonder et al. (1999) there are two types of model that could simulate the responses of aquifers to different impacts, and could be used for management purposes:

- Lumped parameter models are only suitable to study economic and policy matters that involve groundwater resources. These models do not consider groundwater flow equations but conceptualise aquifers with simple water mass-balance equations.

- Distributed parameter models combining aquifer simulation with optimization methods, explicitly solve the partial differential equation to evaluate efficient use of the aquifer; the models are integrated with assessment of the different impacts at specified points in the aquifer.

Both types of model are important, the first being a simplified approach but often the only viable option in the light of insufficient data and uncertainties regarding the interactions and mathematical representation of impacts. The CRD/MA method would also fall under the first type. In the case of the second type a hydrodynamic model is not only a more elegant method to use but could accommodate most interactions and impacts. In the case of the North-west dolomitic aquifers a reasonable amount of data has been accumulated, especially time series of water level fluctuations and in some cases sufficient abstraction data, to model the systems. The impacted points could be critical boreholes, springs or aquatic ecosystems and the changes of the groundwater heads have to be related to the effects induced on the different components and especially on the reserve. A limit to the hydraulic-head vs. component interaction has to be defined and should not be exceeded. By means of modelling, compliance of the system to these limits could be checked for different scenarios of abstraction, different spatial configurations of pumps, and variable rainfall conditions. This type of modelling is usually applied on a trial-and-error basis to assess the impact by inspection. However, if response relationships could be expressed mathematically the aquifer model could be linked to an optimisation routine, allowing optimal management to be achieved. In view of conflicting interests, and difficulties of setting up response relationships, sustainable utilization of an aquifer that would still meet the constraints is a difficult task. *Hydrodynamic modelling of the aquifer should be considered in the next phase of the project, primarily to simulate the entire North-West dolomitic area under investigation, so as to reveal the overall flow pattern and water balance of the system. Later on a more refined simulation of individual groundwater units could be modelled to assess the differing impacts on each unit.*

8.2 Hydrodynamic modelling (AQUAWIN and MODFLOW models)

The model that has been applied with reasonable success in modelling the Grootfontein and Zeerust compartment is the AQUAWIN model (Windows version of AQUAMOD) (Van

Rensburg, 1985; Van Tonder et al., 1999; Bredenkamp, 1996 and Bredenkamp and Nel, 1997).

AQUAMOD for Windows (Van Tonder GJ, Buys J, 1996) is a public domain two-dimensional finite element groundwater model which includes a mesh generator, flow simulation, transport simulation, risk analysis and inverse modelling. The code is a result of a WRC project and has been applied by many professionals in South Africa.

Difficulties experienced in dolomitic aquifers are to simulate the flow of springs and get fast responses of water levels after periods of recharge, and to obtain good correspondence with observed water levels during validation over an extended period (Bredenkamp and Nel, 1997). This is probably due to the fact that the AQUAWIN is a 2-dimensional model and cannot accommodate heterogeneous flow occurring at depth. However both 2 and 3-dimensional flow could be incorporated by MODFLOW, but assigning realistic parameter values with depth would be difficult.

For numerical (conceptual) modelling, the following additional data are required: hydrogeological boundaries of a geohydrological region, proposed abstraction rates, and existing abstraction rates within the region.

Numerical model

1. Use the MODFLOW program to build a conceptual model to calculate the interaction between groundwater and surface water.

2. Calculate the water balance of the study area, from which to obtain the potential groundwater reserve.

Methods for determining the amount of water being used by vegetation

Setting Resource Quality Objectives (RQOs)

The reason of this step is to set objectives for the maintenance of the groundwater level and piezometric head, their rates of change, and water quality, which will maintain the integrity of the aquifer as a water resource and meet the needs of groundwater-dependent ecosystems. The latter will include the requirements of the other components of the reserve: aquatic systems (in rivers), wetlands and estuaries where appropriate and where these components also depend on groundwater.

It is clear from the description above that RQOs can include any requirements or conditions that may need to be met to ensure that the water resource is maintained in a desirable and sustainable state or condition (MacKay, 1998a).

Aspects to be addressed by RQOs:

- a significant drop in groundwater levels;
- deterioration of water quality either by saline intrusion, induction of poorer quality water from adjoining aquifer and/or contaminated water;
- increased risk of sinkhole formation in dolomites;
- negative impact on spring flow;
- negative impact on river flow;
- negative impact on riparian vegetation; and
- negative impact on vegetation (dependent ecosystems).

The confidence level of the reserve quantification is dominated by at least two factors, namely the quality and quantity of the input data such as hydraulic conductivity, transmissivity, recharge rate, specific yield and storage coefficient.

The MODFLOW model is favoured and will be applied to simulate of all five groundwater units as one entity, if approved for the next phase (DWAF – private communication with Jaco Nel). Modelling of the entire region would have the following advantages:

- It would clarify uncertainties regarding the significance and impacts of flow through dykes that have subdivided the dolomite into different compartments, and the total water balance and drainage of the system would be examined.
- Hopefully the flow of springs could be simulated reliably and not, as in the case of the AQUAWIN model, by substituting points of variable abstraction for springs. In MODFLOW the springs would be introduced as drains at the respective nodes.
- By means of MODFLOW either a 2 or 3-dimensional model could be tested.
- There are sufficient data to model the system effectively.

- As is evident from Fig. 3.5.1 there are adequate monitoring points of groundwater levels available in the Grootfontein and Lichtenburg groundwater units, fewer but fairly evenly-spread observations in the Zeerust area, and few but widely spread water level data in the Marico and Ventersdorp units.
- Good records of spring flows are available for the all the units except the Marico groundwater unit. Springflow records have been simulated from levels of the Wondergat, but they have been affected by pumping. All spring discharge records would therefore have to be re-simulated. This would allow a good approximation of the natural flow records to be obtained for the period 1923 until the present time using the CRD/MA methods and corrected values of the Wondergat as reference.
- Reliable estimates of recharge could be obtained by means of the chloride method, and monthly rainfall data are available from the Weather Bureau.

8.3 Cumulative departures from the average rainfall (CRD) and moving average rainfall (MA).

Mathematical formulation and related aspects

The CRD and MA methods represent a simple lumped model of the groundwater balance and allow aquifer characteristics and components such as i) recharge or storativity, and ii) the impact of abstraction or iii) the natural response to different series of rainfall, to be determined. The CRD series is represented by the mathematical relationship:

$$ {}^{m}_{n}CRD_i = \frac{1}{m}\sum_{j=i-m+1}^{j=i} Rf_j - \frac{k}{n}\sum_{j=i-n+1}^{j=i} Rf_j + {}^{m}_{n}CRD_{i-1} \qquad \text{(8.3.1)} $$

Where m = the short-term memory of the groundwater system, n = long-term memory of the groundwater system, k is a coefficient incorporating abstraction $\{k=1+Q/(A \times Rf_{av})\}$ where Q = the abstraction, A = the area of the aquifer and Rf_{av} = average rainfall. There is a linear relationship between groundwater levels and the CRD series:

h_i = a.CRDi + C .... (8.3.2)

where

h_i = the groundwater level for month i

a = proportionality constant, representing the unit response of water levels per mm of recharge, which could be derived from the regression; and
= b/S where b is the recharge coefficient and S the aquifer storativity.

C = the regression constant representing the average depth of the water level below surface.

If, according to the regression k>1, which indicates that pumping or an external impact has affected the water levels, the natural water levels could be simulated from eq. 8.3.1 by setting k=1.

The MA relationship which yields equally good simulations of water levels could be represented by the equation:

$$h_i = \frac{a}{n} \sum_{j=i-n+1}^{j=i} \left(Rf_j - d \right) + C \qquad (8.3.3)$$

where a = b/S, n = the number of months, d = Q/A, and A = the effective aquifer area from which the abstraction Q is taking place, and C = the maximum water level below surface (i.e. $Rf_j - d = 0$) and hence represents the depth of the aquifer below surface.

In the case of natural groundwater levels both the CRD and MA methods mimic the levels quite well, as are indicated by Fig. 8.3.1 and 8.3.2 for borehole C3N021.

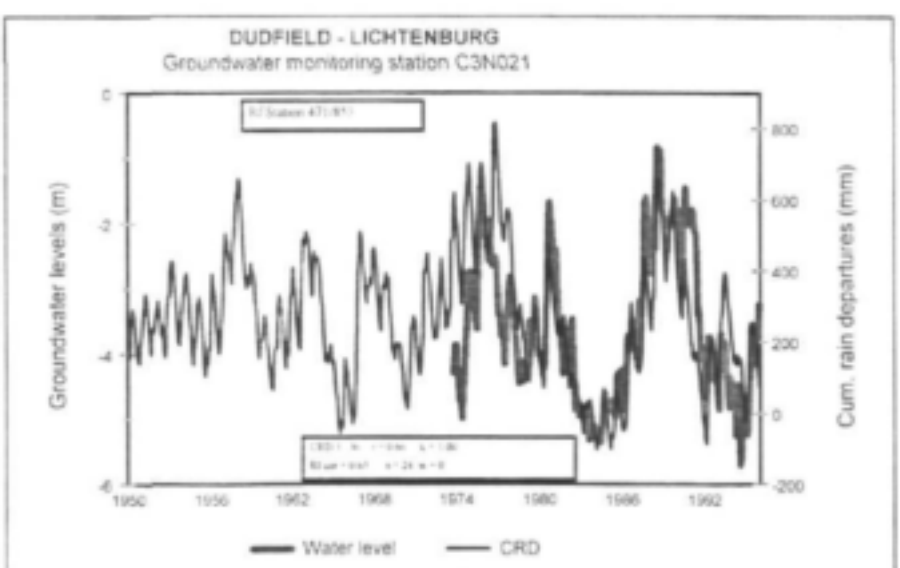


Fig. 8.3.1 Correspondence between the groundwater levels and the CRD series.

It is of particular significance that the effect of abstraction on the water levels is manifested as a reduction (=d) of the loss component (= Rf_{av}) and therefore only a fraction (a=b/S) of the abstraction would cause a change in the groundwater level. (See eq. 8.3.2 and 8.3.3). It is for this reason that some surplus water could be available for irrigation, but only for as long as the groundwater reserve is not exceeded, as the pumping would still negatively influence the water levels. More effective utilization of the aquifer will only be possible during periods of high recharge, but during periods of droughts probably only basic needs could be satisfied and very little irrigation.

