

Groundwater Reserve Determination Study for the Olifants/Doorn Catchment

Report Prepared for
Department of Water Affairs & Forestry
DIRECTORATE: RESOURCE DIRECTED MEASURES

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SRK Project Number 348965

**SRK Consulting
The Administrative Building
Albion Springs
183 Main Road
RONDEBOSCH 7700
South Africa**

**Postnet Suite #206
Private Bag X18
RONDEBOSCH
7701
South Africa**

Tel: (021) 659-3060

Fax: (021) 685-7105

M Fortuin; mfortuin@srk.co.za

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Compiled by:
M Fortuin & A.C. Woodford
Project Consultants

Reviewed by:
PN Rosewarne
Principal

Authors: M Fortuin & A.C. Woodford

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GROUNDWATER RESERVE DETERMINATION STUDY FOR THE OLIFANTS/DOORN CATCHMENT

1 INTRODUCTION

1.1 Objectives of the Reserve Determination Module

The study area is the Olifants/Doring River system which forms part of the Olifants/Doorn Water Management Area (WMA), located some 250 km north-northeast of Cape Town, and has a catchment area of 56,745 km² (**Figure 1**). It comprises six major rivers, i.e. the Groot Tra-Tra, Tankwar, Doring, Sout River and the Olifants River, and their tributaries. The most important of these rivers, from a water resource perspective, are the already heavily developed Olifants River, and the relatively undeveloped Doring River.

Following on from a rapid review of the groundwater situation in the study area, carried out by GEOSS (2003), there are differing levels of groundwater importance and sensitivity and, in places, groundwater has been significantly impacted. Due to the large size of the study area, it is not possible to complete a Reserve for the entire area at a high level of confidence. Thus, based on the importance, sensitivity and demand for groundwater, differing levels of determinations are required.

The project was subdivided into three phases, namely.

- Phase 1 Inception Phase,
- Phase 2 Study Implementation, and
- Phase 3 Project Termination.

The objective of Phase 1 was to consult with the client and mobilise the project team, thereby initiating the project. The project team identified and reviewed all relevant information (for example documents, maps, aerial photographs) currently available for the study area. Based on the results of the literature review, the project team developed a project plan, including scheduled tasks and activities required to calculate the Groundwater Reserve per Resource Unit. An assessment was also made about the confidence level required to calculate the Groundwater Reserve per Resource Unit and for different Resource Units. A multilevel approach was followed culminating in the Inception Report. The Inception Report serves as a baseline against which project progress was monitored. This report was submitted in September 2005 and accepted by the Client before work commenced on Phase 2.

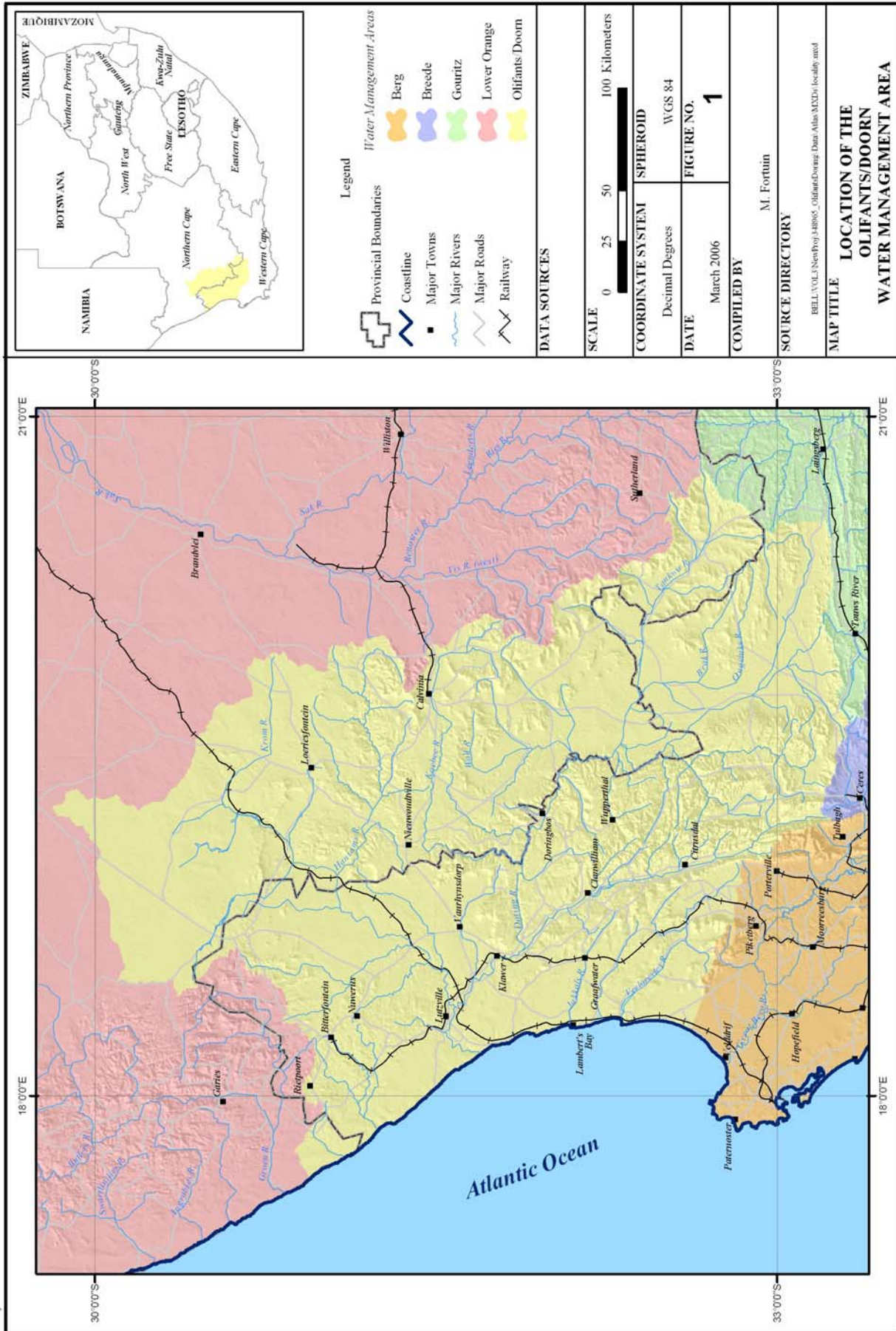


Figure 1: Location of the Olifants/Doorn Water Management Area.

In Phase 2 the following was undertaken:

- The classification of each Resource Unit, both in terms of Desired Category as well as Management Class;
- The determination of the quantity and quality of the Groundwater Reserve;
- Setting of Resource Quality Objectives (RQOs) and the implementation of the tasks and activities in the project plan.

The key components of the study were:

- Description of Study Area
- **Quaternary catchments G30, F60 and E10 are to be excluded.** Medium confidence Reserve determinations are required for catchments E21A – K; E22C, D; E24M; E3E – H and E40A, B. Low confidence determinations will suffice for the remaining catchments (**Figure 2**).
- Background Information
- Physiography and Climate
- Geohydrology
- Delineate Resource Units
- Classification of the Resource Units
- Set Groundwater Reserve
- Set RQO's

All surface water and ecological data was made available from parallel studies.

Once all the objectives have been achieved the client will terminate the project (Phase 3). The project team will then:

- Supply delivery dates of final documents and products
- Close all contracts
- Complete and submit all reports
- Submit final accounts and financial report

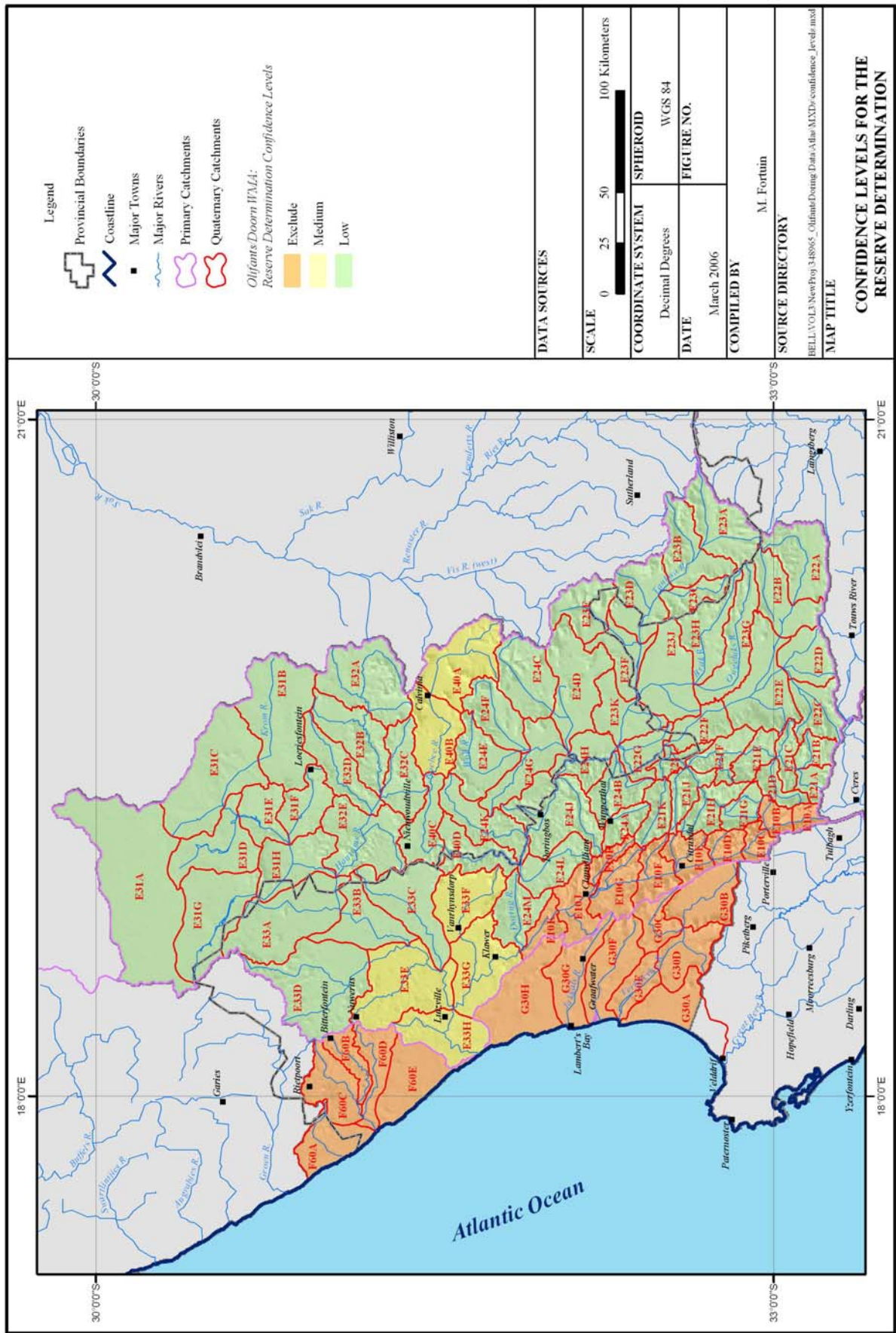


Figure 2: Confidence levels for the Reserve determination as set out in the Terms of Reference.

1.2 Scope of Services Required

The Scope of Services Required for the study, as outlined by Xu *et al*, (2003) entailed the following:

- Delineate the area.
- Delineate groundwater regions.
- Delineate groundwater response units.
- Delineate areas of common groundwater use.
- Indicate the level of importance of various uses, ascribed by the stakeholders.
- Delineate areas of multiple groundwater use.
- Identify conflicting and non-conflicting multiple uses.
- Describe the reference conditions of the response zones.
- Describe the present status of preliminary groundwater management units.
- Indicate the vulnerability of the groundwater response zones with respect to:
 - Ecological dependency.
 - Inherent contamination vulnerability.
 - Inherent drought vulnerability.
 - Over-exploitation risk.
 - Current degree of impact.
- Delineate management units based on:
 - Current and future requirements for groundwater use.
 - Vulnerability.
 - Common actions necessary to manage groundwater for desired levels of use.
- Describe scenarios of management goals and actions for each management unit and the consequences of assigning likely management classes for:
 - All current groundwater uses.
 - Potential and natural groundwater uses.
 - Land-care management.
 - Economic development.

1.3 Technical Approach

1.3.1 The Reserve Determination Process

The “Reserve” as defined in the National Water Act, constitutes the quantity and quality of groundwater required to:

- Satisfy basic human needs by securing a basic water supply for people who are now or who will in the foreseeable future be dependent on groundwater.
- Protect aquatic ecosystems, to ensure ecologically sustainable development and use of the relevant water resource.

The Basic Human Needs (BHN) reserve has been established by DWAF for certain catchments. The ecological Reserve is largely reliant upon expert judgment and set at a value so as to ensure that the aquatic ecosystem of the identified area is maintained or improved, depending on the Management Class set. The Reserve is defined as both the quantity and quality of the whole water resource, and will vary depending on the class of the resource.

Resource Quality Objectives provide goals within the management class. They may be seen as goals to aim for, if the management class represents an improvement on an impacted resource, which represents the limit of acceptable impact. RQO's are seen as being particularly important for groundwater as they are not restricted to aquatic ecosystems and may therefore represent the important role of aquifers to the wider environment.

If groundwater is of minimal importance for basic human needs and the ecology, then a low to medium confidence assessment can be conducted. However, if the region is stressed or sensitive and there are many dependencies on groundwater, a high confidence assessment will be required.

Although the title of this report refers to "Reserve" determination, the study has to take into account all components of Resource Directed Measures (RDM) including Classification, RQO's and monitoring. Emphasis will be placed on achievable RQO's, which in turn will aid in the successful management of the system. In addition, the correct classification of the resource will play a vital role in ensuring the long-term sustainability of the resource. ***The quaternary catchment is the fundamental unit of analysis.*** For each quaternary catchment a Classification, Reserve and RQO's has been set, depending on the level of confidence of the assessment required.

The project approach is aligned with the National Water Act (Act 36 of 1998) which places emphasis on the protection of water resources for their sustainable utilization. To meet the requirements of the RDM Directorate the project covers the three important components of RDM, namely: Classification, Reserve determination and RQO's. The reserve covers both Basic Human Needs (BHN) and the Ecological Reserve (ER). The National Water Act requires that before a new water use can be considered for licensing, the Reserve must be determined and taken into account. Determination of the Ecological Reserve is for aquatic ecosystems and entails investigation of the relationship of major interactive components of the hydrologic cycle, namely groundwater and surface water bodies including rivers, lakes and estuaries.

It is generally accepted that groundwater plays a role in the Ecological Reserve determination if there is a direct hydraulic connection between groundwater and surface water bodies that jointly sustains aquatic ecosystems (Xu *et al*, 2003). In such situations the often complex role of groundwater (in terms of water level, volume and water quality), in supporting the ecosystem has to be ascertained so that groundwater is not subsequently misallocated. Where aquifers have no connection with aquatic ecosystems, the groundwater component of the Reserve is then only the Basic Human Need (BHN)

requirement (25 l/person/day, multiplied by the number of people using the groundwater supply in the area).

The broader environmental role of groundwater in supporting important terrestrial ecosystems and hypogean life also needs to be taken into account within RQO's (Xu *et al*, 2003). The National Water Act provides for the development of National Water Resource Classification System, which is required so that appropriate levels of protection can be set for the groundwater resources. The application of the classification system leads to the delineation of a groundwater management unit and the classes to be set i.e. Protected, Good, Fair or Severely Modified. These four classes imply different levels of protection and impact acceptable to stakeholders. They provide a frame of reference for the implementation of groundwater protection, use and management plans for that management unit.

Groundwater management units are areas of a catchment which require consistent management actions to maintain the desired level of use and protection of groundwater. Their delineation according to a level of impact acceptable to the stakeholders will be the final outcome of the classification process. It is essential that liaison takes place with the DWAF Catchment Manager for the Olifants/Doorn Water Management Area (WMA), and that the relevant Forums are addressed and are part of the classification process and decision making.

Understanding groundwater interaction with surface water bodies is a prerequisite for determination of the groundwater component of the Reserve. Xu *et al* (2003) provides a good review of techniques, both shortcomings and benefits. Parsons (2003) has also reviewed the interaction of groundwater and surface water. Appropriate literature and software will be used in addressing the level of groundwater and surface water interaction.

1.3.2 Specific Technical Approach

It was proposed that a functional approach be adopted, considering the functions and importance of groundwater use by humans and the environment. Once the functions and importance have been determined the objectives will be formulated to safeguard those functions. The objectives should be practically measurable and preferably summarized as key indicators. A range of hydraulic indicators (e.g. groundwater gradients, water levels); hydrochemical (e.g. TDS, nitrate); and biotic indicators (e.g. thriving vegetation, hypogean fauna) should be selected to indicate that aquifers are effectively fulfilling their important roles.

The approach to be taken for each quaternary catchment within the study area will be similar but the associated confidence levels will range from low to high according to the level of the determination required.

The project team also makes recommendations on the required monitoring, both of groundwater quality and groundwater levels. The distribution of monitoring points, the frequency of measurements and the chemical/physical parameters to be measured will also be addressed.