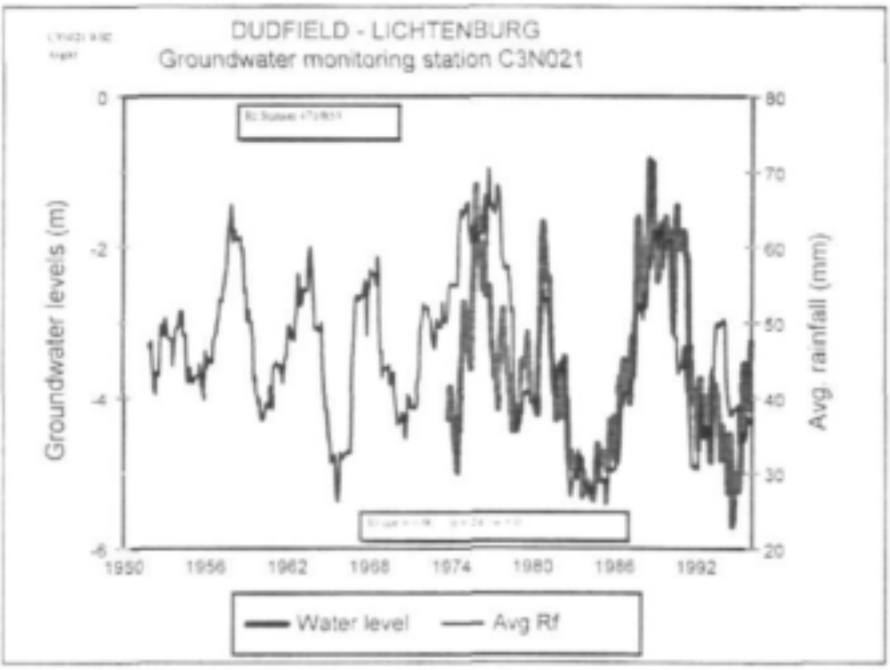


Fig. 8.3.2 Correspondence between the groundwater levels and the moving average rainfall (MA) over 24 months.

The CRD and MA series can also be used to simulate impacted or natural spring flows (Bredenkamp et al. 1995) and Bredenkamp (1999). The CRD and MA series emphasize the importance of monitoring and maintaining rainfall measurements. Monthly observations of water levels and of rainfall are sufficient and would reduce the cost of monitoring. The collected rainfall water should be used to determine its chloride concentration.

A range of applications of the CRD and MA series to hydrological interpretations and problem-solving has been presented in the guide (Bredenkamp, 1999). Fig. 8.3.3 shows the excellent comparison between groundwater levels and CRD series applied to the first part of the record of groundwater levels of borehole GN41 in the Grootfontein compartment. The effect of abstraction is indicated by the subsequent deviation from the simulated natural levels.

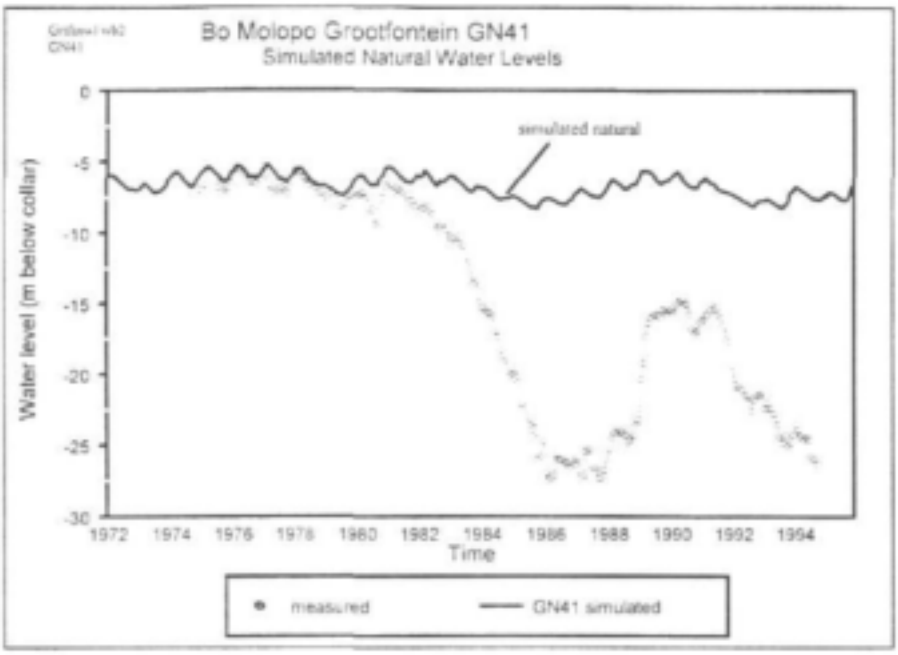


Fig. 8.3.3 Comparison of measured water levels affected by pumping and the simulated natural water level fluctuations derived by means of the CRD series.

A similar situation is evident from the record of borehole BB 35 situated fairly close to pumping at the Grootfontein eye (see Fig. 8.3.4).

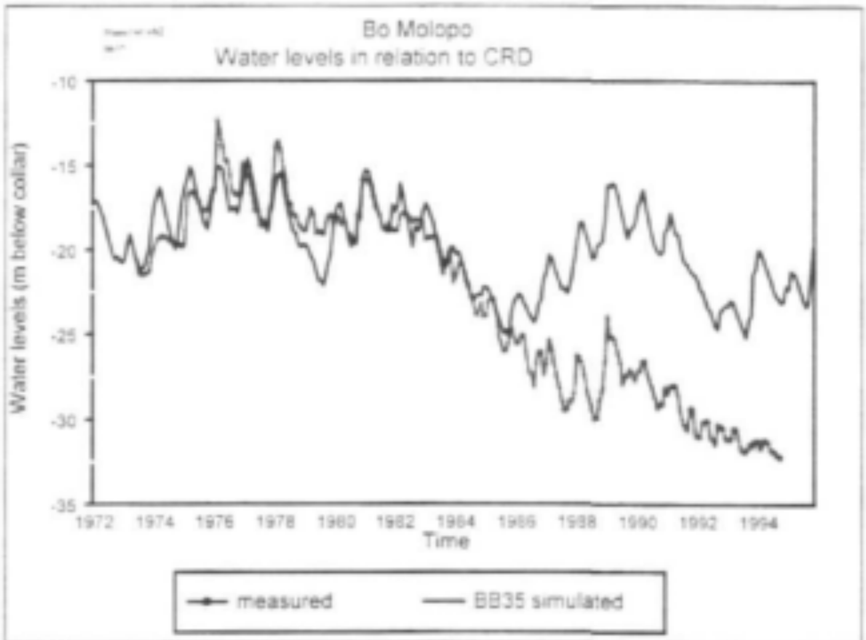


Fig. 8.3.4 Water level of borehole BB 35 in relation to the natural water level fluctuations derived from the CRD series.

Fig. 5.1.1 shows the effect of abstraction on the flow of Molopo eye implying that the levels of the Wondergat have also been affected by pumping. The inverse of the CRD series (i.e. minus CRD) has also been shown to correspond to fluctuations of the water quality as reflected by sulphate concentrations (see Fig. 8.3.5).

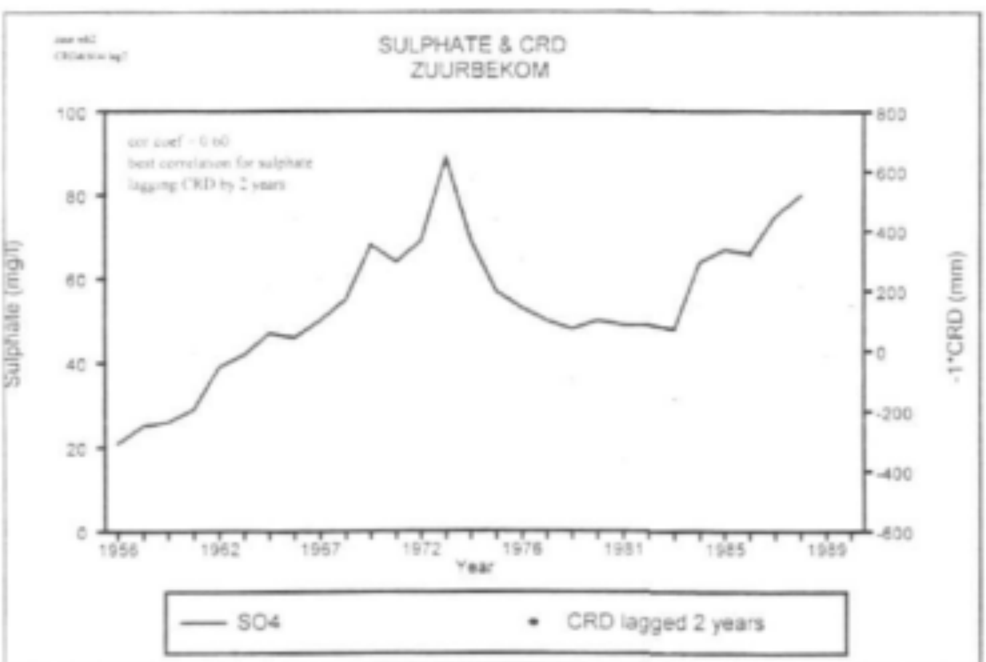


Fig. 8.3.5 Inverse correspondence between the CRD and sulphate concentrations.

The CRD and MA methods have not yet been thoroughly assessed as a means of predicting the water-level variations in an aquifer, but practical application would entail the following:

1) It would be necessary to select the most appropriate parameters (m,n and k in the CRD equation and n and d in the MA equation) which should then be used to mimic the water-level fluctuations under natural conditions. If some water-level data are available (even intermittent measurements over a period of time) and a reasonable match can be obtained with the CRD series, the latter could be used to simulate the water-level responses.
2) To predict natural groundwater level fluctuations from the CRD equation requires rainfall data covering not only the same period as the water-level records but also the preceding period. A record extrapolated from a nearby rainfall station could be used if local data are not available or if gaps in the record have to be filled by data generated stochastically.
3) The natural response of the groundwater levels over extended periods could be obtained using various sets of rainfall records that have been generated stochastically. Subsequently the range and extent of the variations of the water-levels could be analysed using probabilistic methods, which would allow the severity of the water-level declines to be determined relative to some selected critical limit e.g. the recurrence interval of exceedance, or the duration for which the defined limit is exceeded.
4) The water-level response in the case of exploited aquifers can be determined by adjusting the CRD reference value by increasing the value for the long-term memory Rf_{av}, even without knowing the area of the aquifer. If the areal extent of the aquifer is known, the abstraction can be converted to an equivalent depth of precipitation, which has to be incorporated in the k-factor. The margin by which this coefficient deviates from 1 determines the cumulative effect that would be induced by the artificial abstraction over a period. The effect of pumping (Q) on the groundwater levels could be simulated by inserting a value for k ($= 1+Q/A.Rf_{av}$) in the CRD equation, or d ($= Q/A$) in the MA equation. In this way it is possible to examine the impact of different rates of abstraction on the groundwater levels in a simple but effective manner. With regard to the effect that lowering the water levels would have on the springs, wetlands and ecology, the regional natural level of 1410,5 mamsl of the Wondergat has proved

to be the stage at which all springs in the area would stop flowing (see Fig. 3.3.2). This level is equivalent to a water level decline of almost 6m below the average groundwater level of any compartment sustaining spring flows. If this level were regarded as the ultimate ecological limit of the groundwater level there would probably be an S-type relationship to describe the impact of water levels on the ecological components. First there would be an exponential improvement of ecological conditions from the base level (although the spring flows would increase only linearly) up to the average groundwater level of the aquifer, and for higher levels the improvement of the beneficial effect would gradually decline. The inverse relationship would apply if water levels were to decline instead of rise. A linear relationship between the water levels and the ecological impact could also be assumed. It is for the ecologists and biologists to define the relationship.

This S-type relationship could be incorporated in the hydrodynamic model and could even be extended to yield relationships for individual ecological parameters and species.

8.4 Sustainability of borehole yields determined by pumping tests

It is most important for local communities that the yields of their production boreholes be sustainable in the long-term. Assessing by how much the sustainable yield will be reduced if other pumps nearby also operate is equally important.

Pumping tests are usually performed on boreholes to determine the rates of abstraction and characteristics of the aquifer using standard methods of interpretation. However by means of improved new software (Xu, 2001) based on an extension of a study by Van Tonder and Xu (2000) it is not only possible to determine S and T by interactive simulation of the drawdown curve, but also to obtain the maximum sustainable yield of the borehole at different levels of assurance.

This software could easily be applied to all boreholes that have to be tested after drilling, or to re-testing them from time to time e.g. when water levels have been affected by drought or nearby pumping.

9. KEY ISSUES TO BE ADDRESSED IN THE MANAGEMENT STRATEGY -- CONCEPTUAL APPROACH

9.1 General procedure

Introduction

Certain basic information will be required by whoever is to be responsible for the management of the groundwater resources of the North-West dolomite. From an institutional perspective the delineation of the sub-units within which the area forming geohydrological entities could be managed effectively, has to be accomplished. The five groundwater units that have been demarcated according to existing information and perceptions of the groundwater flow, are merely provisional subdivisions. Key issues are whether

1) the groundwater units as delineated at present have to be the basis for the establishment of WUAs; and whether
2) preliminary boundaries selected according to the geology, which fail to coincide with surface drainage catchments, need to be shifted so as to achieve more effective control in terms of administration and policy making. Even if some local farm boundaries were to transgress into different CMAs, groundwater units could be accommodated without serious complications. Such transgressions would be the exception and are not a high priority at this stage. However the delineation of the macro groundwater units is a preferential priority.

Any decisions regarding the groundwater WUAs and allocation of groundwater permits are closely related to

1) reliable estimation of the exploitation potential of the groundwater resources of the total area of investigation;
2) the natural drainage, which is to be established from the overall groundwater piezometric contours;
3) the extent to which the groundwater level contours have been affected by pumping;
4) the influence of bounding dykes, the major fault, and formation contacts on the groundwater flow.

It is therefore of critical importance to derive the piezometric contour map of the entire region under study. This would entail

i) close scrutiny of all groundwater levels measured at monitoring boreholes;

ii) establishing by means of the CRD and MA methods if the water levels are representative of natural conditions or have been affected by abstraction;

iii) quantifying (as equivalent depths of precipitation) the impact of abstraction, if that is present, by means of the CRD and MA methods;

iv) removing the stress factors and simulatinge the natural response of the aquifer.

From the natural water levels at a specific date the regional piezometric contours should be drawn and the drainage of the groundwater be inferred. The groundwater drainage should be towards natural points of outflow i.e. springs, river, wetlands and leakage across certain geological boundaries e.g. the Black Reef Formation to the south of the area.

A survey of collar elevation of those boreholes for which this information has not yet been obtained should be conducted as a matter of great urgency in Phase 2 of the project. It is important that the survey should extend slightly beyond the boundaries of the area of investigation. The collar elevations of monitoring boreholes in the Zeerust, Grootfontein and Lichtenburg/Itsoseng areas have been surveyed but not those of the Grootpan and Ventersdorp groundwater units. It is important that the elevation of the point, from which the water levels of the Wondergat are being measured, also be surveyed accurately. The outflow heights of the springs should also be determined and at the same time water samples from the springs should be taken for chloride analysis.

Overall groundwater balance

The natural groundwater drainage map used in conjunction with the flow of the springs, would assist in the delineation of the recharge areas of the different springs, in the following way:

a) The natural flow of the eyes would have to be obtained by means of the CRD and MA methods, or in relation to the water levels of the Wondergat, after correction of the Wondergat levels for the impact of abstraction.

b) The natural flows of the springs for the same date as that used to draw the piezometric contours should be used by incorporating the recharge (determined by means of the chloride method) and the areas that feed the springs. The sizes of the recharge areas could then be compared to the areas delineated according to the flow lines derived from the piezometric map and drainage to the springs. If the recharge areas are smaller than the drainage areas, the flow measurements of the springs are probably too low. If the theoretical recharge areas are bigger than the areas inferred from the drainage map the possibility of leakage/overflow from higher lying compartments should be investigated; alternatively the recharge could be higher. Leakage through bounding dykes could also contribute to the spring flows. The total flows of the springs in comparison to the total recharge over the entire area would indicate the extent of diffused losses in the form of leakage or evapotranspiration from the aquifer via trees and other vegetation.

c) The role of the dykes and of the fault traversing the dolomitic area should be examined closely to establish from the step in water level across a dyke, whether it acts as a boundary or not.

Assessment of the impact of abstraction has to be based on the following:

a) the deviations from the natural status as indicated by the CRD and MA relationships with observed groundwater levels;

b) the piezometric map that has been based on the actual measured water levels, to ascertain if it indicates cones of depression affecting outflow from the area;

c) the difference between the natural and contours affected by abstraction, represented as a saturated volume fluctuation. This difference could be converted to a volume of water by means of the storativity of the aquifer and the area should correspond to that where pumping is most intensive.

The natural piezometric contour map would provide the natural reference levels for calibrating of the hydrodynamic model needed to simulate the interactions between recharge, abstraction, spring flow, evapotranspiration losses and the recharge to the total area under investigation.

Allocation of water

The allocation of water to the different users on an equitable basis is difficult, as it has to ensure the integrity of the aquifer and more particularly sustain both the aqueous environment and long-term utilization of the resource. To quantify the basic water demands according to an allocation per capita is straightforward, unlike the assessment of the water requirements, and impacts on the aqua-ecosystems due to declining water levels. The relationship between the flow of the springs and the water levels of the Wondergat indicate that all springs would stop flowing if the water levels of the Wondergat were to diminish to 1411 mamsl (see Fig. 3.3.2). This does not imply that there is a direct connection between the Wondergat and the flow of the springs, but that the water level series of the Wondergat is a regional indicator of the relative fluctuations in other dolomitic compartments as well. The Wondergat level has never reached the critical value of 1411 mamsl under natural conditions even during the most extreme droughts, but abstraction could lower the water levels to that level. The crux of the matter is to be able to quantify the environmental impact of the lowering of groundwater levels. This is an aspect requiring further research in Phase 2 of the project. The groundwater levels at which the different springs would stop flowing should signify a worst-case scenario; the effect would be insignificant if the average groundwater levels could be sustained. An exponential-declining-impact relationship between the general water levels in the recharge area determining the spring flows could be used to scale the environmental impact.

Proposals by Van Tonder and Dennis (2001) with regard to basic water balance approaches to estimate of the impact of declining water levels on the environmental components should also be examined and tested.

9.2 Groundwater modelling

General

It is inevitable that the aquifers would have to be modelled to achieve effective management of the system. Such a model should incorporate all components impacting on the groundwater balance. In the case of the dolomitic aquifers it appears that two-dimensional models (e.g. AQUAWIN) have not provided very good simulations of spring flows and water level responses. This could have been due to inaccurate water levels and spring flow data used to calibrate the model. In Phase 2 of the project MODFLOW (a finite difference model) should be applied as it could be used for both 2 and 3 dimensional modelling. A 3-dimensional model would be more suitable for simulating extremely heterogeneous aquifers as is the case with dolomites.

In addition, the application of the CRD and MA methods should be evaluated as simple though effective means of simulating the response of the aquifer to fluctuations in rainfall and abstraction. The usefulness of the methods in dolomitic aquifers has been proven in the case of springs and for individual boreholes, but for the simulation of an entire aquifer it has not been tested. It is envisaged that the methods could be used to establish the impacts of all pumping by superimposing the impacts at specific points where water levels and spring flows have been measured. If successful the CRD and MA methods could be developed into a simple yet extremely useful simulation technique that would work in heterogeneous aquifers such as the dolomite.