In addition, existing groundwater use within the study area has been assessed. This has been done on a catchment basis, to enable DWAF to determine the allocatable amount of groundwater. If possible the locations where groundwater abstraction is taking place within the catchment should also be determined.

An initial rapid level assessment is required for which a RDM assessment should be done. Areas of concern or 'hot spots', e.g. over-abstraction, contamination, ecological sensitivity, sole source etc, will then be investigated at an intermediate level. Based on these requirements and the level and type of available data, the following approach was followed for the literature study:

- **National Scale**

Relevant national scale projects/data that assisted with the rapid level assessment were:

- Conrad and Parsons National aquifer classification.
- GRA 1: Hydrogeological map series at 1:500 000 scale. The Calvinia map covers the study area. This indicates aquifer types, yield classification, existing use.
- GRA 2: Quantification of groundwater resources. This provides quantitative information on aquifer storage, recharge, groundwater/surface water interaction, exploitable groundwater (updated Harvest Potential), aquifer classification, and existing use.
- WR2005: This provided further, updated information on groundwater and surface water resources. This is an ongoing project.

- **Regional Scale**

Regional scale studies that provided essential information to assist with both the rapid and intermediate level assessment included:

- The CAGE Study.
- DWAF/DANIDA Integrated Water Resources Management. Groundwater Guidelines: Implementation and Testing: Olifants/Doorn WMA.
- WRC Report 1332/1/04. Identification and prioritization of type areas for detailed research in terms of the regional variability of the groundwater and ecological characteristics of the TMG Aquifer systems. Covers much of the study area (not just TMG) in terms of recharge, climate, geology, vegetation/biomes, ecological importance rating.
- The reports of Kotze and Conrad as supplied with the ToR.

- **Local Scale**

At a local scale there have been many municipal groundwater supply projects such as at Calvinia, Niewoudtville, Klawer, Vanrhynsdorp, Ebenezer and Loeriesfontein. These reports provide detailed local scale information on aquifers, borehole yields, aquifer parameters, groundwater use, quality and monitoring data.

This information was sufficient to produce the Inception Report.

1.4 Report Layout

The findings of the study in respect of the Olifants/Doorn WMA are presented in **9** sections that make up the main body of this report, and a number of appendices containing mainly statistics for the quaternary catchments that make up the WMA. The section headings are:

Section 1	Introduction
Section 2	Description of the study Area
Section 3	Hydrogeology
Section 4	Delineation of the Resource Units
Section 5	Resource Classification
Section 6	Quantification of the Reserve
Section 7	GRDM Assessment
Section 8	Resource Quality Objectives
Section 9	Conclusions and Recommendations

2 DESCRIPTION OF THE STUDY AREA

2.1 Technical Information

The following is a list of information that has been collected in order to establish the characteristics of the Olifants/Doorn Catchment.

- Geology.
- Surface water hydrology (Rivers, dams, estuaries, vleis etc).
- Vegetation types and ecologically important systems.
- Existing or future Nature Reserves (categorised).
- Mean Annual Rainfall.
- Borehole information (NGDB) and springs ('hot' and 'cold' water) database.
- Hydrochemistry.
- Regional Classification of Aquifer Systems.
- Aquifer recharge and discharge areas.
- Recharge estimates.
- Groundwater Exploitation Potential.
- Existing and future large-scale groundwater abstraction.
- Groundwater/Surface Water Interaction.
- Groundwater available for abstraction in terms of the General Authorization of the New Water Act.

- Quaternary catchments based hydrological information.

2.2 Locality

The Olifants/Doorn water management area (WMA) is located along the west coast of South Africa, extending from about 100 km to 450 km north of Cape Town and has a total area of approximately 56,745 km². The south-western portion falls within the Western Cape Province and the arid north-eastern portion in the Northern Cape Province. The water management area borders on the Lower Orange Water Management Area to the north and east, on the Gouritz, Breede and Berg Water Management Areas in the south while the Atlantic Ocean forms the western border.

The WMA comprises the entire E Primary catchments and parts of the F and G Primary catchments. The WMA is made up of 11 Tertiary catchments and 88 Quaternary catchments.

The major river in this WMA is the Olifants River, with the Doring River as its main tributary. Flow in the Doring River is highly variable, whilst only small occasional flows occur in the Sout River tributary. There are also a number of smaller and highly intermittent coastal rivers and water courses. **Figure 1** shows the general layout and location of the Olifants/Doorn water management unit.

2.3 Physiography

In the west the Olifants/Doorn WMA is bounded by the Atlantic Ocean. The rugged Cederberg, Koue Bokkeveld and Olifants River Mountains, from which the Olifants River originates, demarcate the Olifants River Valley in the south, flowing to the north-west. Its deep narrow valleys widen and flatten downstream of Clanwilliam until the river flows through a wide floodplain downstream of Klawer. The southwestern area has peaks that rise to more than 1,800 m above mean sea level (m.amsl) (**Figure 3**).

Typical Karoo landscape extends over the north-eastern parts, with plains and rocky hills covering most of the fan-shaped Doring River Basin. These regions are referred to as the Knersvlakte, Hantam and Hardeveld. The main river rises in the south and flows in a northerly direction. It is first intersected by the Groot River and then the Tra-Tra River flowing from the west and the Tankwa River from the east, before flowing in a westerly direction to its confluence with the Olifants River.

2.4 Climate

Climatic conditions vary considerably as a result of the variation in topography. Climate in the Olifants/Doorn water management area is temperate to hot, and generally semi-arid to arid. Minimum temperatures in July range from -3°C to 3°C and maximum temperatures in January range from 39°C to 44°C.

Rainfall occurs in the winter months in the south-western portions, while the north-eastern portions receive winter rainfall as well as occasional summer thunderstorms. The annual rainfall ranges from 100 mm to 300 mm over most of the WMA. A small area in the southern mountains receives > 1,000 mm of rain per year, which is where most of the

runoff originates, whilst rainfall in the northern portion of the water management area reduces to < 100 mm per year (**Figure 4**).

The mean annual potential evaporation is more than an order of magnitude higher than the rainfall over most of the area, as shown in **Figure 5**. It varies across the basin from about 1600 mm/a in the south to about 2600 mm/a in the north and southeast.

2.5 Vegetation

The vegetation of the area is characterized by the Succulent Karoo, Nama Karoo and Fynbos biomes (**Figure 6**) of which the distribution is determined by the climate, topography and soil type. The main vegetation types found in the area are Upland Succulent Karoo, Lowland Succulent Karoo and Mountain Fynbos with smaller areas of Strandveld Succulent Karoo and Little Succulent Karoo. Also found along the coastal areas are West Coast Renosterveld and sand plain Fynbos. In the mountainous regions Central Mountain Renosterveld and Escarpment Mountain Renosterveld can be found. In the northern most region of the Karoo landscape the Bushveld Nama Karoo dominates.

2.6 Conservation

Important conservation areas include the Tankwa Karoo National Park, the Verlorevlei wetland which enjoys Ramsar status, the Cedarberg Wilderness Area and the northern section of the Groot Winterhoek Wilderness Area. The Olifants River and Doring River are important from a conservation perspective because they contain a number of species of indigenous and endemic fish that occur in no other river systems, and that are endangered (DWAF, 2005). Reaches of some of the tributaries are unspoiled by human development and are rated high to very high in ecological importance. The Olifants estuary is one of three permanently open estuaries on the west coast of South Africa, thus representing a critical habitat to many estuarine associated fish species. The estuary also supports at least 86 species of estuarine waterbirds and has a wide range of habitats. It plays an important role in bird migration and is considered to be in the top ten South African locations of importance for the conservation of waterbirds. The coastal wetlands of Verlorevlei, Die Vlei (Wamakersvlei), Wadrioutsoutpan and Lambert's Bay in the Sandveld are vulnerable due to the pressure placed on the groundwater resource by over-utilisation and pollution.

2.7 Population

The Olifants/Doorn WMA is the least populated WMA in the country with a population of approximately 113,000 people. More than half the population live in urban or peri-urban areas, and the rest in the rural areas. The distribution of the population density according to the Census 2001 data within the study area is shown in **Figure 7**. **Appendix III** summarises the population per quaternary catchment.

The general trend of an increasing urban population and associated decreasing rural population is expected to continue and can be attributed to the lack of strong economic stimulants, migration of young people and the impacts of HIV/AIDS (NWRS, 2004). There is a strong migration of seasonal workers into the WMA during the harvest and planting seasons.

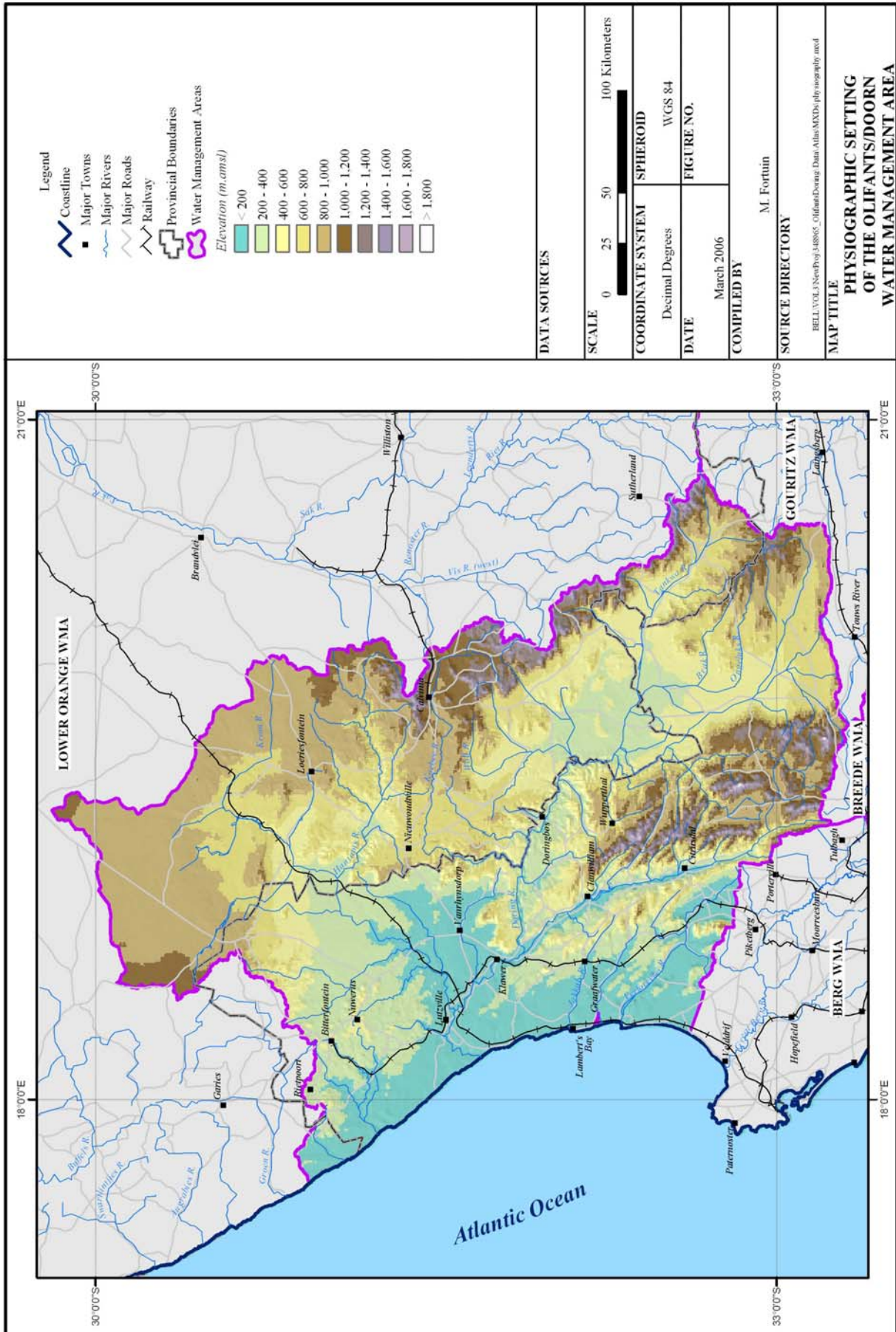


Figure 3: Physiographic setting of the study area.

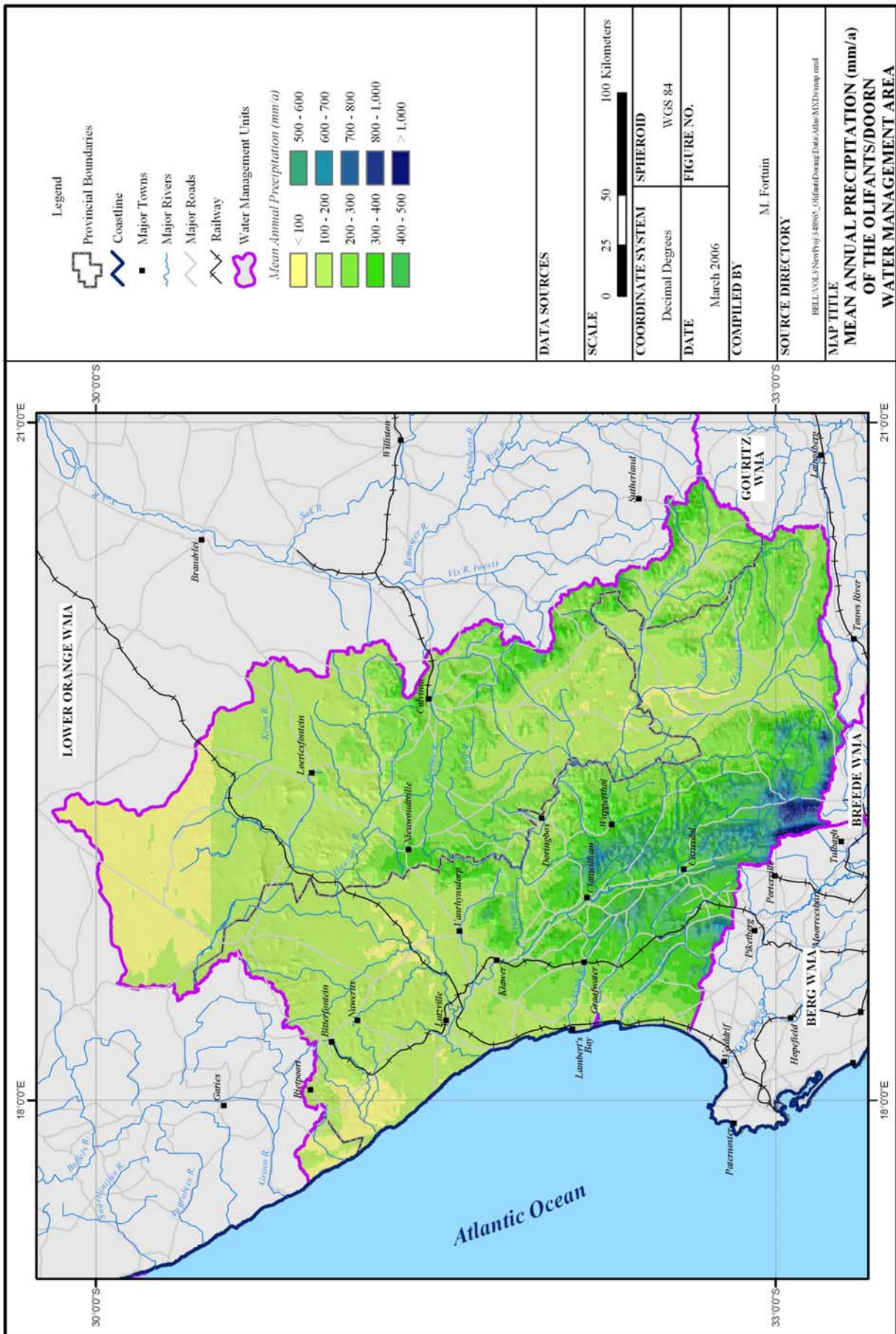


Figure 4: Mean Annual Precipitation (mm/yr) of the study area.

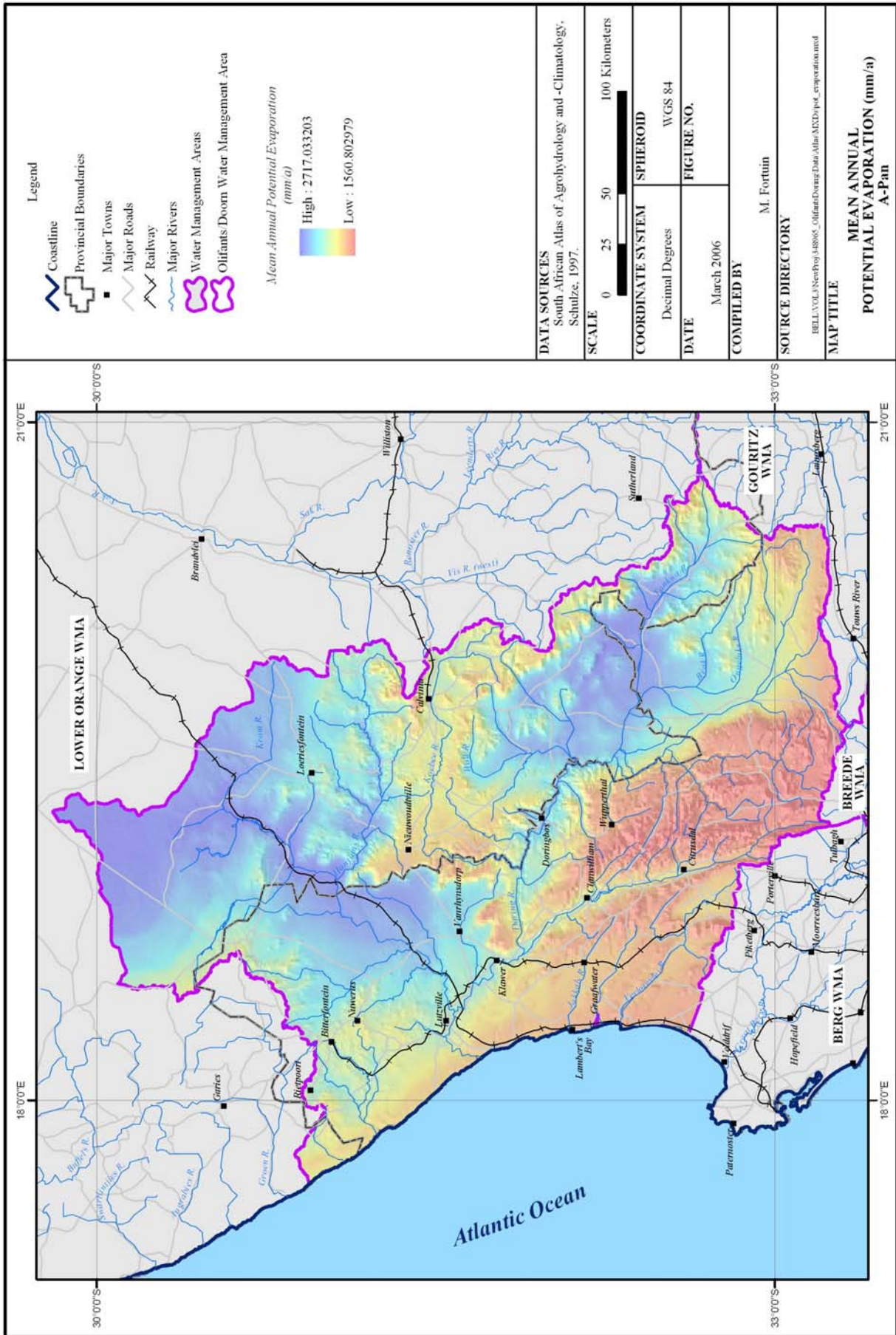


Figure 5: Mean Annual Potential Evaporation (A-Pan) (mm/a).

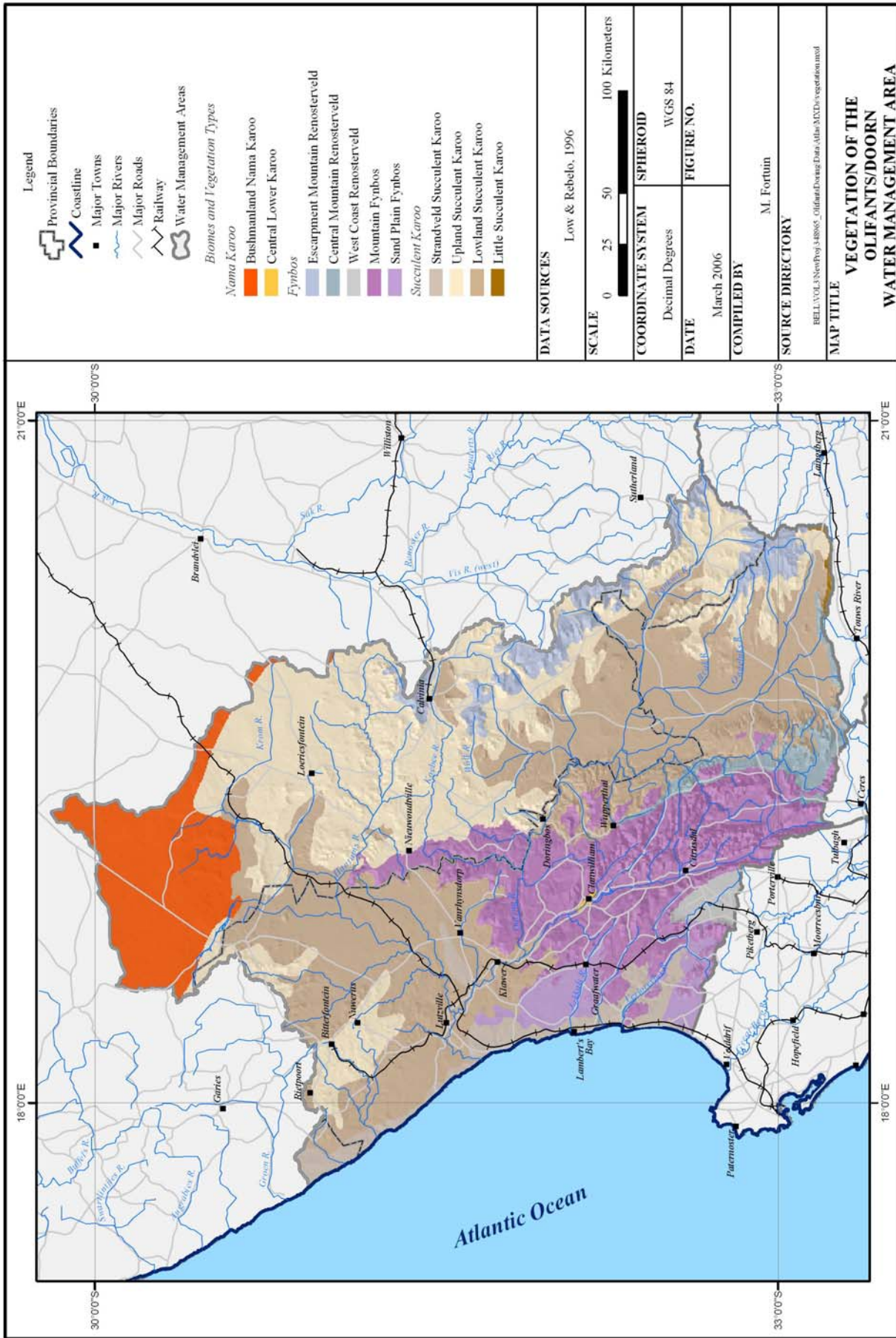


Figure 6: Biomes and Vegetation of the study area

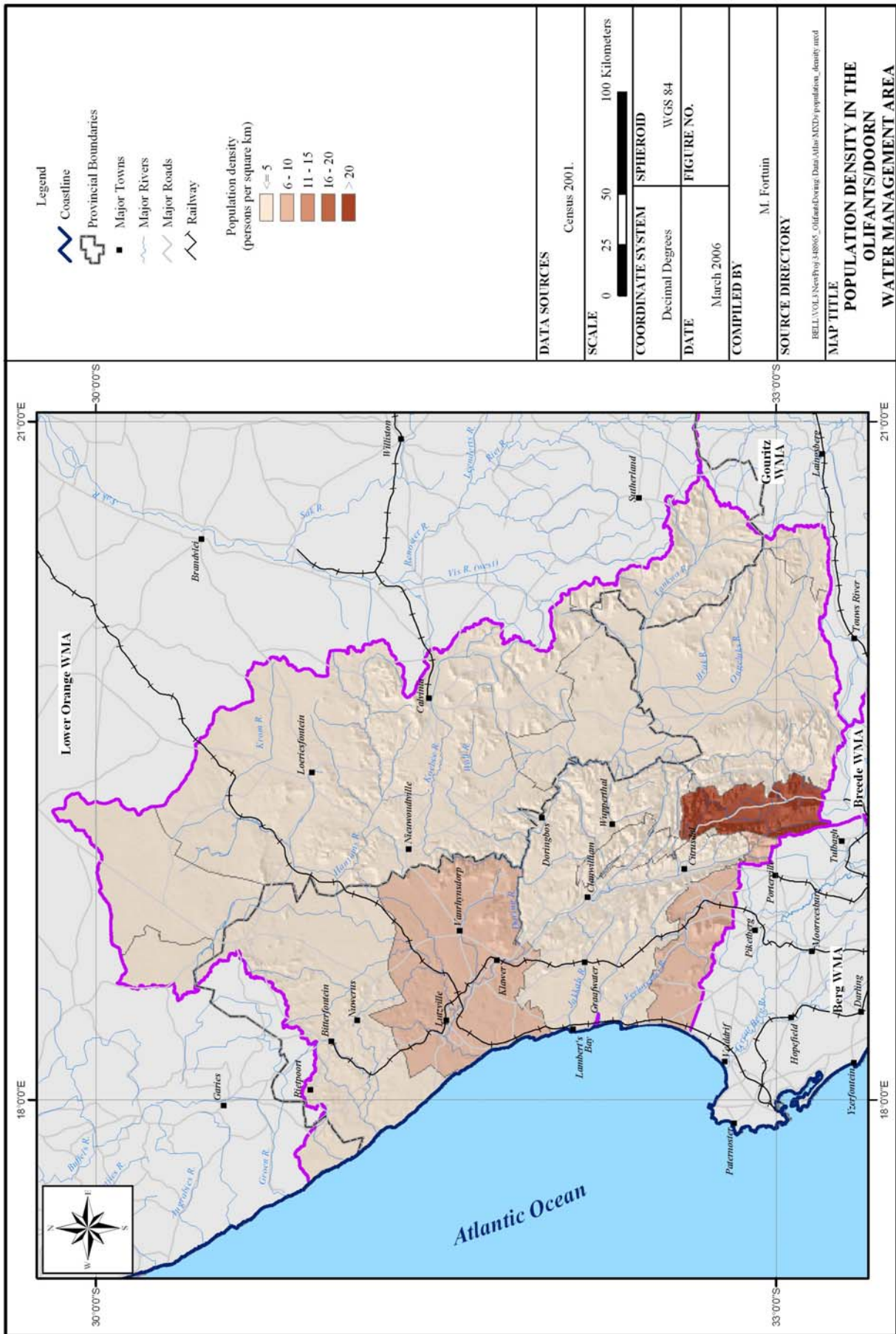


Figure 7: Population density.

2.8 Landuse

The mean annual precipitation over much of the area is less than < 300 mm (**Figure 4**), with the result that, except in the wetter southwest, the climate is not suitable for dryland farming on a large scale. Consequently, more than 90% of the land is used as rough grazing for livestock, predominantly sheep and goats. An estimated 2,190 km² equating to 4% of the land area, is cultivated for dryland farming.

Figure 8 and **Table 1** summarises the landcover for Olifants/Doorn WMA.

Table 1: Summary of the National Landcover (2000).

Description	Area (km ²)	% of Total Area
Barren rock	16.0	0.03%
Cultivated: permanent - commercial irrigated	494.2	0.87%
Cultivated: temporary - commercial dryland	3,500.7	6.17%
Cultivated: temporary - commercial irrigated	795.0	1.40%
Degraded: shrubland and low Fynbos	46.9	0.08%
Degraded: thicket & bushland (etc)	7.6	0.01%
Dongas & sheet erosion scars	1,060.7	1.87%
Forest	1.7	0.00%
Forest plantations	10.7	0.02%
Improved grassland	6.9	0.01%
Mines & quarries	0.6	0.00%
Shrubland and low Fynbos	45,716.5	80.59%
Thicket & bushland (etc)	3,399.7	5.99%
Unimproved grassland	1,488.8	2.62%
Urban / built-up land: residential	28.3	0.05%
Urban / built-up land: residential (small holdings: grassland)	0.2	0.00%
Waterbodies	102.1	0.18%
Wetlands	48.1	0.08%
Total Area	56,724.6	

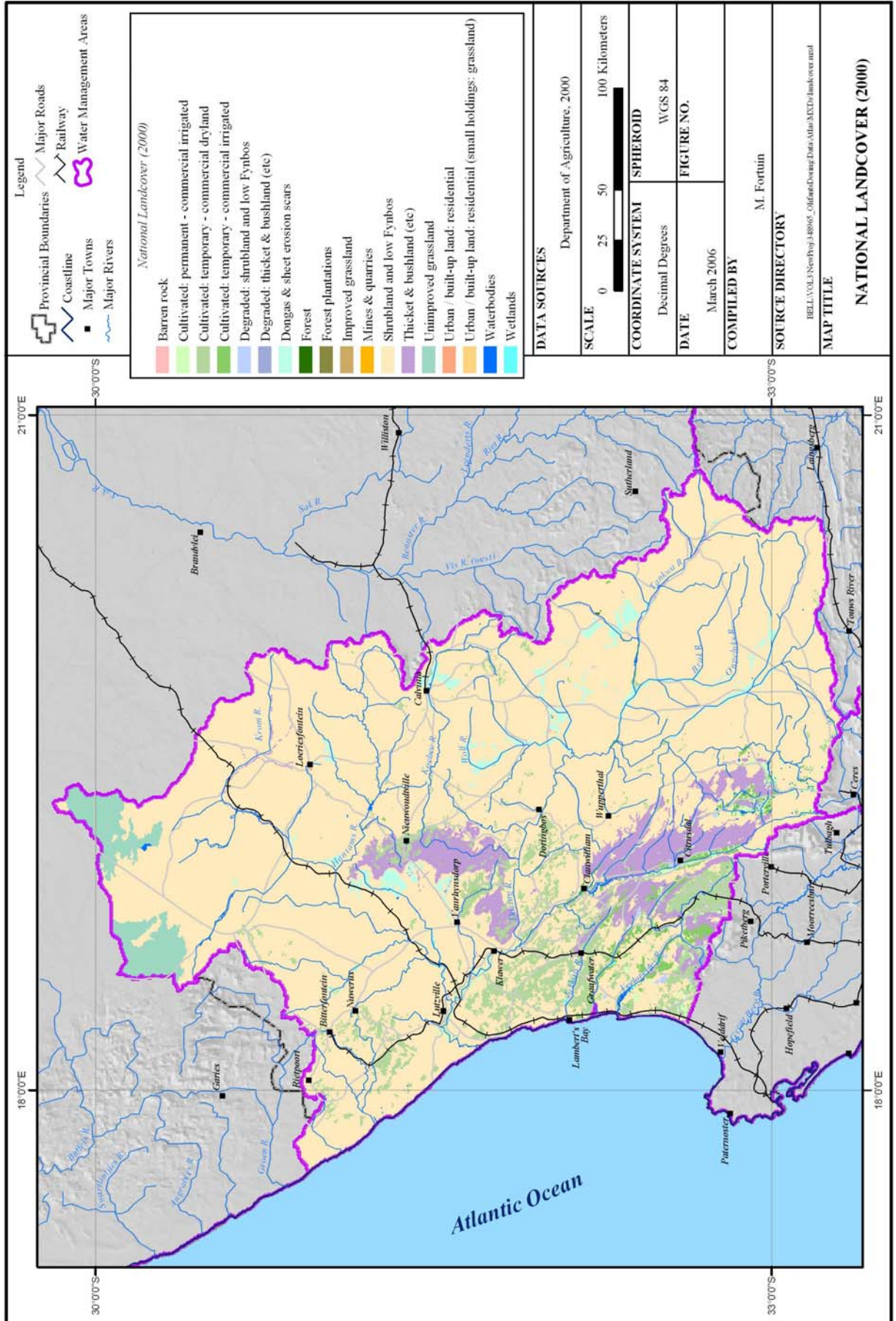


Figure 8: National Landcover (2000).

3 HYDROGEOLOGY

The hydrogeology of the Olifants/Doring WMA is characterised by aquifers formed by sedimentary rocks of the Cape Supergroup (TMG Aquifers) and lower part of the Karoo Supergroup (Karoo Aquifers). Small exposures of pre-Cape metamorphic rocks (Vanrhynsdorp Group) occur in the north-western corner, along the lower part of the Oorlogskloof (Koebee) River and around the Doring/Olifants confluence (BKS and Ninham Shand, 1998). The north-eastern corner of the area contains exposures of intrusive Karoo dolerite dykes and sills. Alluvial deposits correlated with the Sandveld Group overlie the Cape Supergroup rocks in parts of the Olifants and Doring Rivers along the coast.

3.1 General Geology

Figure 9 and **Table 2** summarises the geology of the Olifants/Doorn WMA. The nature and composition (lithology) of each of the different stratigraphic units is considered. Hydrogeological characteristics, with regard to the permeability of the unit and its classification as an aquifer, aquitard or aquiclude, is also included.

The geology of the Olifants/Doorn WMA is dominated by metamorphic rocks of the Nama Group in the north and sedimentary rocks of the Cape Supergroup in the southern and southwestern parts. In the northern and north-eastern parts, the rocks of the pre-Cape Van Rhynsdorp Group, the sedimentary rocks of the lower Karoo Supergroup as well as intrusive Karoo dolerites are dominant (**Figure 9**). Various metamorphic rocks (i.e. quartzites, granulite and schists), augen gneisses as well as mafic gneisses of the Garies and Bitterfontein Subgroups (Okiep Group) are overlain by sediments of the Nama Group in the north-western portion of the WMA near Nuwerus (Woodford, 2001). Tertiary to Recent sediments occurs along the major river courses and extensively along the coast (including north-west of the town of Graafwater).

The main characteristics of each of the main aquifers as well as the status quo of groundwater abstraction and exploitation potential in the Olifants/Doring WMA, are summarised below.