Data requirements of aquifer models

The following data inputs would be required to model the entire dolomitic area that is being studied:

1) time series of groundwater level fluctuations at observation boreholes representing either
   - the natural status of the aquifer that could be checked by the CRD and MA methods; or
   - the measured groundwater levels which have been affected by abstraction;
2) the recharge of the aquifers as determined by
   - the chloride method applied to spring waters;
   - the saturated volume fluctuation method (SVF method);
   - the outflow of springs during recurrent events of equal flow;
3) water abstraction from the area according to pumping rates and irrigation scheduling;
4) monthly rainfall data for the area, obtainable from official monitoring stations of the Weather Bureau.

It is also recommended that the water abstractions derived from the irrigation of crops and areas under irrigation be checked against estimates of abstractions derived by the CRD and MA methods.

Representativeness of monitoring points

The extent to which the groundwater level monitoring stations adequately represent the integrated response of the aquifer to many controlling factors has to be evaluated with the view to determining

- if and where additional monitoring points have to be established;
- the effect on the reliability of assessments if some of the monitoring boreholes were to be closed.

By means of a dynamic model the quantities of water could be assessed that could be reallocated for abstraction, whether for domestic, municipal or irrigation use. Thus the modelling of the dolomitic system, either in its totality or as individual units, for different scenarios of input and abstraction is important. To model the total aquifer would involve a great deal of work to prepare the data, but once that has been completed the compilation of the model e.g. grid elements and assigning values to the nodes would be fairly straightforward. However calibrating the model could be time-consuming as it would involve interactive manipulation of parameter values and assessment of the degree of fit between observed and measured water levels and outflow of springs. If parameter optimization were to be used it would require long runs of computer time, and initial values assigned to parameters would have to be fairly spot-on to reduce computer simulation time and obtain realistic simulations.

The problem of WUA boundaries not corresponding to the CMA boundaries can only be addressed once the regional flow of groundwater has been established from the piezometric contours. This would require that the collar elevations be resurveyed using accurate GPS instruments. At the same time the water levels should be measured. The resurveying is a matter of high priority.

10. CONCLUSIONS AND RECOMMENDATIONS

The main objectives of the desk study have been achieved and available data and information relating to the delineated groundwater units of the dolomite contained in previous reports and surveys of different areas within the delimited area of investigation have been examined. The following are recommended:

1) Simulation of all five groundwater units by one overall model should be considered in order to minimize uncertainties regarding the flow between different sub-compartments. A MODFLOW finite difference model that could incorporate 2 and 3-D modelling of the aquifer appears to be the most suitable model to use. By changing the transmissivity of the dykes it could be ascertained if they play a significant role in the drainage of the groundwater. The proposed modelling of the entire dolomitic area would indicate if the water level observations are reliable and sufficient to calibrate the model; and if this is not the case the network of monitoring points should be increased. The integrity of the water level data should be checked by means of the CRD and MA methods which could also be used to simulate the aquifer's response to abstraction in terms of the saturated volume fluctuation over the entire aquifer.

2) Water sampling for chemical analysis of borehole water from production boreholes should be carried out twice per year but is not a high priority at this stage as little evidence of pollution has been detected thus far. However, chemical analysis of the spring water should continue, as not only would it help to detect pollution but the chloride concentrations could be used to determine the recharge. Water samples of rainfall would have to be collected for more reliable estimation of the chloride input.

3) Rather infrequent inspections of aqua-ecosystems would be required if the water levels at these points do not decline much.

4) For the purpose of optimizing the management of these aquifers it is necessary to formulate relationships between the water level responses and ecological impacts, and specify response-criteria which should not be exceeded.

5) It is of critical importance that the use new software for the interpretation of all pumping tests be applied. It could be considered to test all production boreholes by means of the latest techniques. This would not only yield estimates of aquifer storativity and transmissivity, but also the maximum sustainable yield of a borehole, with or without interference from other boreholes in close proximity. This is in many instances of greater practical value to local communities than to know what the general water decline due to abstraction is.

6) Awareness of problems and conditions related to groundwater pollution should be propagated amongst all users. Distribution of the Handbook of groundwater quality protection for farmers is recommended (CSIR Environmentek, 1999).

7) The selection of a database that could be used to assimilate all the information to be collected, and to store it in an organized way, is strongly recommended. The suitability of the WISH database has to be evaluated.

8) In view of the fairly advanced level of technical input and methodology required to assess the impact of different scenarios of abstraction and recharge, WUAs and even higher levels of management would for some time have to rely on technical support by qualified geohydrologists.

There is very little information on these groundwater-dependent systems, and studies are urgently needed to obtain more detailed information regarding the water resources being used by the vegetation, and the nature and extent of groundwater dependence.

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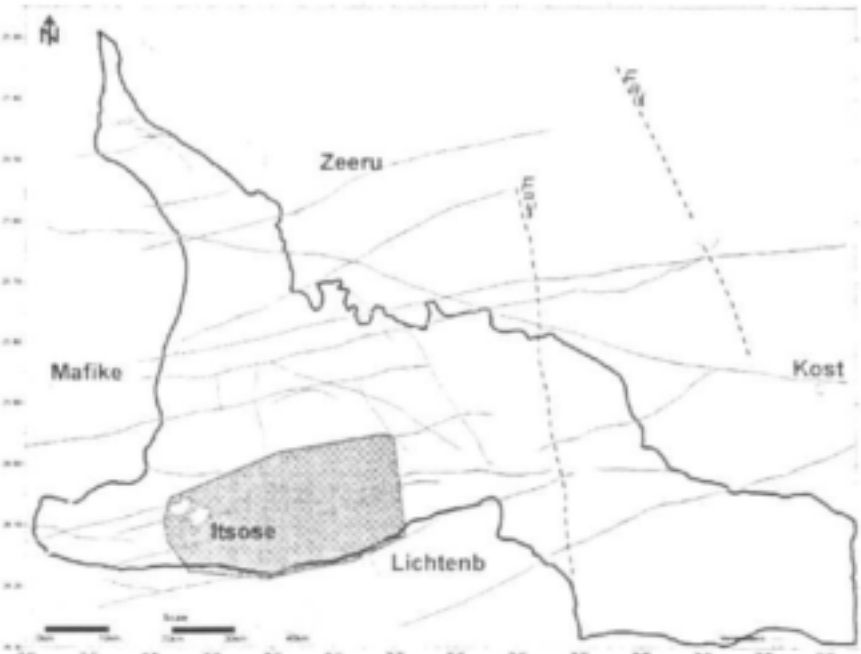
ANNEXURE 1

Geohydrological studies

Comprehensive geohydrological studies have been carried out in parts of the groundwater units. The different areas that have been studied are shown in corresponding figures that are inserted with the text.

1. Lichtenburg-Itsoseng area



One of the most comprehensive investigations is a study carried out by Taylor (1983), and a borehole survey covering an area of 500 km^2 that entailed the following:

- compilation of piezometric maps;
- assessment of recharge and aquifer storativity;
- studying limited spring flow records and groundwater drainage,
- limited geophysical surveying to detect dykes and identify drilling sites to reveal the geology and compartmentlization of the aquifer;
- drilling of several exploration boreholes;
- pump-testing to establish yields and derive aquifer characteristics.

From the study, statistics of boreholes in the Lichtenburg area have been obtained (see Table1).

Table 1. Information on boreholes in the Lichtenburg area (after Taylor 1983).

Number of boreholes	% of total boreholes pumped	% of total abstraction	Area under irrigation (ha)	Volumes Pumped ($10^6\ m^3/a$)
Pumped				
Highly productive ones	17	100		
Used for irrigation	56	13	790	6,5
For municipal use	23	3		2,6
For industrial use	14	1		1.6
Domestic and stock use				0,8
Total				

The abstraction volumes derived by Taylor (1983), were obtained from the different consumers, but the irrigation component was based on information supplied by the farmers and irrigation schedules, pumping rates and hectares under irrigation

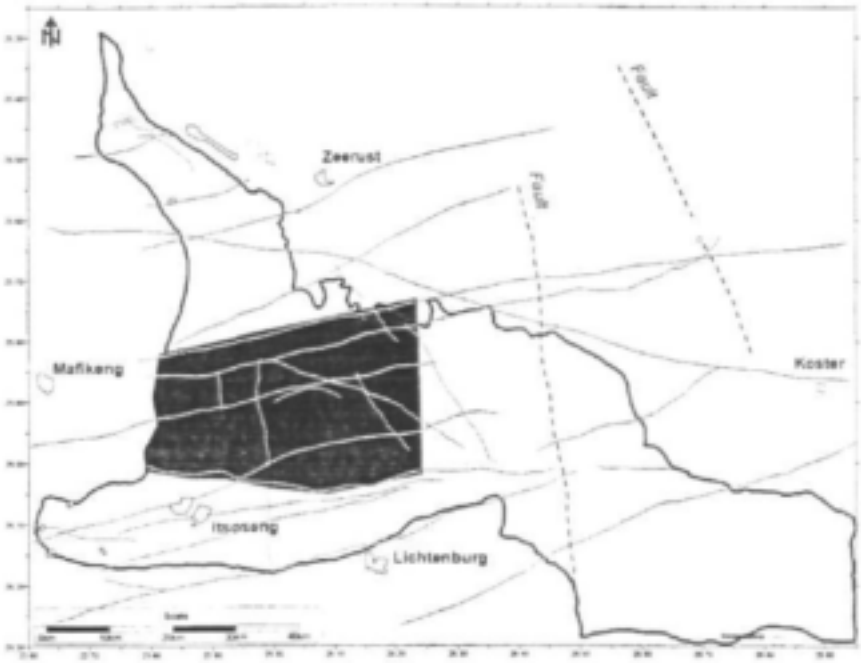
Spring flows

Ten springs issue from the area with an estimated yield of about $8x10^6\ m^3$ per annum for the period 1981-1983 (Taylor, 1983), based on limited measurements carried out on 8 springs. As these flows were derived after a period of good rainfall, they are not representative of the average annual discharge of the springs. A full time series of monthly flows would have to be obtained from a relationship between the existing flow data and the corresponding levels of the Wondergat.

2. Itsoseng-Polfontein in the Ditsibotla District of Bophuthatswana

In the Itsoseng area geohydrological studies have been carried out by Partridge Maud and Associates (1990), with a view to augmenting the water supply of Sheila-Itsoseng and the settlement around Polfontein eye. The exploitation potential of the aquifer and the effect of abstraction on the flow of the Polfontein eye have been determined by Bredenkamp (1992) based on a relationship between the flow of a spring and the water level of the Wondergat. Accordingly the flow record could be simulated back to 1923. Clear evidence has been obtained that the flow of the Polfontein has been affected by pumping in the area that supplies the local townships and settlements with water.

3. Extended Grootfontein area



A number of sub-compartments bounded by dykes are enclosed within the boundaries of the extended Grootfontein groundwater unit that has been delineated as one of the groundwater entities to be controlled and managed by a WUA. Several springs also issue from this unit, one of which is the well-known Grootfontein eye – a main source of the water supply of Mafikeng. According to surveys and hydrological studies the recharge area of the spring has been delineated at about 169 km^2; and has been the focus of many studies to determine recharge and the storativity of the aquifer. It is not practical to summarize all aspects related to the present project but a list of the relevant studies and aquifer parameters that have been quantified, appears in Table 3.

Bredenkamp (1996) has estimated the abstraction for irrigation from boreholes in the Grootfontein area based on a linear relationship established between the pumping and the average rainfall over the preceding 12 months.

Groundwater levels

Groundwater level monitoring points have been established as part of geohydrological studies that have been carried out in the different areas. The distribution of the monitoring stations is indicated in Fig. 3.5.1. and water level observations have been interpreted in different ways to obtain the characteristics of the aquifers. The contours of groundwater levels relative to sea level indicate the drainage pattern that for most aquifers conforms to the topographical drainage. This is not necessarily the case in dolomitic aquifers. The groundwater levels are mainly controlled by the recharge and transmissivity of the aquifer. The groundwater level gradient increases if the transmissivity is small and becomes flatter where transmissivities are higher. Steeper gradients also occur if the groundwater flow is obstructed as by a diabase dyke or decreasing thickness of the aquifer e.g. wedging out of the dolomite thickness on the edges of the basin. A sharp drop in groundwater levels normally indicates the presence of a dyke. However when the water levels have been drawn down appreciably the dykes could act as impermeable boundaries and have a significant impact on the exploitation of water.

Groundwater recharge and aquifer storativity

Recharge of the groundwater is of critical importance to the long-term exploitation of the resource and is difficult to determine reliably because of recharge, abstraction, evapotranspiration and lateral flow all simultaneously affecting the groundwater level response. For this reason estimation of recharge from water balance studies requires simplifying assumptions. For example, recharge is equal to the abstraction during periods of equal volume and could be related to the corresponding rainfall. (Bredenkamp et al. (1995) have compiled a manual on the estimation of recharge and aquifer storativity using a variety of methods that have been developed as part of studies of the Grootfontein dolomitic aquifer. These included water balance studies and analysis of chloride and tritium profiles of the unsaturated zone. Storativity is usually determined by means of pumping tests but these have proved not to be representative of a fractured/cavernous aquifer such as the dolomite (Bredenkamp et al., 1991).

Recharge has also been derived from the ratio of the chloride concentrations of the rainfall to that of the spring water (chloride method), or from the average flow of a spring in relation to the recharge area (Bredenkamp et al., 1994).

The abstraction volumes derived by Taylor (1983) were obtained from the different consumers, but the irrigation component was based on information supplied by the farmers and on irrigation schedules, pumping rates and hectares under irrigation

Spring flows

Ten springs issue from the area with an estimated yield of about $8x10^6$ m^3 per annum for the period 1981-1983 (Taylor, 1983), based on limited measurements carried out on 8 springs. As these flows have been derived after a period of good rainfall, they are not representative of the average annual discharge of the springs. A full time series of monthly flows would have to be obtained from a relationship between the existing flow data and the corresponding levels of the Wondergat.

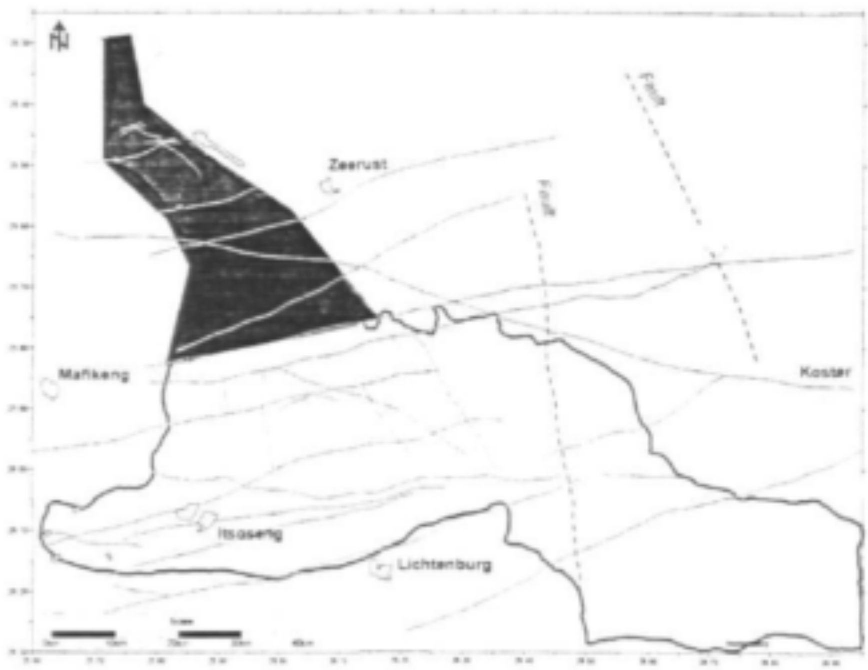
Table 3. Relevant information obtained from various studies in the North-West dolomitic area.

Reference	Storativity	Recharge mm/a	Comments
Recharge of a dolomitic aquifer as determined from tritium profiles (Bredenkamp et al., 1974)	0.03	25 – 35	Recharge underestimated
Initial simulation of the Grootfontein aquifer (Cogho et al., 1982)	0.025 – 0.05	46	Recharge derived from simple soil moisture model Cl, SVF and DPEM methods
Estimation of the Zeerust/Rietpoort groundwater model (Botha, 1993)		22-123	Highly variable soils
Chloride profiles in soil cover (Bredenkamp, 1993)	0.023		SVF method
Simulation of Grootfontein compartment (Bredenkamp et al., 1987)	0.009 - 0.013		
Grootfontein – Bo Molopo aquifer (Bredenkamp, 1999)		49	Interpretation of hydrographs CRD method

Water abstraction fluctuates depending on the rainfall cycles but has shown a steady increase from about 4 mil cub m/a in 1964 to almost $11x10^6$ m^3/a in 1991/2. The latter figure exceeds the estimated average annual recharge of $8.4x10^6$ m^3/a and has caused water levels to diminish.

Abstraction from the Grootfontein area to supply Mafikeng has increased drastically from about 1 mil cub m/a in 1967 to $5x10^6$ m^3 /a in 1994. However, it has fluctuated proportionally to the annual rainfall over the preceding 12 months (Bredenkamp, 1996b) – see Fig. 4.1.

4. Zeerust groundwater unit



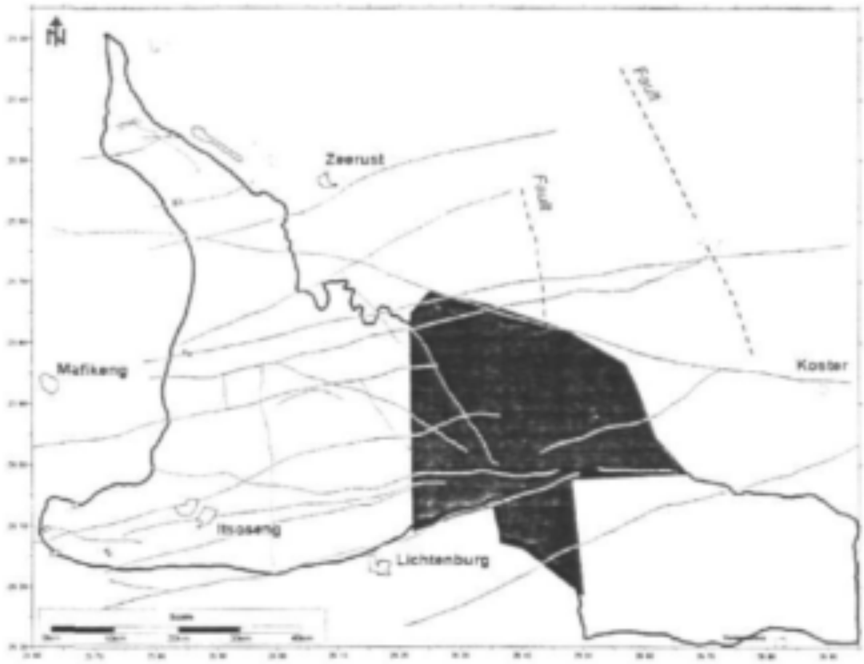
This unit is of great importance as groundwater is the only available source to supply Zeerust with water. The town's water consumption was about $1.4x10^6 m^3$ in 1978 and has been fairly constant at about $2.6x10^6$ m^3/a from 1983 to 1995 (Bredenkamp and Nel, 1997). Apart from borehole censuses that were carried out, several geohydrological studies have been conducted within the area in connection with the supply of water to the Zeerust and the Dinokana/Lehurutse townships. (Partridge, Maud and Associates, 1992). The main focus has been to estimate recharge and determine aquifer characteristics as well as to estimate the impact of proposed abstraction on the flow of the springs.

The following groundwater investigations have provided useful technical information on the geohydrology of this groundwater unit:

Bredenkamp and Zwarts (1987), Botha (1993), Theron (1989)

and Partridge, Maud and Associates (1992 and 1995).

5. Groot Marico groundwater unit



The Groot Marico compartment was surveyed as part of an extensive geohydrological investigation of the Malmani Subgroup dolomitic aquifers by Polivka (1987) to evaluate the water-bearing properties of the dolomite. The survey covered an area of about 1500 km^2 and over 850 boreholes were included. The most representative morphological features of the area are sinkholes, smaller valleys, and pans like the Grootpan. In the western, central and south-western part of the study area brecchiated quartz veins occur.