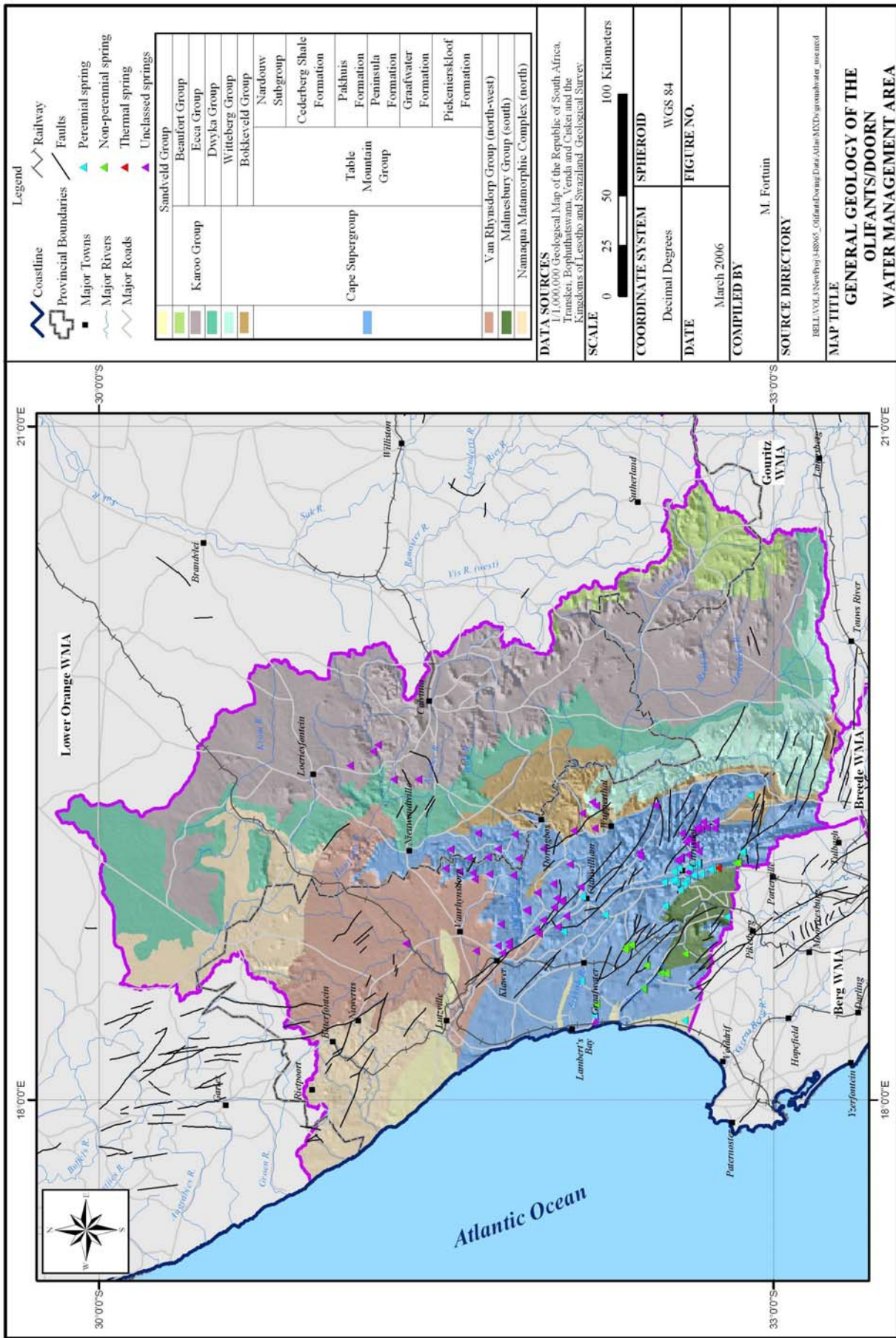


Table 2: The stratigraphy of the Olifants/Doorn WMA (CAGE, 1999; Visser, 1989)

Lithostratigraphic Unit		Era	Characteristics	Hydrogeological Significance	
Sandveld Group		Cenozoic			
Karoo Dolerite (north-east)		Mesozoic		Fractured contact zones and metamorphic aureoles serve as aquifers. Also barriers to flow.	
Karoo Group	Beaufort Group	Mesozoic	6000m alternating arenaceous and argillaceous sediments.	Localised significance as aquifer systems.	
	Ecca Group	Paleozoic	Dark grey shale and interbedded sandstone.	Middle to upper thin sandstone strata may have greater hydrogeological significance.	
	Dwyka Group		Tillite.	Aquiclude.	
Cape Supergroup	Witteberg Group	Paleozoic	Alternating sandstone and shale.	Marginal hydrogeological significance.	
	Bokkeveld Group		Alternating sandstone and shale.	Little significance, else regolith aquifer.	
	Table Mountain Group		Nardouw Subgroup	1100m to 810m alternating sandstone and shale with lenses of quartzite.	Top aquifer of TMG-2. Confined above by lowermost shale unit of Bokkeveld Group.
			Cederberg Shale Formation	50m to 120m shale.	Top confining layer for lower aquifer system (TMG-1).
			Pakhuis Formation	40m.	Major fractured rock/secondary aquifer system. Middle aquifer (TMG-1).
			Peninsula Formation	1800m to 2150m sandstone.	
			Graafwater Formation	Sandstone.	
			Piekenierskloof Formation	Conglomeratic base, followed by 800m coarse sandstone.	Basal aquifer unit (TMG-1).
	Klipheuvel Group		Paleozoic	Lower conglomeratic formation and an upper red mudstone formation of approx. 2000m.	Aquitard of limited hydrogeological significance.
Van Rhynsdorp Group (north-west)		Paleozoic	A succession of shallow sediments deposited on a tidal plain.	Impermeable aquiclude.	
Malmesbury Group (south)		Namibian		Impermeable aquiclude.	

3.1.1 Sandveld Aquifer (G30)

According to Conrad 2002, the Sandveld Aquifer constitutes a poorly defined area on the Cape West Coast, extending from the coastal plain of G30 west to Piketberg in the east to the Berg River, which forms the southern boundary.

The Sandveld Aquifer constitutes a primary aquifer, composed of alluvial sands and gravels around the main drainage channels, overlying bedrock composed of Malmesbury shales, Klipheuvel mudstones/shales and the lower formations of the Table Mountain Group (mainly Piekenierskloof, Graafwater and Peninsula Formations). Considerable sand deposits occur within the area of the Sandveld Group. The regional geology is dominated by low-lying sand flats (Tertiary to Recent deposits), while sandstone outcrops of the TMG, fine grained rocks of the Malmesbury Group and shales of the Klipheuvel, are also present. The Langvlei River and associated wetlands, which terminates in the Wadrif saltpan, is almost exclusively dependent on groundwater.

Most of the area comprises porous sandy soil, low in nutrients and with a low agricultural potential. The soils derived from sand have a low water retaining capacity and are both acid and relatively infertile, or nearer the coast, alkaline with a distinct horizon of lime accumulation.

The area has long been recognised by botanists for its high plant species diversity, due to its transitional location between the fynbos and karroid vegetation types. With respect to agricultural activity, the expansion of centre pivot irrigation began following the introduction of Eskom power lines to these areas in the mid-1980s. The centre-pivot boom relies on electrical power to drive the system in its circular motion.

Most of the indigenous vegetation, which is being cleared for centre-pivots in the surveyed region, falls into the Strandveld type. This is described as an open semi-succulent shrub of Fynbos form, intermediate between Coastal Fynbos and Succulent Karoo.

Various springs occur in the study area and unique vegetation, dependent on the spring flow, has developed in the proximity.

Most of the centre-pivot systems in the area are used for the irrigation of potatoes. One of the most notable features of centre-pivot irrigation in these sandy areas is the small percentage of circular fields supporting actively growing crops at any given time. Typically one may observe one green circle surrounded by many brown circles. The reason for this phenomenon relates to the disease free conditions required for seed potato production.

The various formations give rise to different water qualities. The Graafwater Formation in particular has very poor quality groundwater. Farmers only abstract the good quality water, which degrades the water quality that feeds the surface water.

At a recent Sandveld Aartappel Werkgroep meeting (2002), it was reported that the total area under cultivation was approximately 7500 ha, with 2500 ha being for seed potatoes and 5000 ha for table potatoes.

The source of irrigation water is mainly from groundwater abstracted from the extensive primary aquifer in the area. Boreholes also abstract water from the underlying fractured secondary aquifer (TMG Aquifer). In addition, irrigation water is supplied from filtration dams, which are often located in close proximity to major water bodies.

The last round of groundwater monitoring in the Sandveld was carried out in 1978, after which extensive development of irrigation systems for potato irrigation took place. An investigation by SRK (Maclear, 1998) indicated that groundwater abstraction from the TMG Aquifers does not influence water levels in the primary Sandveld Aquifer. However, it is postulated that the Sandveld Aquifer is recharged by excess groundwater in the TMG Aquifer. Hydrochemical results clearly show the difference between groundwater abstracted from the primary aquifer from that of the TMG Aquifer. Umvoto (2001) indicated that the Sandveld Aquifer is recharged along major hydrofractures (fractures) extending as far as the Cederberg Mountains. Detailed studies are required to differentiate between the sources of groundwater to accurately determine the groundwater Reserve.

A study is currently being undertaken by DWAF to characterise the Sandveld Aquifer and conceptualise groundwater flow and recharge mechanisms. Given the dependence of the coastal towns of Graafwater, Strandfontein, Lamberts Bay and Elands Bay on groundwater, the large-scale groundwater abstraction for potato irrigation and the rich variety of botanic life above the primary aquifer, a comprehensive Reserve determination is recommended for the area.

3.1.2 TMG Aquifers (E10, E21 and part of E24)

The TMG Aquifer is a regional scale fractured aquifer. Groundwater movement takes place in various scales of fractures, ranging from hydrofractures to smaller scales of fractures. A hydrofracture is defined as a fracture, fault, line of intersection between planar structures or a fold closure, which is characterised by a hydraulic permeability that is greater by orders of magnitude relative to the surrounding rock matrix (Umvoto, 2000). The TMG Aquifer system is complex and the most intensive work carried out to date is summarised in the CAGE report (Umvoto, 2000).

The TMG Aquifer constitutes three major fractured sandstone aquifers, separated by two shale-bearing units, forming aquitards, i.e. acting as confining layers for groundwater flow (Umvoto, 2000). The Piekenierskloof Formation forms the basal aquifer unit, overlain by the Graafwater Formation (the confining layer). The Peninsula and Pakhuis Formations form the middle aquifer unit, confined by the Cederberg Shale confining layer. The uppermost aquifer is the Nardouw Aquifer, which is confined above by the lower-most shale of the Bokkeveld Group. Different groundwater quality is associated with the different Formations. Umvoto (2000) indicated that geochemical fingerprinting and characterisation of aquifers requires further investigation.

Groundwater occurs in various scales of fractures, cross-cutting several formations and extending over large areas. Umvoto (2000) identified the following major megafault zones:

1. Saron-Aurora Megafault Zone;
2. Gydo-Verlore Vlei Megafault Zone;
3. Twee-Riviere-Leipoldville Megafault Zone; and
4. Krakadouw-Klawer Megafault Zone.

All the above-mentioned fault zones have a major effect on the regional TMG hydrogeology and create complex hydrogeological conditions and groundwater flow scenarios, subdividing the Olifants/Doring catchment into different groundwater zones. Groundwater flow along these fault zones needs to be quantified.

The TMG Aquifer underlies part of the primary Sandveld Aquifer and exists in the Lower, Middle and Upper Olifants River, Cederberg/Doring, Koue Bokkeveld and part of the Nama Karoo water forum areas.

The areas underlain by TMG Aquifers contain natural vegetation that belongs to the extraordinarily diverse Cape Floral Kingdom, including the Cape Coastal and the Cape Fold Mountain 'Fynbos' – a low growing, highly diverse, fine-leaved, sclerophyllous shrub community that is particularly fire-adapted (Umvoto, 2000). Other elements of this floral kingdom are heathlands and dense Afro-montane riparian trees or podocarpus forests. Various groundwater dependent ecosystems exist in areas underlain by TMG Aquifers, particularly around river valleys fed by springs and groundwater seepage areas. In the Koue Bokkeveld area, vleis and groundwater seepage areas are highly ecologically sensitive and a high conservation value is placed on the limited remnant natural vegetation (Umvoto, 2000).

Groundwater abstraction from the TMG Aquifer is mostly confined to the Nardouw Aquifer in the Olifants River Valley, upstream of Clanwilliam Dam, for the cultivation of citrus plantations. Abstraction is in the order of 12 million m³/a (DWAF, 2005). Citrusdal is the only town with standby boreholes drilled into the TMG Aquifers and has the only known boreholes in the Peninsula Aquifer. From a strategic point of view, huge groundwater potential for future use is locked up in the relatively unexplored Peninsula Aquifer of the TMG. Annual recharge of the Peninsula Aquifer is estimated to range between 20 and 40% (Fortuin *et al.*, 2004). Although the Koue Bokkeveld area mostly makes use of surface water and groundwater is only used with surface water in periods of drought, the Koue Bokkeveld and Cederberg Mountain areas are the main recharge areas for the Peninsula Aquifer.

Groundwater abstraction in the Cederberg area is very limited, with only a few private boreholes in operation for domestic and stock watering purposes on farms. Forestry development in the Cederberg Mountains has resulted in the reduction of stream activity, baseflow and recharge (Kotze & Xu, 2003).

Although a qualitative hydrogeological conceptual model for groundwater flow in TMG Aquifers exists in the CAGE study, several uncertainties exist in terms of quantifying the water balance of various domains of the TMG Aquifers. They are:

- The uncertainty of the role of the Piekenierskloof Formation, which seems to act as a valve, controlling groundwater flow;
- The magnitude of discharge from the TMG Aquifer to the coastal plain, i.e. tertiary catchments G30 and F60 (Sandveld Area);
- The impact of snowfall on springflow;
- The impact of daily rainfall frequencies on aquifer recharge and springflow;
- Although a reasonable knowledge of annual abstraction exists, springflow needs to be investigated, together with the impact of abstraction on springflow;
- The need to develop an understanding on the dynamics of vertical and lateral recharge, which differs considerably within the different domains in the TMG Aquifer;

- Discharge from one catchment or domain to another needs to be conceptualized and quantified;
- The interaction between surface and groundwater is time dependent and needs to be investigated further; and
- The discharge from the TMG Aquifer to the Karoo Aquifer in the east is also unknown.

Bearing in mind the existing groundwater abstraction from the TMG Aquifer, future exploitation potential and the strategic importance of this aquifer, which provides recharge to bounding aquifers, i.e. Karoo and Sandveld, a comprehensive Reserve determination is required. However, a combined Reserve determination for the TMG Aquifer as a whole will not work due to intrinsic differences in the hydrogeological conceptual models for different domains of the TMG Aquifers and the uncertainties listed above.

Although the CAGE study by Umvoto has provided a great deal of information on the hydrodynamics and major groundwater flow mechanisms of the TMG Aquifer, more intrusive studies are required to quantify the groundwater Reserve and to quantify hydrotests.

During earlier studies, two project areas were identified as target areas for the development of the irrigation potential in the Olifants/Doring catchment, i.e. the Aspoort Project on the Aspoort/Doorniver in the Ceres Karoo (Northern Province) and the Melkboom Project in the Atties Karoo (Western Cape Province). To date, the Northern Province has not initiated any further investigations. The Western Cape Provincial Administration appointed Umvoto to investigate the possibilities of groundwater development for irrigation in the Melkboom study area, as environmental concerns exist with the building of a dam. This study, known as the Western Olifants/Doring River Irrigation Forum (WODRIF), has been undertaken by the Department of Agriculture (Western Cape) and acts as an extension of the CAGE Project. It investigates target areas for groundwater development and quantification of aquifer systems.

The Doring River is a pristine river system. DWAF is investigating the possibility of building a dam on the Doring River, where it meets the Olifants River, for future irrigation water demands in the coastal zone. However, innovative groundwater exploitation of the TMG and other aquifers has proven to be the most cost-effective in this area, given the high evapotranspiration.

3.1.3 Karoo Aquifers

Groundwater is found in three distinct geological situations in Karoo Aquifers (BKS and Ninham Shand, 1998) as follows:

- Alluvium;
- Fractured sedimentary shales and sandstones on the margins of dolerite sills and dykes; and

- within dolerite intrusions.

The Karoo Aquifers occur in the Hantam and Ceres Karoo areas within the Olifants/Doring WMA. A few small towns, i.e. Calvinia, Nieuwoudtville and Loeriesfontein are solely dependent on groundwater for domestic water supply purposes. Very little groundwater is used for irrigation in this area. Wupperthal receives water from the Tra-Tra River weir as well as springs and small streams in the vicinity. The towns of Bitterfontein and Nuwerus receive groundwater from the South Namaqualand Government Water Supply Scheme comprising six boreholes and a reverse osmosis desalination plant. Intrusive work, conceptualizing Karoo Aquifers, was carried out by Woodford (2001).

A potential concern exists in the Koekenaap area, where Namaqua Sands make use of seawater for some of their operational processes. This saline water is discharged locally and could result in salinisation of fresh groundwater resources.