The geology is similar to that of the other regions in that the Monte Christo and Eccles dolomitic formations are the most productive groundwater areas. The occurrence of groundwater in the different dolomitic formations is indicated in Table 5.1.

As in the other units diabase dykes traverse the dolomite and subdivide the dolomite into smaller compartments that interact when water levels are high but could act as separate units if the dykes restrict the inflow and outflow.

A piezometric map has been compiled by Taylor. The general gradient of the groundwater conforms to the topography. Monitoring boreholes have been established in the area, but records do not extend over a long period and have not been analyzed in relation to rainfall or interpreted by means of the CRD and MA methods to derive aquifer characteristics.

Table 5.1 Boreholes and yields in relation to the geological formations in the Groot Marico area (after Polivka, 1987a).

Dolomitic Formation	Average yield in l/s	Number of boreholes
Frisco	39,4	20
Eccles	17,9	89
Lyttelton	21,6	18,8
Monte Christo	18,8	73
Oaktree	12	45

Groundwater Use

According to information obtained from the farmers, 3482 ha are being irrigated. This represents an annual abstraction of $44,6x10^6$ m^3/a. However, based on irrigated land and crop water requirements the abstraction is estimated at $28x10^6$ m^3/a, indicating that 50% excess irrigation is being practiced, or that the farmers have claimed higher allocations than the actual irrigation use. Irrigation represents about 95% of the total consumption of water and only 5% is used for stock watering and domestic use.

Groundwater Potential

The recharge of the area has been assumed to be 13% of the rainfall, based on regional rainfall/recharge values. The same recharge percentage has been derived from the Cl method. Several springs issue from this unit and are listed in Table 5.2.

The flow of the springs has not been monitored regularly, but has been measured during the study or has been estimated from the recharge and the sizes of areas feeding the springs.

Table 5.2 Farms and springs with estimated annual flows.

Springs and Farm names	Estimated annual Flow in $10^6 m^3/a$
Rhenosterfontein	
RN 11	0,015 (occasionally dry)
RN 12	0,045
RN 22	0,126
RN 23	0,126
Rietspruit	
RT 1	2,37
Rhenosterhoek	
RK 5	0,22
RK 7	3,07
Grootfontein	
GF 21	13
Duikerfontein	
DN 22	1,26
Bronkhorstfontein	
BN 15	0,13
Bokkraal	
BK 21	0,90
BK 22	1,4

6. Schoonspruit dolomitic groundwater unit

Survey by Polivka

Polivka (1987b) carried out a geohydrological study of the area covering about 1900 km^2 and 1200 boreholes. Maps showing the geology, dykes, positions of high abstraction and the extent of irrigation have been prepared. An attempt to draw a map of the groundwater drainage failed due to the inaccuracy of the collar elevations of the monitored boreholes. Borehole yields in relation to the geology have been examined, and have indicated that the Eccles and Monte Christo Formations have higher yielding boreholes than the Oaktree and Lyttelton Formations.

The geology is similar to that of the other areas and several dykes also traverse the dolomite to form sub-compartments. A few quartz veins occur in the area and probably act as barriers rather than being a preferential zones of water flow. The prominent fault running from north to south shows an abrupt fall in groundwater levels on the western side. This indicates that the fault acts as a partial boundary rather than as a conduit of high flow.

Several springs rise in the area, of which the Schoonspruit eye is by far the most productive. It has an estimated average flow of 60×10^6 m^3/a and drains a recharge area of about 760 km^2 which is less than half of the study area. In spite of this there is clear evidence that the flow of the eye has been affected by abstraction.

An estimated 4200ha is being irrigated, representing only 2% of the total catchment. The total volume abstracted for irrigation, based on information obtained from the farmers, is 60.10^6 m^3/a, but according to the water requirements of the crops and areas that are being irrigated, 32×10^6 m^3/a is used for irrigation.

New groundwater level contours would have to be compiled once accurate collar elevations have been obtained. The drainage areas of the springs and the influence of dykes could then be determined.

Survey by Schoeman and Partners

In view of the declining flow of the Schoonspruit eye (see Fig. 1.3) that has been attributed to a dramatic increase of irrigation from groundwater since 1975, the assumed recharge area of the spring was proclaimed an underground water control area in June 1995. The firm Schoeman and Partners surveyed the area for the registration of boreholes and water works in compliance with the proclamation. The area surveyed is indicated in the inserted figure. The following statistics are of interest:

- 59 farms were visited, and
- of the 1412 boreholes in the area 721 were in use at the time of the proclamation;
- the total irrigable area is 52000 ha of the total area of 1600 km^2, which is a more reliable estimate than that of Polivka; the estimated abstraction of water for irrigation totals 24×10^6 m^3/a, compared to 32×10^6 m^3 calculated by Polivka.

Of particular significance to the establishment of a WUA for the Schoonspruit area is that a valuable database of basic information on ownership, properties and boreholes has already been put in place.

ANNEXURE 2

Sustainable yield of boreholes

The sustainable yield of boreholes can be assessed by means of the EXCEL program modified by Xu and developed by Van Tonder and Xu (2000).

By means of this program the impact of long-term abstraction, as well as the influence of a nearby borehole and protection area around a production pump could be assessed. A typical print-out from the program is attached.

ANNEXURE 3

Groundwater Management

Introduction

Groundwater management has become a specialized field and employs various approaches and techniques that are usually applied in the assessment and management of surface water resources. A comprehensive study was carried out by Van Tonder et al. (1994), covering the subject in great detail, but the CRD and MA methods were not incorporated despite their great potential as a simple yet effective way of predicting the performance of aquifers for different scenarios of recharge and abstraction.

> The management of a groundwater resource essentially entails assessing and controlling the degree of fluctuation that can be tolerated in an aquifer, to ensure that the levels remain above the minimum which signals the critical point at which further pumping could cause harmful and often irreversible effects.

Fluctuations of the groundwater level are a function of the factors involved in the following interrelationships:

FACTORS CONTROLLING THE LEVELS OF GROUNDWATER		
Storage volume of aquifer	Replenishment	Losses
↓	↓	↓
Area, storativity (S), aquifer thickness	Average recharge and ↓ Annual variability	Natural losses and Abstraction

Compared to surface water systems, the management of groundwater is probably one of the most neglected aspects of water resource utilization, mainly because in the past the variability of recharge and the storativity of aquifers could not be quantified accurately. An additional complicating factor is the difficulty of delineating the aquifer area and defining boundary flow. These factors together with the hydraulic parameter of the aquifer are essential for the compilation of a sound hydrodynamic model of the aquifer. Such a model is the commonest tool with which to simulate the response of an aquifer that is subjected to different stresses such as variable exploitation or recharge. The management approach based on the integrated response of the water-level, using a lumped SVF integration or the CRD method, can provide useful results which can also incorporate probability concepts and risks of failure associated with different assessments of assured yield.

The optimization of aquifer exploitation is not an objective of this report, but it generally involves:

- development of a model that will simulate the response of the aquifer;
- estimation of the exploitation potential of an aquifer;
- defining specific objectives for practical applications;
- setting constraints on variables;
- obtaining best solutions, using optimization techniques.

The assessment of the groundwater resources of an area is the first step in planning the strategy for developing and managing a groundwater resource. Estimation of groundwater recharge is regarded as one of the key issues in the management of an aquifer. The provision of some viable, practical techniques can greatly improve reliability of groundwater recharge and storativity estimates. Although it is preferable to estimate the recharge on a monthly basis, lumped annual recharge inputs would be adequate for most aquifer management purposes, which could be reduced to 12 monthly values. Although the estimation of recharge by various methods has been discussed, the SVF, CRD and MA methods are considered to be the best ways of simulating the water-level response of an aquifer in a simple way, because they reflect the water balance on an integrated basis.

Management

In groundwater management several factors have to be considered depending on the specific demands made on a system. Lloyd (1986) and Foster (1988) have listed general guidelines. These relate mostly to recharge and practical considerations in identifying the most important unknowns. The approach of aquifer exploitation (after Foster, 1988; Lerner et al., 1990) is presented in schematic form in Fig. 3.1.

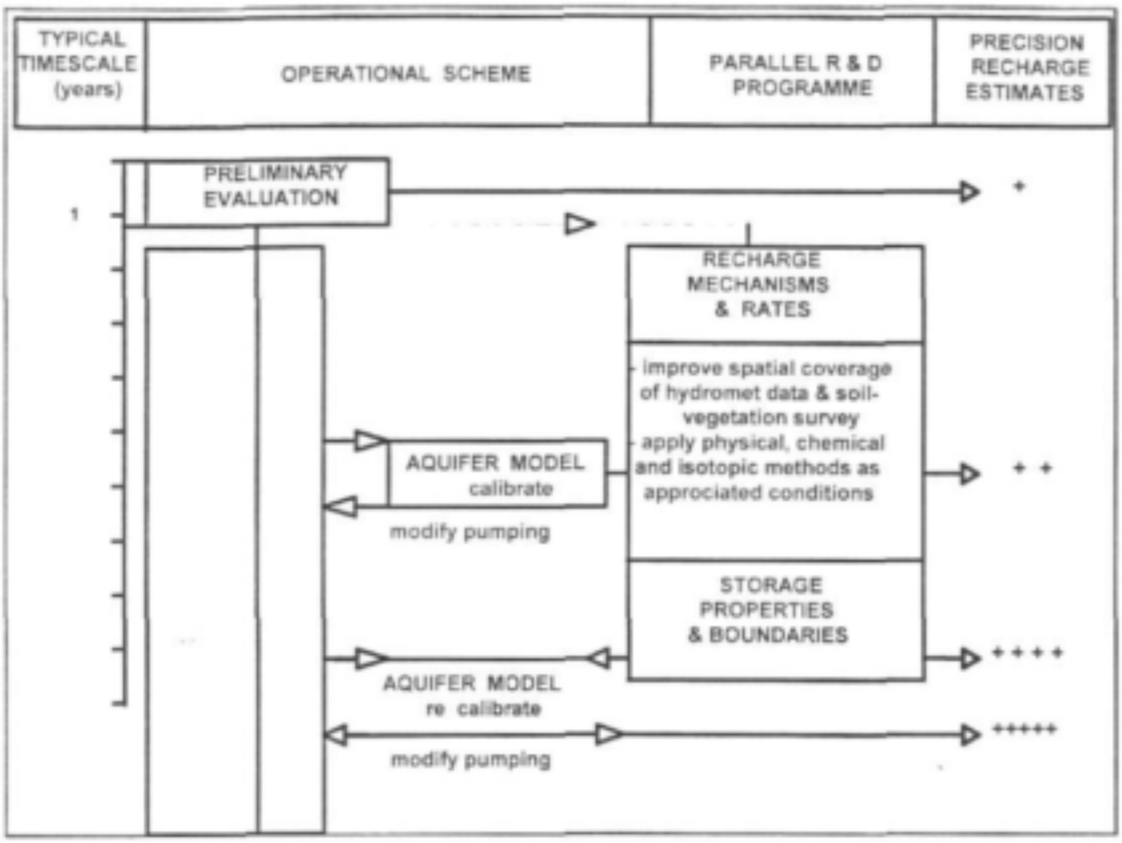


Fig. 3.1 Schematic diagram of the approach that generally has to be adopted in view of limited available data on recharge (after Foster, 1988).

It presents a pragmatic dissection of the modus operandi that usually has to be adopted in areas where little data are available at the start of the exploitation phase. In the course of time, as more data are accumulated, the prediction of the water-level reactions could be simulated with greater reliability, while in the interim exploitation of the water can proceed as there are groundwater reserves in storage on which to draw.

This largely trial-and-error management procedure can be improved upon by using methods to be applied to the dolomitic area of the North-West Region. These methods will improve the confidence limits of the initial projections of the water-level responses, permitting a realistic appraisal of the aquifer performance and limiting the risk of failure. Continual reassessments will naturally have to be made as more data are acquired during the exploitation phase, allowing certain parameters to be defined more accurately.

An extensive list of the main considerations in groundwater management has been compiled by Van Tonder et al. (1994), but the following simple presentation depicts some practical objectives that can be addressed in groundwater management:

GROUNDWATER MANAGEMENT		
Objective		How to achieve
1) Low cost/benefit ratio		
- minimum number of abstraction points	→	◆ Siting boreholes on highly permeable zones ◆ Optimal spacing of boreholes
- maximum sustainable yield	→	◆ Abstraction geared to recharge
- minimum pumping heads	→	◆ Minimize drawdown in pumping borehole
- maximum utilization	→	◆ Use water for maximum benefit, viz. . water supply (domestic) . irrigation (crop types and irrigation efficiency) . stock watering
- best quality water	→	◆ Effective mixing of water of different qualities
2) Minimizing harmful effects ◆ to the environment (eco-systems) - drying up of wet-lands - spring flow reduction - vegetation (indigenous flora) - humanitarian considerations	→	◆ Establish critical constraints pertaining to the . sensitivity of species . habitat requirements . long-term established water rights
◆ to the water quality of the system	→	◆ Prevent admixture of groundwater of a poor quality

It is clear from the outline above that there can be serious conflict of interests because water supply objectives are often directly opposed to those of say mining or environmental preferences or priorities.

Aquifer yield determination

In the past the main emphasis has fallen on the determination of the safe yield of an aquifer. Different definitions of what the safe limit of an aquifer implies, have been offered stating more or less that the safe yield to annual abstraction should not

i) exceed the average annual recharge;

ii) lower the water-levels excessively (cost implication); and

iii) deplete water-levels to the extent that an influx of water of undesirable quality is mobilised.

In more recent times, following the trend that was set in surface hydrological developments, the terminology and focus have changed to an assessment of the sustainable yield of a groundwater system, which incorporates an assessment of the risk of failure associated with a specified rate of abstraction. Therefore the sustainable yield (Q_{sus}) can be expressed as follows:

$Q_{sus} = f\,(Re, h_t, Q_{loss})$

where

Re	=	recharge, which is a function of the areal and temporal variation of rainfall and of the characteristics of the catchment;
h_t	=	the piezometric head at time = t, which is determined by the water balance as well as the interference between boreholes pumping in close proximity to each other;
Q_{loss}	=	the term incorporating abstractions; natural losses from the system are seldom taken into account but are partly accounted for in the initial calibration of a model.

The water-level fluctuations will reflect the combined response to pumpage, natural losses such as outflow or evapotranspiration, and recharge. Hence if the maximum permissible drawdown in an aquifer is a critical factor, for example because of its environmental impact, the extent of the natural variation in groundwater levels has to be taken into account.

Planning groundwater management

In groundwater evaluations the main question of concern to water planners, is whether a specific abstraction could be sustained by an aquifer and what the associated risk of failure would be. Failure could be signified by different criteria but generally occurs when a specified critical groundwater level or abstraction rate cannot be maintained.

In addition to obtaining a more reliable estimation of recharge and storativity, the following simple methods could be used to good effect in the assessment of an aquifer's response to different management scenarios.

Saturated volume fluctuation method (SVF)

As has been shown this method reflects the water balance on an integrated basis allowing the effective recharge and aquifer storativity to be obtained, and the water-level response for different scenarios of recharge and abstraction to be simulated (Van Tonder et al., 1999).

The risk factor can be determined in statistical terms as the probability that the water levels over a specific period would exceed a specified critical water level. These exceedance or non-exceedance probabilities will depend critically on the abstraction and the rainfall events that control recharge. For example the integrated water level in the aquifer can be simulated for different rates of abstraction, using the historical rainfall record, to determine the probable variation of recharge. In the case of the Grootfontein aquifer, rainfall data were generated by stochastic techniques to yield the probability density distribution of the water-level fluctuations for each month (Van Rensburg, 1995), as is presented in Fig. 3.2.

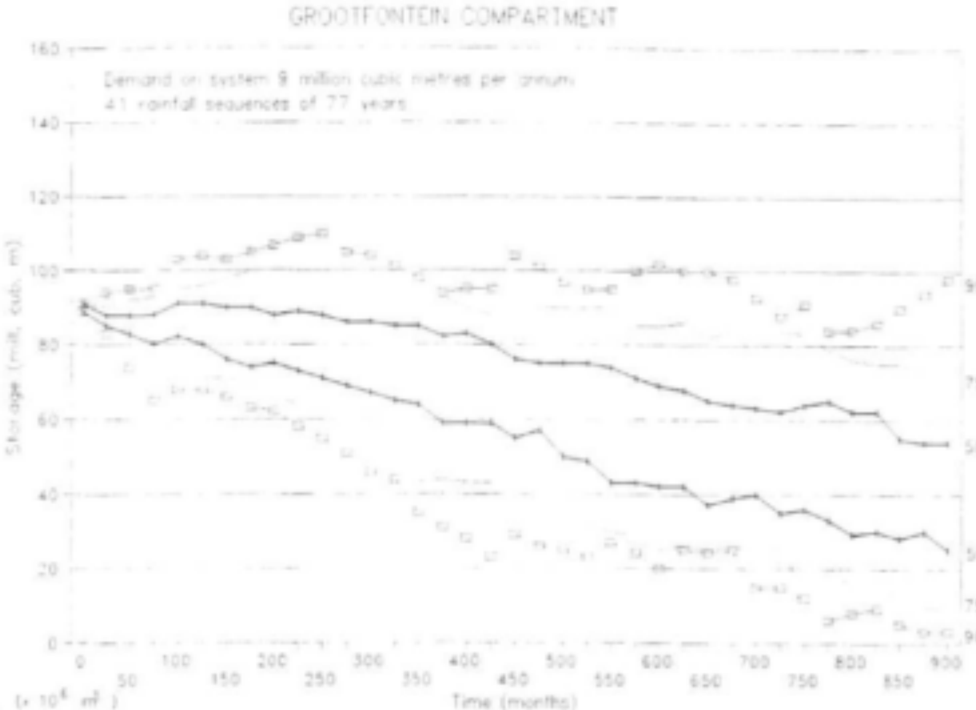


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Fig. 3.2 The probable variations of the water levels in the Grootfontein aquifer due to the natural variability of the recharge and the rate of abstraction from the system (probability on the right-hand scale).

Several case studies in the manual by Bredenkamp et al. (1995) illustrate more examples of the practical answers produced using the SVF approach to obtain an integrated picture of the groundwater level response. In the case of the dolomitic aquifers that have high transmissivities, this integrated approach is acceptable for most evaluations, as the SVF would reflect the overall water-level response over the entire aquifer quite accurately. However, when the transmissivity of an aquifer is low the SVF simulation might be too crude, depending on the number of observation points; a dynamic flow model would then have to be compiled.

Dynamic model

The use of a hydrodynamic flow model has the advantage that the water-level response at individual nodes can be obtained, enabling one to find the best spacing of boreholes, using optimization techniques if necessary. At the same time the effects of the regional variability of the aquifer transmissivity, storativity and recharge can be incorporated.

The recharge of an aquifer can be obtained from the rainfall/recharge relationship that emerges from the equal volume assessments, or the chloride method, whereas the

CRD and MA method would yield a better estimate of the variability of recharge. Hence by using the estimated monthly recharge values as input, a dynamic model could reveal the water-level responses for any number of rainfall sequences generated. Each of the simulated sets would represent a likely rainfall time series for the specific area, which could be used to calculate the recharge input, as has been demonstrated by Van Rensburg (1995). Rainfall and therefore also recharge can vary markedly from one year to the next, hence the longer the rainfall record, the more representative of long term conditions will the rainfall average be. To optimize for the best spacing of boreholes and to obtain the highest abstraction rates, still within a predetermined range of tolerances in the water-level fluctuations, requires immense computer processing.

Cumulative rainfall departure method (CRD) for aquifer management

The CRD method, which has been discussed, incorporates the cumulative departures of the rainfall from the long-term average value, usually on a monthly basis although the same result is obtained if the cumulative departures are calculated on an annual basis. The following equation applies:

$$CRD_i = CRD_{i-1} + Rf_i - Rf_m \qquad \text{eq. 1}$$

where Rfm $= k \times Rf_{av}$

where k $= 1$ indicates natural conditions

and k > 1 applies if pumpage occurs.