3.1.4 Bokkeveld and Witteberg Aquifers

The Witteberg and Bokkeveld Aquifers are considered to be aquifers of lesser importance, both in terms of groundwater quality and quantity. The Witteberg Quartzite does not have a large storage capacity, but does have a particular relationship to the hydrogeology. Abstraction from the Bokkeveld Aquifer occurs in the Agter-Witzenberg Area but it is regarded as an aquitard elsewhere within the WMA. A comprehensive Reserve determination is therefore not required for these aquifers.

3.1.5 Vanrhynsdorp Aquifer

A localised karst aquifer occurs in the Nama-Karoo Area. The town of Vanrhynsdorp uses groundwater abstracted from a wellfield in this karst aquifer. The towns of Klawer and Vanrhynsdorp make conjunctive use of surface water from the Olifants River Government Water Supply Scheme and groundwater. A considerable amount of information is available from a hydrocensus carried out in 1993. The relationship of this aquifer with the TMG Aquifer is unknown. However, it is postulated that the two aquifers are not linked due to the different hydrochemical fingerprints of groundwater. A comprehensive Reserve determination is, therefore, not required for this aquifer.

More intrusive groundwater investigations are required to conceptualise this aquifer. In particular, more detailed investigations are required to investigate the reason for the degradation of the water quality of the Tra-Tra River irrigation scheme.

3.2 Spring and borehole distribution

The mapped distribution of springs in the Olifants/Doorn WMA is based on the 1/500,000 Geohydrological Map Sheets and the systematic hydrocensus survey of the Citrusdal Artesian Groundwater Exploration (CAGE) Project (**Figure 9**). Spring location is closely correlated with the TMG Aquifers and hydrotect structures.

The borehole distribution of the National Groundwater Database (NGDB) reflects the actual pattern of use as well as an area-specific focus in data collection in the past (**Figure 10**). A

high density of boreholes exist in the Calvinia-Nieuwoudtville area (from shallow regolith, Karoo dyke and alluvial aquifers), and in TMG aquifers along the arid coastal plain between Eland’s Bay and Doring Bay. This reflects groundwater dependence.

There is an uneven spread of boreholes throughout the rest of the area, with localized concentrations in the Koue Bokkeveld, Vanrhynsdorp and around Bitterfontein in the Northern Cape. The number of boreholes reflects good groundwater sources in spite of rather arid to semi-arid climatic conditions. The abstraction pattern shows a relatively high level of summer season groundwater dependence from whatever aquifer sources are locally available. The groundwater resource has not been systematically explored and developed and its monitoring is uneven.

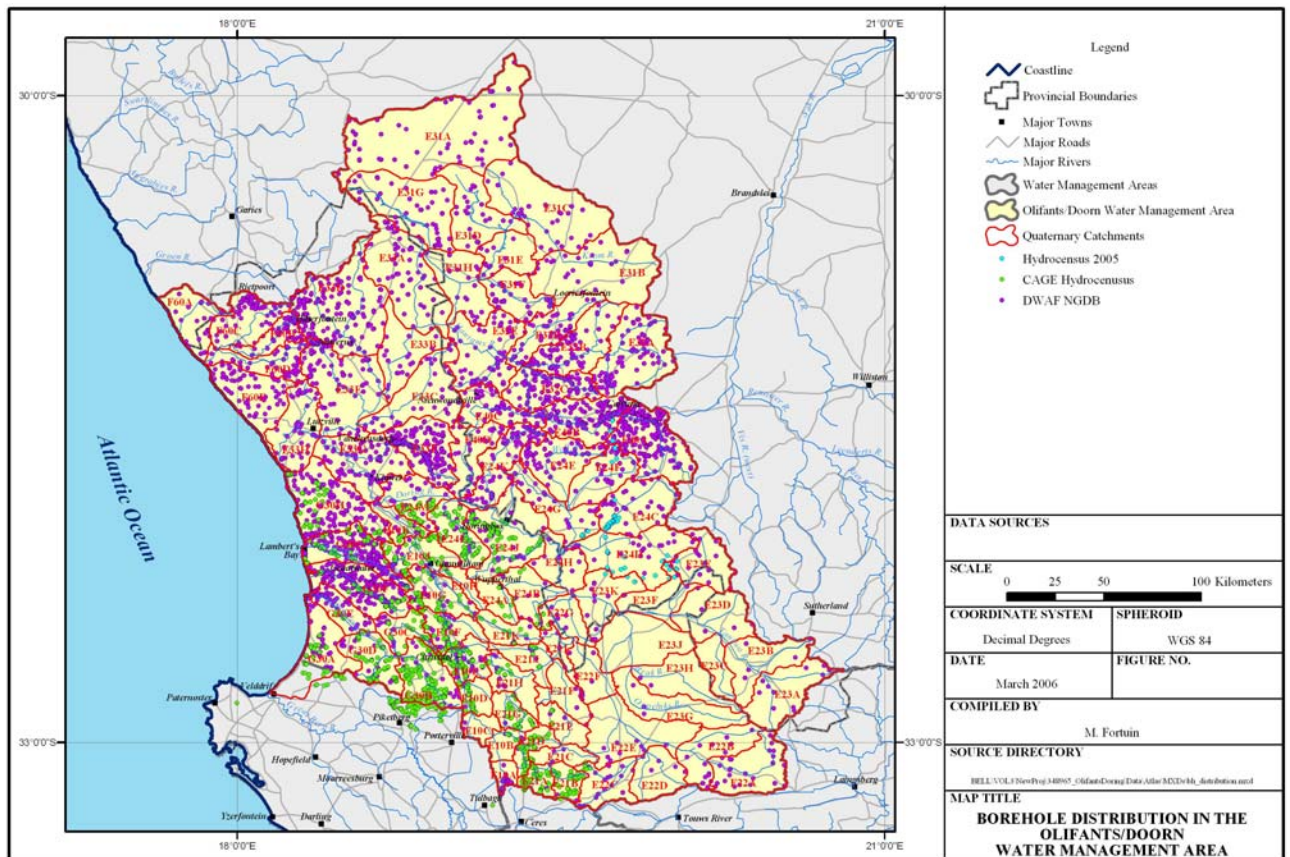


Figure 10: Borehole distribution in the Olifants/Doorn WMA.

3.3 Water-level

Figure 11 shows the depth to groundwater within the Olifants/Doorn WMA. The waterlevel map was derived by creating a 50m X 50m raster grid of boreholes of the DWAF NGDB, hydrocensus and other reports using the ArcInfo software .The average groundwater depth for each Quaternary Catchment is summarised in **Appendix I**.

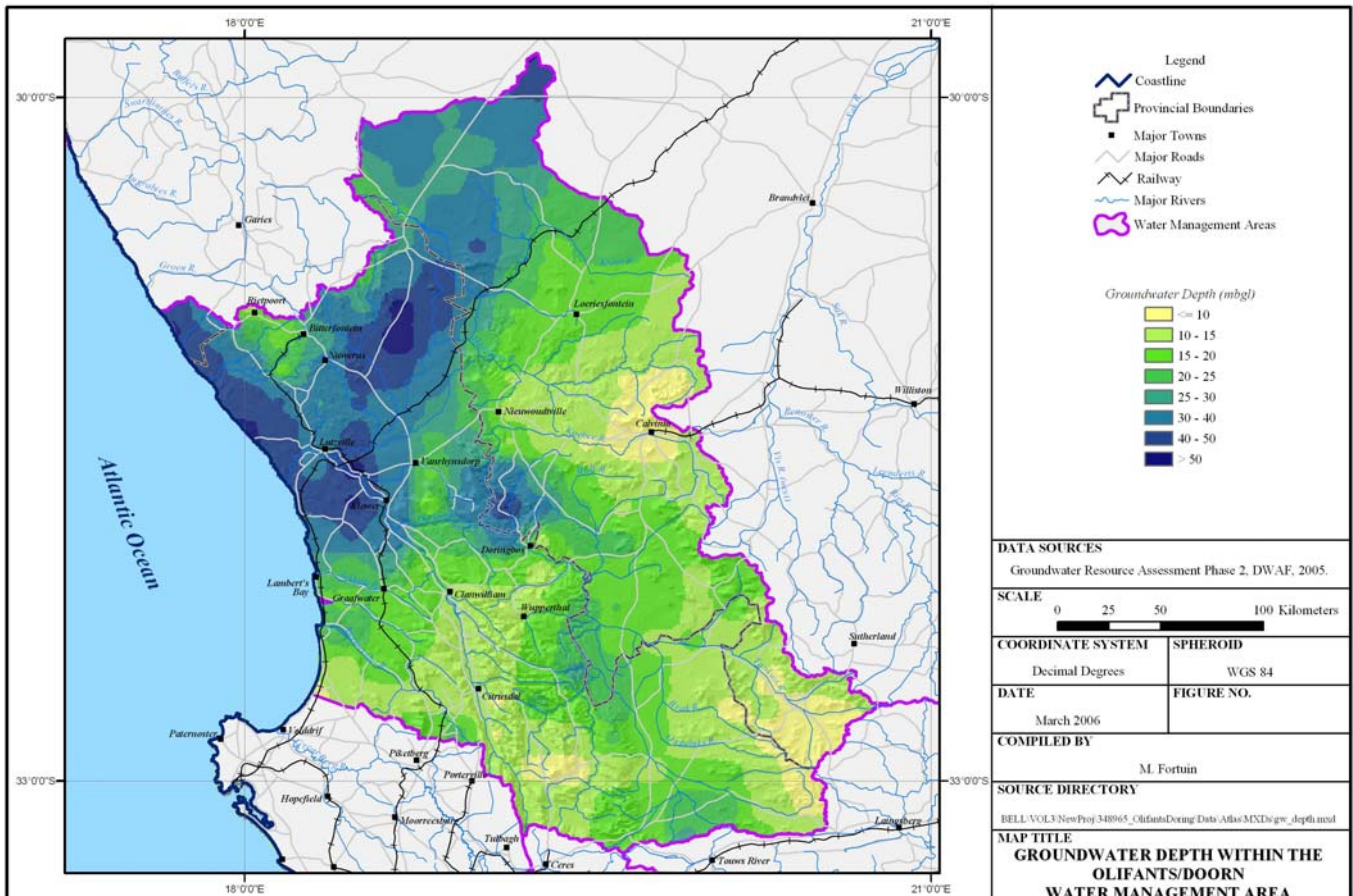


Figure 11: Depth to groundwater (m.bgl).

3.4 Groundwater Use

A literature review of all the relevant work done in the area was undertaken. The main purpose was to determine groundwater use as well as the volumes extracted in the Olifants/Doorn Primary Catchment. For the purposes of this specific section of the study “use” is seen as the amount of groundwater extracted and used for irrigation, livestock, municipal and rural use.

Groundwater use can be distinguished in five general categories:

- Rural domestic
- Livestock/agricultural
- Bulk water supply

- Irrigation
- Industrial (mining)

Rural/Domestic ranges from individual boreholes for primary water supply to rural landowners, villages, schools, clinics, hospitals, through small scale reticulation over short distances (2 – 5km), to larger schemes based on several boreholes that would either fall under schedule 1, general authority, or license agreement. **Figure 12** shows the surface water versus groundwater municipal use as well as the municipal groundwater use.

The livestock/agricultural category refers to individual boreholes for stock watering, vegetable gardening, etc. largely falling under Schedule 1 or General Authorizations.

Irrigation consists of larger schemes requiring well developed and managed groundwater resources/wellfields requiring to be licensed or General Authorizations if allocation is adequate (based on property size).

Bulk water supply refers to wellfields in large or extensive aquifer systems consisting of several high yielding boreholes requiring to be licensed.

Industrial/mining groundwater use refers to medium to large sized reticulation schemes based on several boreholes or a wellfield.

Table 3, extracted from DWAF (2002) Situation Assessment, summarises the groundwater usage in the above categories. The groundwater use per quaternary catchment is presented in **Appendix II** and displayed in **Figure 13**.

Table 3: Groundwater Use in the Olifants/Doorn WMA (NWRS).

Use	Annual Volume (Mm ³ /a)
Irrigation	42
Agriculture: rural/livestock	1.5
Rural domestic	0.5
Municipal urban (bulk water)	2
Industrial/mining	-
Total	46

The data from the DWAF NGDB was analysed and summarized per Quaternary catchment. Data extracted from the WARMS database was also analysed, as well as data extracted from various sources, to determine the volumes being extracted.

In each case specific variables were taken into account, such as volumes of groundwater being used for activities, area and utilisation of groundwater within the Olifants/Doorn WMA, excluding the Sandveld and E10 catchments.

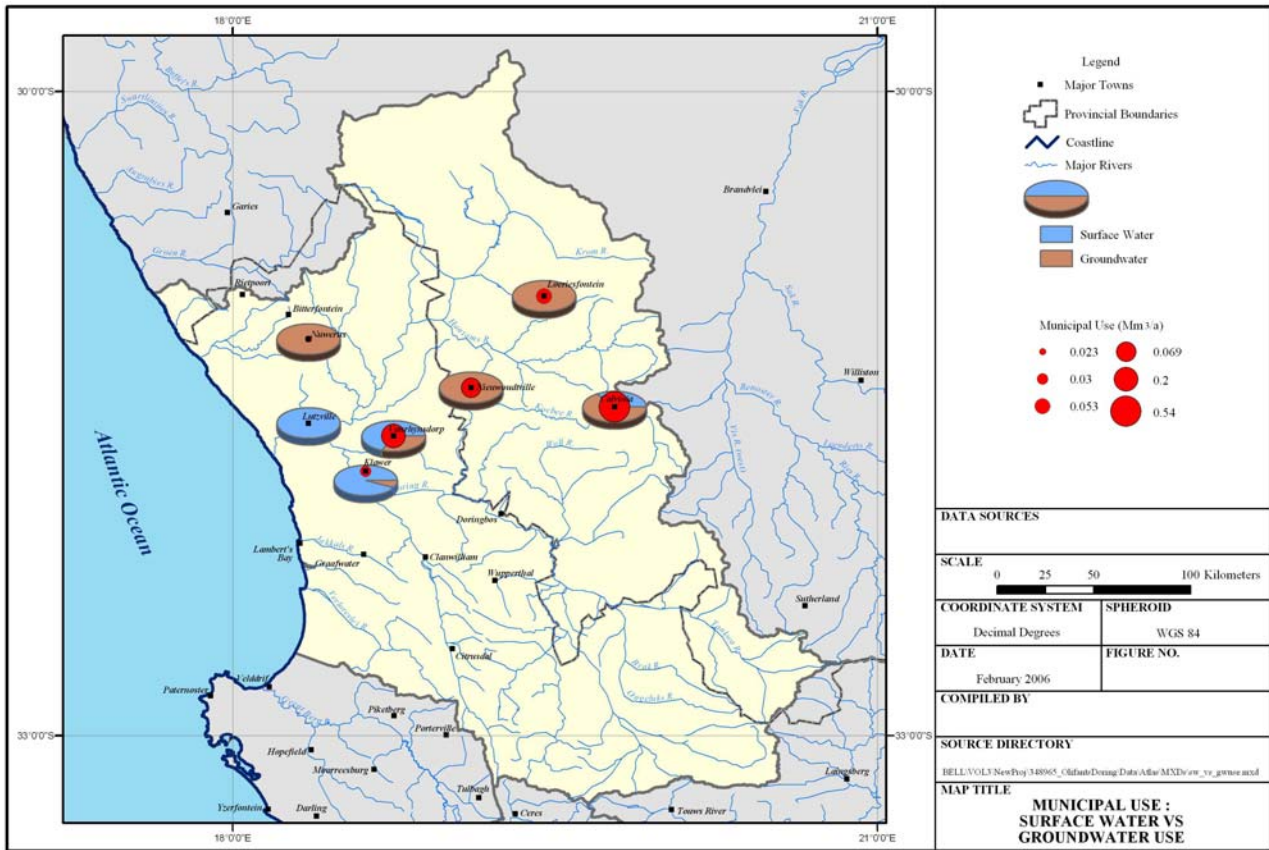


Figure 12: Municipal Use - surface water versus groundwater use.