Equation 1 can mimic the water-level fluctuation quite well, but the following relationship makes it possible to simulate the natural groundwater level fluctuations even more closely:

$$CRD_i = \frac{1}{m} \sum_{j=i-(m-1)}^{j=i} Rf_j - \frac{k}{n} \sum_{j=i-(n-1)}^{j=i} Rf_j + CRD_{i-1} \qquad \text{eq. 2}$$

Although the CRD method might seem a rather empirical approach, its mathematical formulation has been validated (Bredenkamp et al. 1995). Van Tonder and Xu (2001) suggested a slight modification of the CRD formula that would provide a more accurate series if there was a trend in the rainfall series used. It has been demonstrated convincingly that it is one of the best approaches with which to mimic the groundwater level response.

The CRD method can be applied

1. to reveal the variations of the groundwater levels due to the natural forces acting on the system;
2. to ascertain the effect that abstraction would impose on the natural balance.

The distinction between natural and exploitation impacts is most important, and the latter were found to dominate the response of the water-levels especially where vast quantities of groundwater are abstracted for irrigation and in the dewatering of mines.

The CRD method represents a simple lumped approach, which utilizes only the rainfall variations to simulate the piezometric response caused by natural forces and pumpage. The latter effect is incorporated as an increased loss factor.

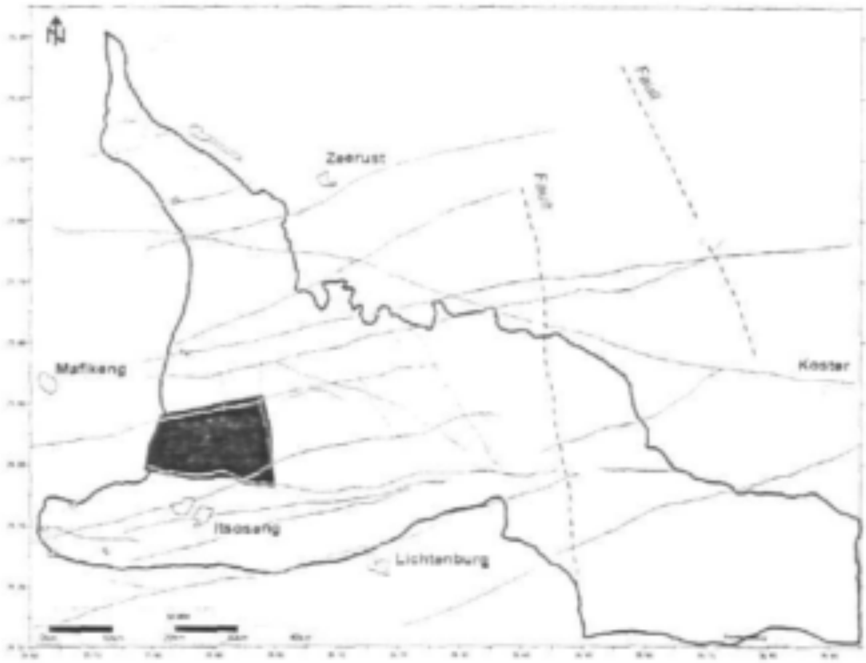
In any groundwater balance the known abstractions could be incorporated as an equivalent increment in the parameter k. However the pumpage could equally well be obtained from the best regression fit of parameter k. In this way the effect of an unknown external influence can not only be proved but also quantified if the area of the aquifer is known, and the average rainfall can be inferred fairly reliably by interpolation if a rainfall record at the specific locality is not available.

The reliability of the CRD method depends on the extent to which the integrated water-levels reflect the change in saturated volume and on whether the precipitation record represents the areal rainfall distribution satisfactorily or not. This emphasizes that for natural systems rainfall is one of the most important parameters determining the regional variability in recharge and the associated aquifer response.

Application of the SVF and CRD methods (which would be similar for the MA method)

Although more work is required, the results obtained in case studies have already illustrated the superior capabilities of the combined SVF/CRD/MA methods. A few applications to aquifer management will be highlighted in the following case studies.

Grootfontein aquifer (after Van Rensburg, 1995 and Van Tonder et al., 1999 incorporating the SVF method).



The water-level response in this aquifer was simulated using a dynamic flow model. The recharge and storativity of the aquifer were obtained by means of the SVF method. The annual recharge was calculated from the equation:

$RE = 0{,}10\ (Rf\text{-}67)$

$= 8{,}4 \times 10^6\ m^3/a$

from which an S value of 0,023 was derived, based on a water balance.

The recharge and storativity values were then used to optimize the transmissivity values used in the dynamic model so as to obtain the best calibration of the piezometric levels. After calibration, the effect of any combination of pumping and recharge could be assessed for different management scenarios, providing useful information on the effectiveness of the spatial distribution of the existing pumps and the probable variation of the water-level fluctuations.

Of even greater concern is the likelihood or otherwise that the aquifer will be able to sustain the yield, in view of the additional pumpage by farmers for irrigation. First the recurrence period of the present status of the aquifer levels needs to be assessed relative to the worst natural status ever experienced. Thereupon the effects of increased exploitation of the aquifer need to be quantified and compared to natural extremes in the water-level fluctuations, thereby providing a measure of the risk factor in practical terms.

The problem of the Grootfontein compartment was approached by simulating the integrated response (SVF) of the water level for different rates of abstraction in relation to the recharge, using a dynamic flow model. The results of these water-level simulations were presented as a series of graphs, similar to those in Fig. 3.2 which depicts the range of likely variation of the monthly water-levels, as well as the probability that a given level will be exceeded or not.

Many more intricate analyses are possible on the same basis to address problems of diminishing yields, optimal spacing of boreholes and environmental impact assessments, all of which can be related to the water-level status of an aquifer.

Although the SVF graph reflects the integrated picture of the water-level response, any borehole, which is part of the dynamic system, would follow a similar fluctuation pattern that is linearly related to the integrated response.

It logically follows that any borehole not reacting in a similar way is not part of the dynamic response of the stressed system, and that such deviations could reveal the effect of an external influence, such as a dyke, fault or additional inflow from an adjacent compartment. In this way the boundaries of the responsive aquifer could be delineated; in some cases boundaries were shown to extend beyond the dykes which had initially been regarded as impermeable boundaries.

Lichtenburg aquifer (CRD method)

The best simulation of the water-level response to abstraction of water from the aquifer is shown in Fig. 3.3. In this case the value of the multiplier factor k was adjusted until the best fit was obtained. The incremental difference $(k-1)Rf_{av}$ is almost the same as the abstraction converted to an equivalent percentage of the average rainfall. The reaction of the water level to an increased rate of abstraction can be obtained by increasing the value of k according to the higher abstraction.

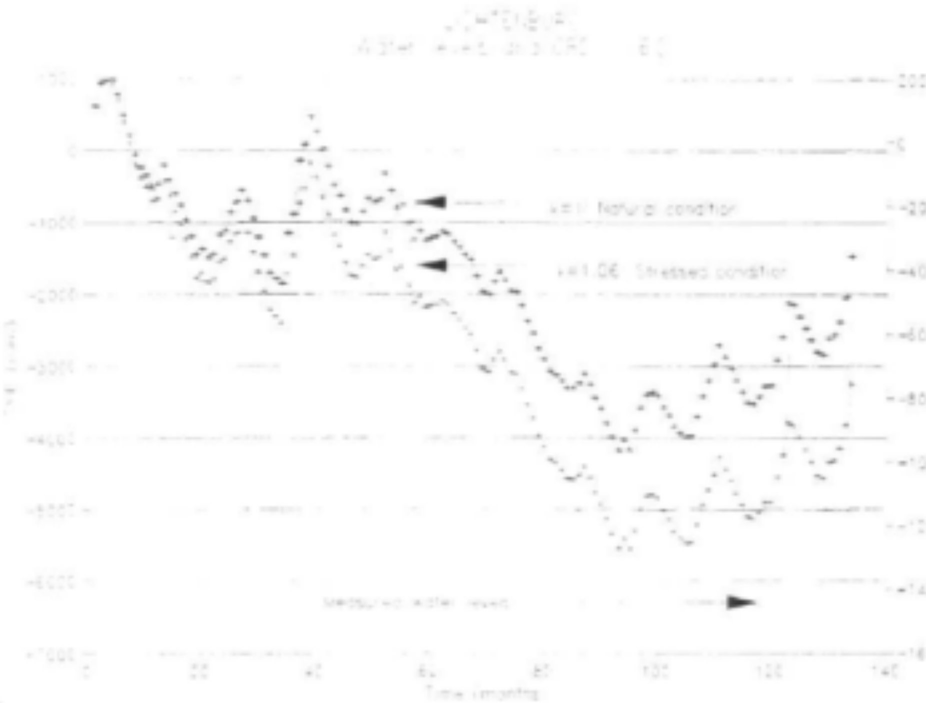


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Fig. 3.3 The excellent correspondence between the integrated water-levels for the Lichtenburg aquifer and the CRD values, incorporating the abstraction as an effective additional stress on the system.

Other related WRC reports available:

Groundwater monitoring: A critical evaluation of groundwater monitoring in water resources evaluation and management

DB Bredenkamp

A major component of the study has been the validation of the integrity of groundwater level observations and the extension of limited data series by means of rainfall records, employing the cumulative rainfall departure (CRD) method. This is because the cumulative departures of rainfall from the average rainfall have been shown to match groundwater level fluctuations fairly well and to mimic the hydrogeological balance of an aquifer based on the rainfall occurring in an area. The CRD method represents a useful hydrologic model of the groundwater balance and the response of water levels to recharge. Consequently, the impact of abstraction can be determined.

The study has provided further insights and perspectives concerning groundwater monitoring activities and the value of reliable long-term measurements. The CRD and moving average (MA) rainfall methods were used to determine the response of water levels in mostly dolomitic aquifers in order to determine aquifer characteristics. Most monitoring records either cover a short period, are intermittent or could contain unreliable data. It is, therefore, important to be able to fill gaps in a record and to extend it back and forth in time. Because the technique facilitates extrapolation of time-series data, it provides for a Acheck@ on monitoring data. Thus, it allows for an assessment of the reliability of data gathered during monitoring programmes. Aquifer parameters were obtained using the CRD and MA series and the groundwater level series. However, the estimation of reliable storativity values remains difficult and requires a process of iteration.

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