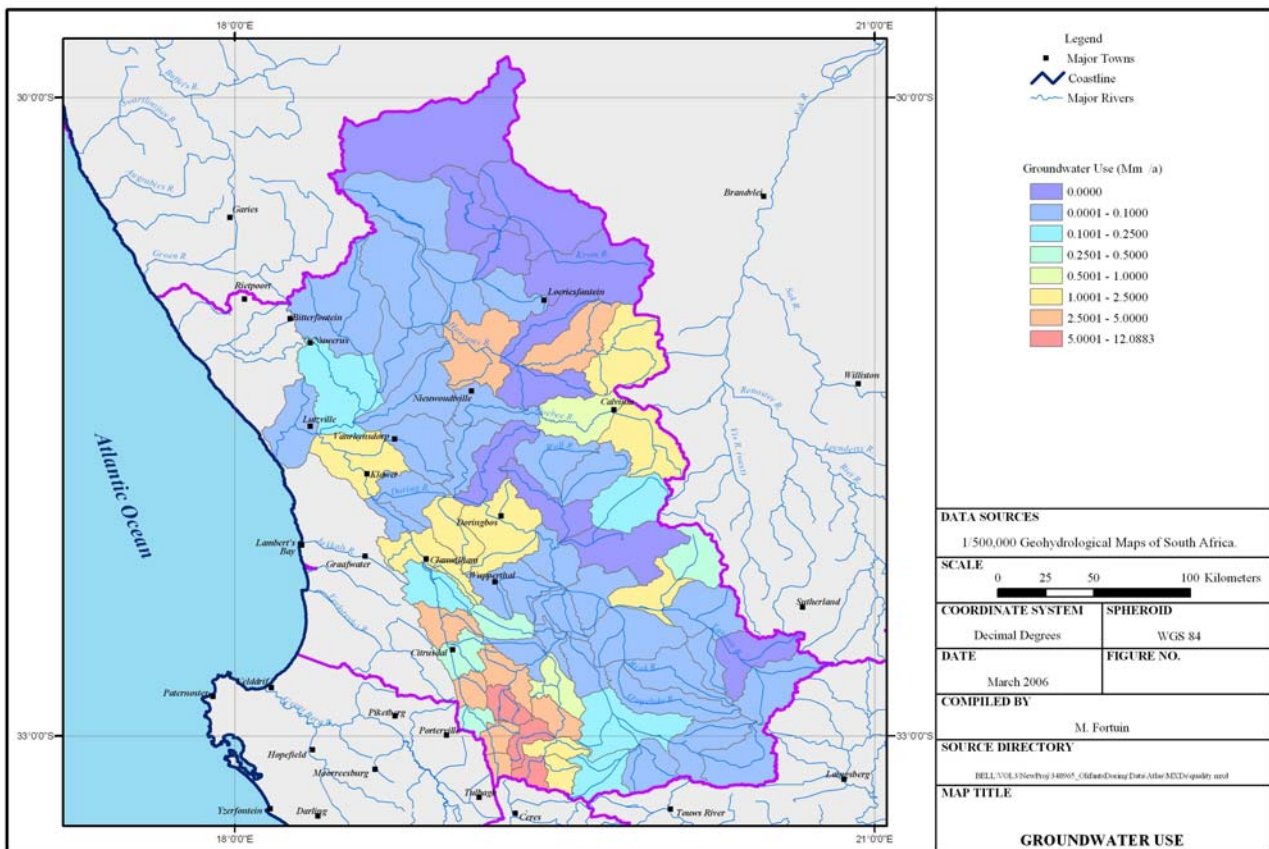


Figure 13: Groundwater Use per Quaternary Catchment.

3.5 Groundwater Quality

Groundwater quality is generally controlled by the aquifer lithology and geochemistry. Accordingly, groundwater quality in the Olifants/Doorn WMA varies significantly between the fractured rock aquifers and the intergranular and fractured rock aquifers that overlie generally impermeable shale- or granite-dominated pre-Cape formations.

The groundwater in the fractured rock aquifers of the TMG and the Witteberg quartzites generally has an EC of < 70 mS/m (**Figure 14**). The regolith aquifers in the Malmesbury Group aquifers only have acceptable water qualities where there is potential leakage from higher quality TMG Aquifers. The regolith aquifers yield neutral to alkaline groundwater with an EC > 300 mS/m and locally > 1000 mS/m.

Bokkeveld groundwater is of acceptable to marginal quality. Compared to the Bokkeveld and Karoo Aquifers adjacent to it, the quality of groundwater in the Dwyka Formation seems very poor (300 – 1000 mS/m). Groundwater of the lowest quality (> 1000 mS/m) is found in the primary aquifers overlying Dwyka tillite and lower Ecca shale in the Kliprand area, and from the Namaqua basement aquifers of low yield and low recharge potential in the northwest.

The groundwater in the south-western part of the WMA is generally of ideal or very good quality (EC < 70 mS/m). It is suitable for use in small towns and rural settlements where surface water scheme supplies do not penetrate or there are no surface water allocations.

Appendix III summarises the EC data per quaternary catchment.

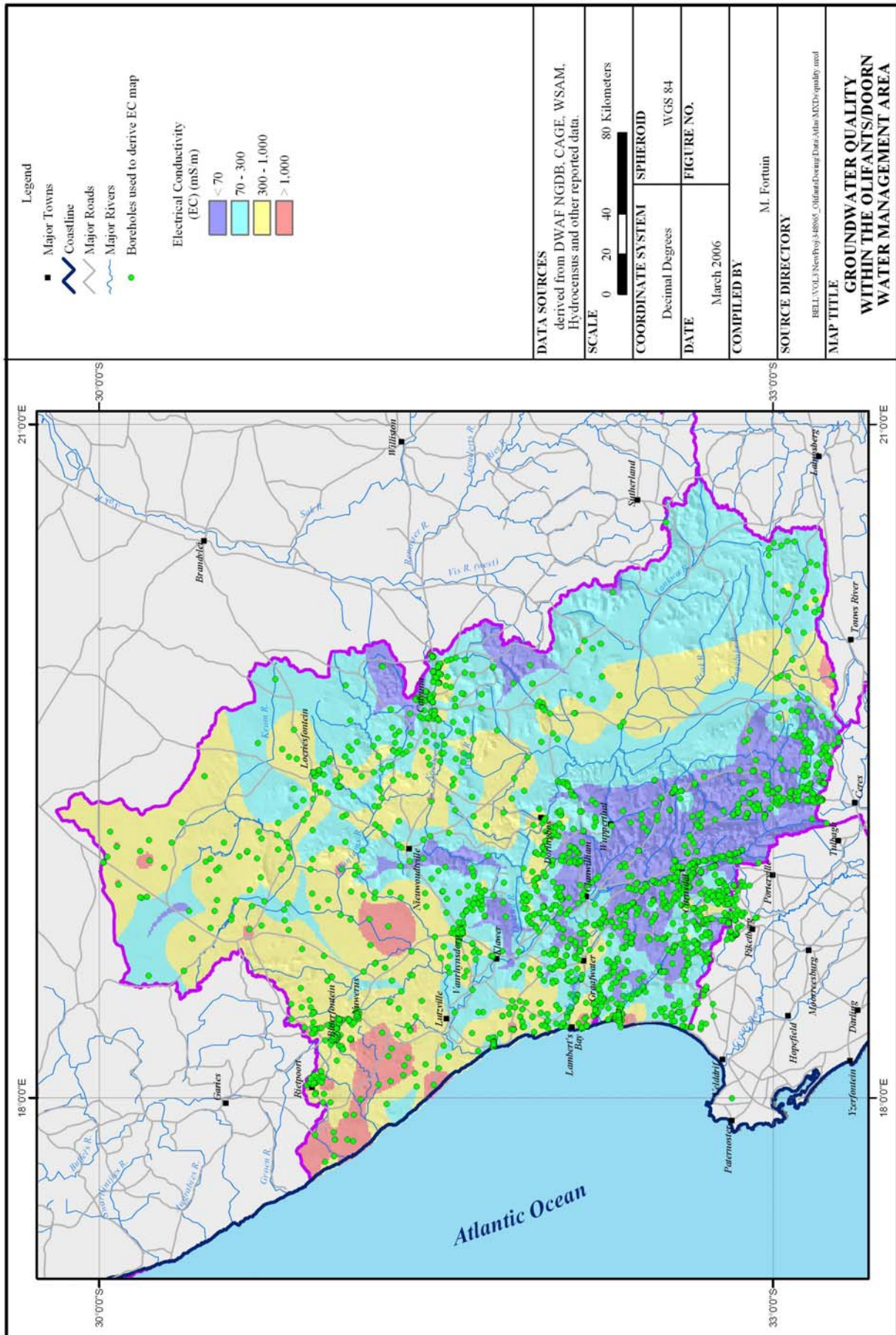


Figure 14: Electrical Conductivity (EC) (mS/m) as a measure of Groundwater Quality.

3.6 Groundwater Pollution

The threat of groundwater pollution increases with increasing population and development (and where aquifers with shallow water tables occur) and can result from:

- Domestic use in concentrated human settlement
- Agriculture
- Industrial and mining activity
- Waste disposal

Existing DWAF vulnerability maps appear to underestimate the potential for aquifer pollution or contamination. “Most vulnerable” areas are shown along the primary coastal aquifer south of and around Eland’s Bay, and also north of Lambert’s Bay, in part reflecting the potential intrusion of sea water.

3.7 Recharge

Groundwater resource potential is of particular concern to the planner, developer and groundwater user. According to Struckmeier (1989) groundwater resource potential embraces the following:

- Accessibility – aquifer depth and drilling risk.
- Exploitability – yield and pumping height.
- Availability – resource and recharge.
- Suitability – chemistry and risk pollution.
- Conservation – size and hydrodynamic situation.

A number of existing spatial datasets have been used to assess the groundwater development potential of the study, i.e. WRC’s Groundwater Resources – Borehole Prospects, DWAF’s Groundwater Harvest Potential and 1/500,000 scale Hydrogeological map. The aim is to develop an exploitation map which essentially considers the resource and recharge.

Sustainable groundwater abstraction depends upon adequate recharge to replace the water being removed from the Aquifer System. In this section, aquifer recharge refers to the amount of precipitation that infiltrates into the vadose zone and then actually enters into the main underlying Aquifer System. The estimated volumes of rainfall recharge therefore already account for evapotranspiration losses.

Owing to the difficulty of modelling such complex processes associated with recharge, the quantification is expressed as a percentage of mean annual precipitation. The Mean Annual Effective Recharge (R_e) from rainfall was estimated using the Mean Annual

Precipitation (MAP), percentage Coefficient of Variance (CV) of MAP, %-Terrain Slope and Lithological-Recharge Factor raster-datasets for the study area. The %-slope grid, computed using ArcView Spatial Analyst, was constructed from a 100x100m grid-cell digital elevation model generated in ArcInfo. The MAP was interpolated from the 1x1km grid data used in the Groundwater Resource Assessment Phase 2 project (DWAF, 2005) and varies between 100mm to in excess of 1000mm (**Figure 4**). The influence of lithology on rainfall recharge was also taken into account by applying a lithological factor that was subjectively determined based on the rock types present within each lithostratigraphic unit.

The following GIS-based spatial-modelling process was used to simulate the mean annual volumes of recharge for the study area:

- A variable recharge rate (R_f) was estimated for each 100X100m grid-cell in the study area, where R_f increases with increasing MAP as follows $R_f(\%) = [\text{MAP (mm)} / 10\ 000]$.
- The effect of terrain slope on the relationship between rainfall infiltration and runoff was account for using a Slope Factor: $S_f = 100 - [\% \text{Slope} / 100]$.
- The positive or negative effects of the various lithological units on rainfall recharge were accounted for using a Lithological Factor (L_f), summarised in **Table 4**.
- Mean annual depth of groundwater recharge (R_e) from rainfall were estimated for each 100X100m grid-cell in the study area, as follows: $R_e \text{ (mm/annum)} = \text{MAP} \times R_f \times S_f \times L_f$

In the case of variable geology, the recharge values were multiplied by a weighted factor according to the underlying geology. The recharge was either enhanced or reduced depending on the lithology. For example, the quartzitic sandstones of the Peninsula Formation were multiplied by a factor of 1.3 indicating enhanced recharge potential while the Malmesbury shale was multiplied by a factor of 0.65 indicating reduced recharge potential.

The mean annual effective recharge (R_e) for the entire study area is estimated at 200 Mm³ (an average recharge rate of 11% of MAP). This is expected to decline to 132 Mm³ during droughts. The R_e was determined for each of the 65 Quaternary Drainage Regions in the study area (Appendix V).

Table 4: Lithological Recharge Factors.

Lithology	This Study	Berg River Study	Breede River Basin Study
Malmesbury Group	0.65	0.65	0.60
Granites	0.85	0.85	0.70
Namaqua Metamorphic Complex	0.85		
Vanrhynsdorp Group	0.80		
Gamtoos Formation	0.85		
Kaaimans Group	0.85		
Kango Group	0.85		
Table Mountain Group			1.00
Peninsula Formation	1.30	1.30	
Piekenierskloof Formation	0.90	0.90	
Graafwater Formation	0.80	0.65	
Pakhuis Formation	0.70	0.65	
Cedarberg Formation	0.70	0.65	
Nardouw Formation	1.10	1.10	
Sardinia Bay	1.00		
Bokkeveld Group	0.80		0.70
Witteberg Group	0.95		0.60
Ecca Group	0.70		
Dwyka Formation	0.75		
Uitenhage Group	0.60		
Enon Formation	0.80		
Adelaide Subgroup	0.85		
Suurberg Group	0.60		
Fluvial Deposits	0.85		
Various Coastal Deposits	1.00		

The resulting R_e dataset was then compared to DWA's Groundwater Harvest Potential Map. The Harvest Potential Map provides an assessment of the harvest potential of groundwater from Aquifer Systems in South Africa. However, for this study DWA's Harvest Potential Map is too broad a classification and since it is vector based it is less accurate for use in raster or grid-based GIS modelling. The R_e gives more detailed information for further analysis by taking into account the effects of slope and lithology.

From the resulting recharge map it is evident that large areas of high potential for large-scale abstraction exist in the mountainous regions, coinciding with the occurrence of Table Mountain Group rocks. In general, production boreholes sited in groundwater units with higher rates of rainfall recharge should be able to sustain higher abstraction rates. However, it may not always be possible to find suitable drilling targets to actually site production boreholes capable of delivering the required yields. It is therefore important to also consider the potential for locating, siting and obtaining a successful borehole.

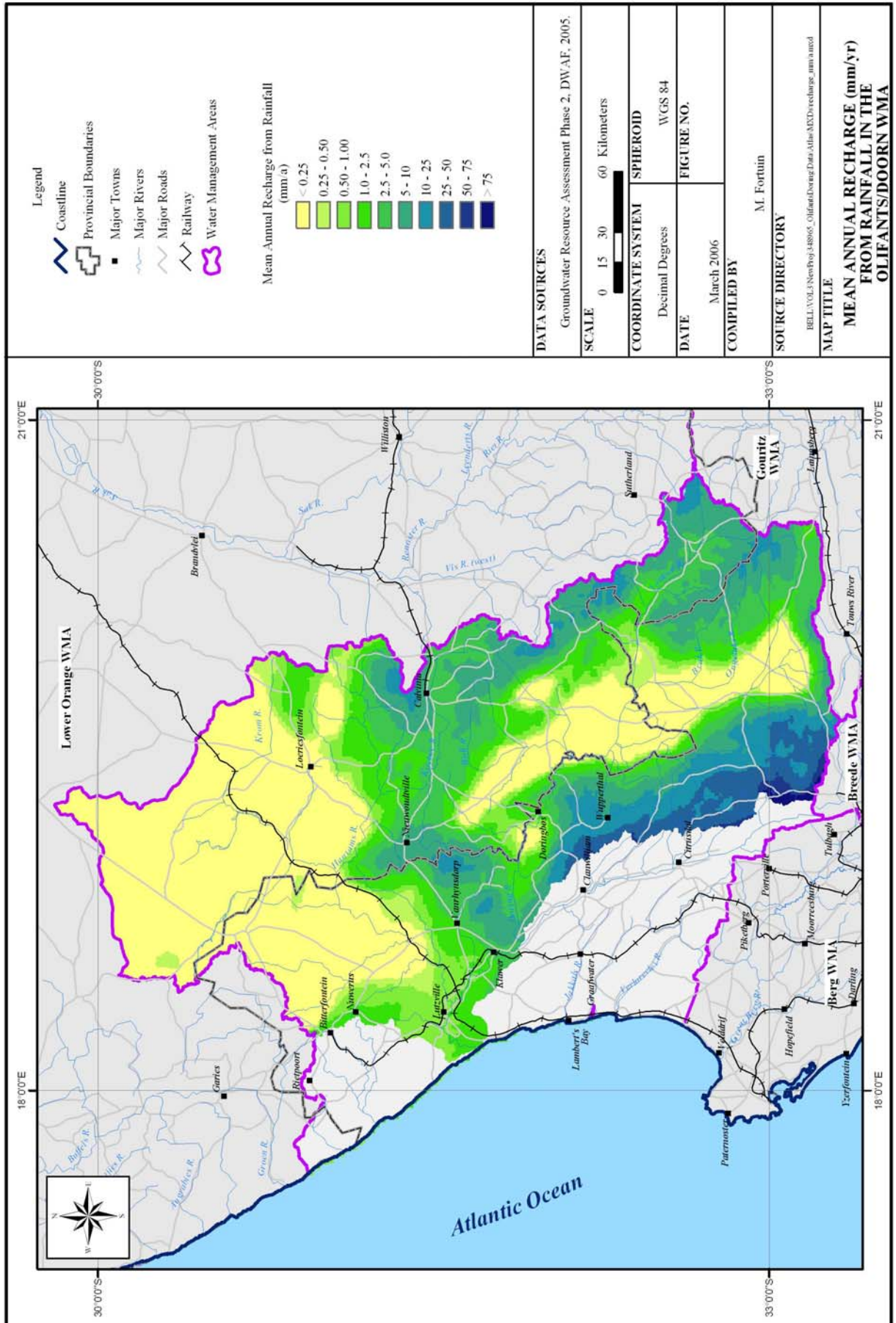


Figure 15: Mean Annual Effective Recharge from Rainfall (mm/a).

4 DELINEATION OF RESOURCE UNITS

The quaternary catchment is used as a starting point for delineating groundwater resource units within a study area. However, the objective of delineation is to group significant water resources with similar characteristics. Xu *et al.* (2003) provided a list of characteristics that could be taken into account when delineating groundwater regions or response units, including groundwater regions as defined by Vegter (1995), hydrogeological terrains, aquifer lithology, recharge, hydrogeochemistry and vulnerability. A ‘groundwater response unit’ is defined as a groundwater body that has been delineated or grouped into a single significant water resource based on one or more characteristics that are similar across that unit. Typically, a GRDM assessment is required for each unit.

The 13 groundwater response units for the Olifants/Doorn Primary Catchment are shown in Figure 16.

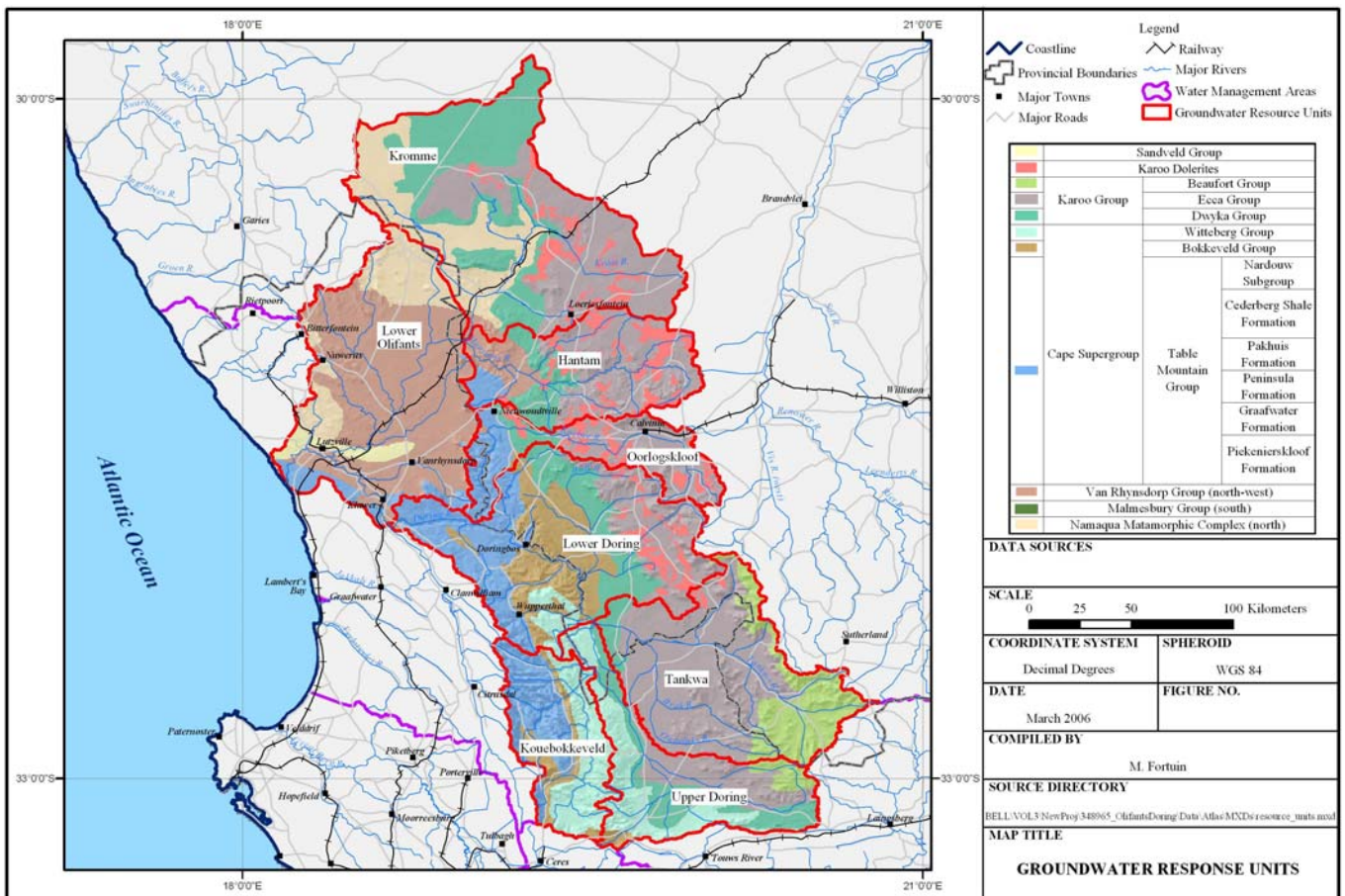


Figure 16: Groundwater Resource Units for the study area.

The resource units were broken down further but after analysis of the data the boundaries were reworked, wherein smaller resource units were combined to immediately adjacent units having similar characteristics.

5 RESOURCE CLASSIFICATION

The National Water Act (Act 36 of 1998) requires that all water resources be classified. The classification of a water resource is to determine the condition of a resource or part thereof in terms of the impacts on it by users as well as the importance of this resource to these users.

5.1 Present Status Category

It was decided to incorporate the classification tools presented by DWAF (1999). A category can be set using generic descriptions in terms of levels of impact (**Table 5**), a stress index based on the volume of groundwater abstracted in relation to annual recharge (**Table 6**) or observed or expected groundwater contamination. Comparison of the volume of groundwater abstracted to estimated recharge was considered the most appropriate method to use to determine the category of each groundwater unit.

Table 5: Present Status Category according to Levels of Impact.

Present Status Category	Generic Description	Affected Environment
A	Unmodified, pristine conditions	No significant impacts observed
B	Localised low level impacts, but no negative effects apparent	
C	Moderate levels of localised impacts - moderate perceived impact on the environment	
D	Moderate levels of widespread impacts - limited but noticeable effect on the environment	Moderate to critical impacts to: spring flow, river flow, vegetation, land subsidence, sinkhole formation, groundwater quality
E	High levels of local impacts - serious effect on the environment	
F	High levels widespread impacts - critical effect on the environment	

Table 6: Present Status Category according to a Stress Index.

Present Status Category	Description	Stress Index (abstraction/recharge)
A	Unstressed levels or low levels of stress	< 0.05
B		0.05 - 0.20
C	Moderate levels of stress	0.20 - 0.40
D		0.40 - 0.65
E	Stressed	0.65 - 0.95
F	Critically stressed	> 0.95

A stress index was developed to facilitate classification of resource units. The index is calculated by dividing groundwater use by recharge (**Table 6**). The index is then used to classify the resource in terms of its present status and water resource category.

An advantage of using this approach is that it allows a link between classification and RQO's. By defining the class of a resource by its level of stress, a tool is established for setting an RQO. If, for example, the public decide they want a particular resource to remain in a "good" state, then 25% of the recharge to a resource unit can be abstracted. However, if they decide the resource should be managed to a "fair" category, then 65% of the recharge can be abstracted.

It must be noted that the stress index is determined for the catchment as a whole. ***It is possible that, locally, the stress index may be higher.***

The classification per Quaternary Catchment is presented in **Appendix V** and shown in **Figure 17**.

5.2 Water Resource Category

Table 7 shows the categorisation of the water resource classification which is presented in Appendix V for each of the quaternary catchments.

Table 7: Categorisation for water resource classification.

Present Status Category	Water Resource Category
A – unmodified natural	Natural
B – largely natural	
C – moderately modified	Good
D – largely modified	
E – seriously modified	Fair
F – critically modified	
	Poor

The water resource category for each quaternary catchment is presented in **Figure 18**.

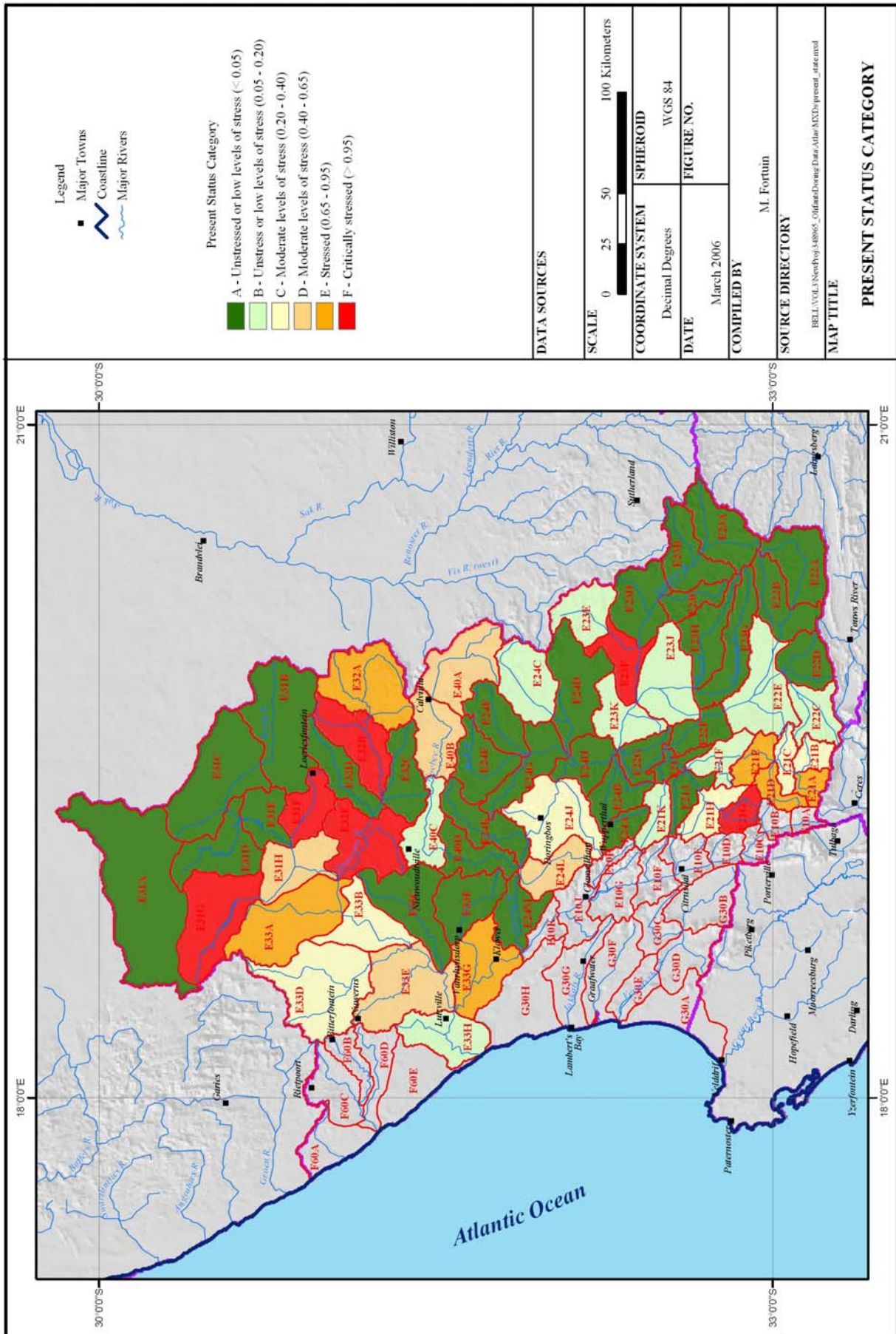


Figure 17: Present Status Category.

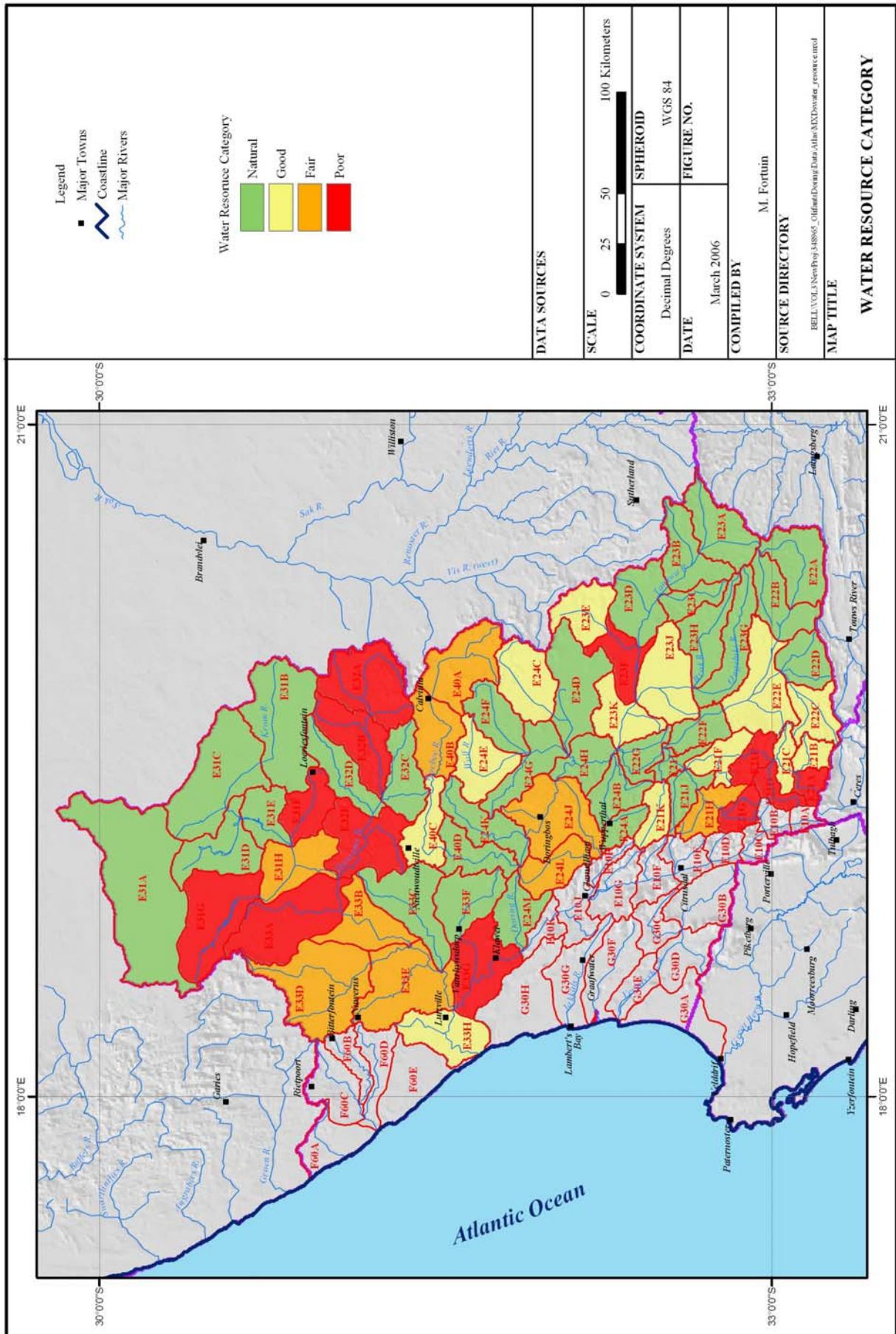


Figure 18: Water resource category.

6 QUANTIFICATION OF THE RESERVE

The GRDM assessment process requires that the resource units be defined, the units be classified, the Reserve calculated and the allocatable groundwater in each unit specified.

6.1 Basic Human Needs

Calculation of basic human needs in a resource unit is a simple task, where each person living within the boundaries of the resource unit is allocated 25 ℓ/p/d. The total population of the Olifants/Doorn WMA is relatively small in the order of 113,000 people. Using 2001 hydrocensus population data for magisterial districts, the population of each quaternary catchment was estimated and rounded up to the nearest hundred. If it is assumed that the entire population is dependent on groundwater as a source of supply and using a basic human need of 25 ℓ/p/d, then the basic human needs of the catchments that fall within the study area is calculated as 0.32 Mm³/a. The basic human needs per quaternary catchment is summarised in **Appendix VI**.

6.2 Groundwater Contribution to Baseflow

One of the outcomes of the implementation of the National Water Act (Act 36 of 1998) is the realisation that the conceptual understanding of the groundwater contribution to baseflow in South Africa Rivers is problematic.

Baseflow is not a measure of the volume of groundwater discharged into a river or wetland, but it is recognised that groundwater does make a contribution to this component of river flow. Low flows in rivers are sustained by both interflow and groundwater, and it is only in the very dry periods that the groundwater contribution dominates. Historically, hydrologists separated river flow into stormflow and baseflow components based on flow characteristics, while geohydrologists tried to consider that component derived from groundwater, i.e. process hydrology. This confusion was exacerbated by failure to recognise the difference between subsurface water and groundwater, nor appreciate the important role of the vadose zone in runoff generation. Parsons (2004) proposed use of the term “groundwater contribution to baseflow” to clarify the origin of the water and adoption of the classical hydrological definition of the term “baseflow” i.e. sustained low flow in a river during dry or fair weather conditions.

Tools to identify and quantify the groundwater contribution to river flow and wetlands are lacking. DWAF (1999) required the maintenance low flow set by the surface water Reserve team be used to define the groundwater contribution to baseflow. This approach was based on the assumption that all maintenance low flow is derived from groundwater. Xu *et al.* (2003) described theoretical considerations of baseflow separation and a range of hydrograph separation techniques. This included a geomorphic classification of streams that could be used to develop a better understanding of the discharge of groundwater into rivers. The approach described by Xu *et al.* (2005) required data not readily available and it was decided that this approach was not suitable. One of the major drawbacks in using flow data to determine the groundwater contribution to baseflow is the lack of good quality

measured flow data. Establishment of two impoundments on the Olifants River (Bulshoek Barrage – 1919; Clanwilliam Dam – 1932) and the absence of gauging stations preclude obtaining measured natural flow data.

Sami (2005) modified the Pitman model to estimate the groundwater contribution to baseflow. A logical stepped methodology has been developed in a MS-Excel environment that determines the impacts of abstraction on baseflow without the necessity of modelling. The methodology is based on sequentially:

- Performing a hydrograph separation to separate groundwater baseflow (baseflow from the regional aquifer) and interflow (baseflow from perched aquifers) from storm runoff on a monthly time scale using WR90, observed flow data or a stochastic hydrograph
- Back calculating subsurface storage to calculate a time series of recharge
- Incrementing groundwater storage from recharge to a maximum level
- Depleting groundwater storage by evapotranspiration as a function of groundwater storage until rest water level conditions are reached
- Calculating groundwater baseflow or transmission losses in a non-linear manner as a function of groundwater storage and runoff volume
- Depleting groundwater storage and groundwater baseflow due to abstraction

Because of opposing views around the perenniality of the Olifants River and lack of gauged data, it is difficult to quantify the groundwater contribution to baseflow with any accuracy. However, from a Reserve perspective, it is often not the volume of contribution that is important, but rather the timing. During late summer, groundwater sustains pools in the river that are critical for surrounding ecosystems. In instances where groundwater sustains pools in the river channel, depth to groundwater would be an important RQO.

For the purpose of this study the most recent data, that produced by the Groundwater Resource Assessment Phase 2 project (DWAF, 2005), was adopted.

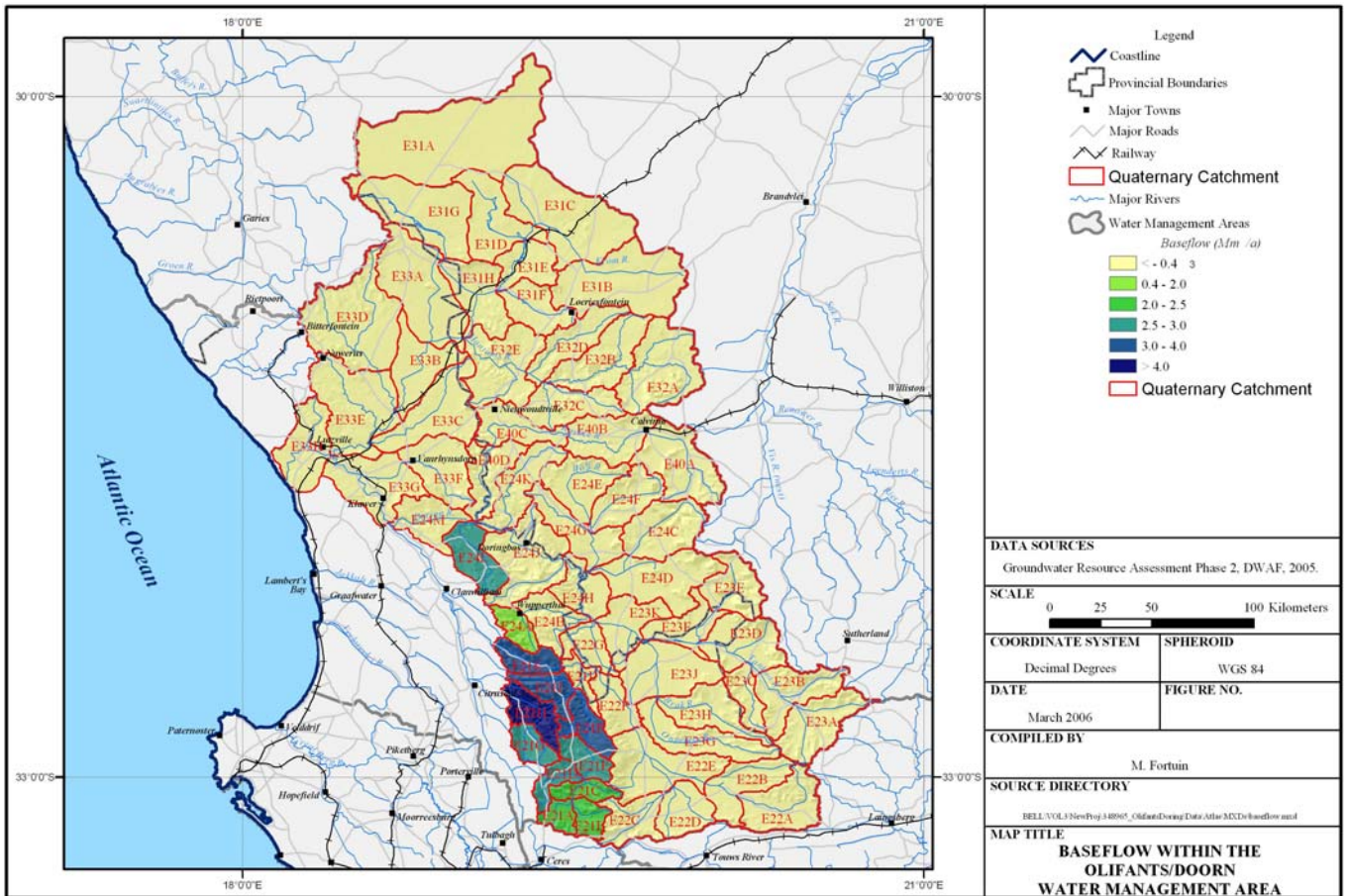


Figure 19: Groundwater contribution to baseflow.

6.3 Groundwater/Surface Water Interaction Zones

A workshop was convened at SRK on 7 April 2006, where an attempt was made to delineate zones of groundwater/surface water interaction in the catchment considered to be of particular relevance to the determination of the Ecological Reserve.

6.3.1 Process adopted

The following process was adopted:

- 1) Zones were selected on the basis of their perceived relevance to the determination of the Ecological Reserve.
- 2) Zones were delineated on the basis of anecdotal information. This means that those delineated may be incomplete and incorrect, in places.
- 3) Three main zones were delineated, each for a different reason. A summary of the key issues in each zone is provided in Section 6.3.3.

6.3.2 Zones delineated

The three zones of groundwater/surface water interaction in the catchment are indicated in **Figure 20**, they are:

Zone 1: The Olifants River from Grootfontein to Clanwilliam Dam.

Zone 2: The Doring River from Doringbos to Melkboom, plus the lower sections of the Koebee River. It is possible that pools in the lower sections of the Groot, Matjies, Wolf, Tra-Tra, Biedou and Brandewyn Rivers are similarly maintained by groundwater during the dry season.

Zone 3: The Olifants Estuary.

6.3.3 Summary of key issues in each zone

Zone 1: Olifants River from Grootfontein to the Clanwilliam Dam

Groundwater abstraction close-to and within the river during the mid- to late summer months impacts on river baseflow in this zone, when the naturally perennial Olifants River is pumped dry, sometimes for up to several weeks. Reserve studies for the river (DWAF 2005) indicated that, although there is some scope for additional abstractions from this section of the river in the winter, these can only be realised if some summer flows are reinstated.

Zone 2: Doring River from Doringbos to Melkboom

The Doring River, and its main tributaries such as the Groot, Tra-tra, Biedou and Koebee Rivers, is particularly important from a conservation point of view. It is inhabited by nine indigenous fish species, seven of which are endemic to the river system. Of these, the

mainstem of the Doring River is most important for the larger species (Paxton *et al.*, 2002). The reaches upstream of the Tankwa River are vital breeding areas for the sawfin (*Barbus serra*), the Clanwilliam yellowfish (*Barbus capensis*), and the Clanwilliam sandfish (*Labeo seeberi*). The latter two are classified as rare Red Data species, while the sawfin is regarded as vulnerable (Skelton, 1993).

Here, summer pool depths and the length of time between the cessation and recommencement of flows are critical factors in respect of fish survival in the system. High densities of indigenous fish species were sampled in the Doring River during February 2001, when populations were forced into ever-decreasing volumes of water in the drying pools (Paxton *et al.* 2002). Evaporation from these pools during the hot summers is extremely high – as evidenced by shrinkage marks on side of pools, and indigenous fish are known to over-summer in pools where evaporation is somewhat off-set by groundwater inflows.

Whether the marked preference of indigenous fish for pools with groundwater inflows is because of a more favourable water chemistry (pools without groundwater contributions tend to become very saline) or a result of some other factor such as pool depth (which is supported by groundwater inflow), or growth of *Potamogeton spp.* (which is hindered by groundwater inflow), is not known. *Potamogeton* occurs in the shallower regions of pool, i.e., <1 – 1.5 m). The indigenous fish will not inhabit the areas infested with *Potamogeton*, whereas the exotic species (*Micropterus spp.* and *L. macrochirus*) survive amongst the *Potamogeton*. This suggests that if flow manipulations increase the duration of the dry season and/or reduce the groundwater contributions to key pools, then survival of isolated indigenous fish populations will be compromised

The Ecological Reserve flows recommended in this section of the Doring River (DWA 2005) calls for a slight INCREASE in dry season lowflow volumes as it seeks to reduce the length of the dry season back towards a more natural situation.

Zone 3: Olifants Estuary

The Olifants Estuary stretches from the mouth (near Papendorp) up to the low water bridge (Lutzville). In terms of conservation importance the estuary is rated the second most important systems in South Africa, based on size, zonal type rarity, habitat importance and biodiversity importance (Turpie *et al.*, 2004).

The zonation of vegetation in the estuary is primarily determined by salinity penetration patterns, e.g. reeds typically occur in areas where salinities are less than 20 ppt for more than 3 months of the year. The groundwater inputs are particularly important to the intertidal and supratidal vegetation with relatively deeper root systems (average 1.5 to 2 m e.g. reeds and salt marshes). For those vegetation types soil salinities are also important, where very high salinities can inhibit plant growth and the establishment of new seedlings (tolerance levels differ depending on the vegetation type). Groundwater plays an important role in preventing soil salinities from reaching unacceptably high values, particularly during periods of low surface runoff.

7 GRDM ASSESSMENT

7.1 Summation tables

Table 8: Summary of waterlevels and volumes stored.

Resource Unit	Average Waterlevel (m.bgl)	Average thickness of Aquifer (m)	Volume of water stored in Aquifers (Mm ³ /a)	5m Drawdown Storage Volume (Mm ³ /a)	Area (km ²)
Hantam	13.78	144	175.42	17.08	4,201
Kouebokkeveld	14.90	258	514.22	33.61	3,072
Kromme	25.52	169	362.70	48.17	9,720
Lower Doring	19.59	250	889.56	64.63	7,646
Lower Olifants	35.63	171	320.39	33.38	8,215
Oorlogskloof	17.21	145	111.57	11.96	2,722
Tankwa	12.80	237	381.87	31.89	6,445
Upper Doring	18.16	246	408.78	30.27	4,154
TOTAL			3,164.51	270.98	

Table 9: Mean Annual Precipitation (mm/a) and Elevation (m.amsl) summarised per resource unit.

Resource Unit	Mean Annual Precipitation (mm/a)						Elevation (m.amsl)	
	Minimum	Maximum	Range	Mean	Standard Deviation	Median	Minimum	Maximum
Hantam	121	433	312	198	44	184	285	1,681
Kouebokkeveld	91	1,171	1,080	410	157	389	385	2,044
Kromme	49	210	161	118	36	122	287	1,224
Lower Doring	70	691	621	231	84	217	30	1,901
Lower Olifants	77	485	408	145	45	135	-1	1,020
Oorlogskloof	157	417	260	255	46	248	157	1,676
Tankwa	66	438	372	198	75	183	269	1,720
Upper Doring	74	939	865	233	95	219	272	1,895

Table 10: Summary of EC (mS/m) as a measure of Groundwater Quality.

Resource Unit	Minimum	Maximum	Range	Mean	Standard Deviation
Hantam	23	1,440	1,417	244	195
Kouebokkeveld	0	1,129	1,135	42	48
Kromme	28	1,267	1,239	441	232
Lower Doring	0	1,288	1,290	219	165
Lower Olifants	0	2,070	2,063	534	327
Oorlogskloof	9	1,216	1,208	212	187
Tankwa	40	840	800	233	95
Upper Doring	3	2,181	2,178	283	245

Table 11: Groundwater Reserve Determination for the resource units.

Quaternary Catchment	Classification		Annual Recharge (Mm ³ /a)	Reserve				Allocation	
	Present Status Category	Water Resource Category		Groundwater Contribution to Baseflow (Mm ³ /a)	Population	Basic Human Needs (Mm ³ /a)	Reserve (% recharge)	Groundwater Allocation	Groundwater Use
Hantam	F	Poor	6.35	0.00	0	0.000	0.0%	6.35	9.18
Kouebokkeveld	D	Fair	58.63	30.51	536	0.005	52.1%	28.10	33.65
Kromme	B	Good - Natural	0.47	0.00	2,400	0.022	4.7%	0.45	0.06
Lower Doring	B	Good	23.17	3.59	2,290	0.021	15.6%	19.56	4.29
Lower Olifants	C	Good	6.19	0.00	19,907	0.182	2.9%	6.01	1.71
Oorlogskloof	C	Fair - Good	8.77	0.00	9,400	0.086	1.0%	8.69	2.74
Tankwa	B	Natural	17.63	0.00	40	0.000	0.0%	17.63	1.60
Upper Doring	A	Natural	10.52	0.00	560	0.005	0.0%	10.52	0.41

Table 12: Groundwater Exploitation Potential.

Quaternary Catchment	Ave. GW Resource Potential		GW Exploitation Potential		Potable GW Exploitation Potential		Utilisable GW Resource Potential		Utilisable GW Exploitation Potential		Utilisable Potable GW Exploitation Potential	
	Mm ³ /a		Mm ³ /a		Mm ³ /a		Mm ³ /a		Mm ³ /a		Mm ³ /a	
	Wet Season	Dry Season	Wet Season	Dry Season	Wet Season	Dry Season	Wet Season	Dry Season	Wet Season	Dry Season	Wet Season	Dry Season
	AGRP	AGRP (dry)	GEP	GEP (dry)	PGEP	PGEP (dry)	UGRP	UGRP (dry)	UGEP	UGEP (dry)	UPGEP	UPGEP (dry)
Hantam	20.23	16.41	7.84	6.35	4.21	3.43	9.23	5.40	3.57	2.10	1.99	1.18
Kouebokkeveld	73.08	46.35	41.20	25.99	32.41	20.42	53.92	26.80	30.99	15.54	25.19	12.97
Kromme	6.76	6.46	2.33	2.21	0.69	0.65	3.25	2.96	1.08	0.95	0.33	0.29
Lower Doring	59.70	46.66	25.27	19.54	11.34	8.63	42.44	29.38	18.25	12.48	8.51	5.78
Lower Olifants	12.57	8.72	4.92	3.38	1.94	1.31	11.11	7.23	4.39	2.85	1.75	1.12
Oorlogskloof	21.02	16.15	7.83	6.03	3.66	2.76	13.95	9.07	5.14	3.33	2.61	1.72
Tankwa	46.28	36.11	22.10	17.19	11.19	8.70	31.21	21.08	14.96	10.11	7.53	5.07
Upper Doring	40.29	34.16	18.91	15.99	11.29	9.49	23.49	17.29	11.23	8.27	6.84	5.01
TOTAL	279.93	211.02	130.40	96.68	76.73	55.39	188.60	119.21	89.61	55.63	54.75	33.14

7.2 Koue Bokkeveld

This resource unit, approximately 3,072 km² in areal extent, is bounded by the Kouebokkeveld and the south-eastern Cederberg mountain ranges. To the east the resource unit is bounded by the Swartruggens. The western half of the resource unit is primarily underlain by formations of the Table Mountain Group while the rest is underlain by the Bokkeveld and Witteberg Groups. Major faults and fracture zones cross-cut these formations especially along a NNW/SSE direction. Younger alluvial deposits occur in restricted areas around the river floodplains.

Although no municipal supply schemes occur in this area, as there are no towns here, over-abstraction occurs as a result of intensive agricultural development on the Bokkeveld shales. Numerous boreholes have been drilled around the TMG-Bokkeveld contact in this region. This over-abstraction has resulted in some of the catchments (E21D and E21G) having a stressed to critically stressed status category.

The most important aquifers in this unit are the Peninsula, Nardouw and Witteberg quartzites. These aquifers range between 100 m to in excess of 200 m in thickness. The groundwater quality is acidic to neutral with the Witteberg becoming alkaline in places. The EC varies but is generally < 70 mS/m (**Table 10**). Outliers above 200 mS/m are associated with the contact zone with the regolith aquifers.

In this unit the regolith aquifers comprises the Bokkeveld Group. In general the weathered and fractured regolith is alkaline and the EC is largely above 100 ms/m. The Bokkeveld sandstone formations have a lower EC and yields between 5 and 20 l/s. The groundwater yield in the Bokkeveld sandstones is, however, dependent upon local discharge from the TMG.

The groundwater use in this unit is estimated at 33.65 Mm³/a (**Table 11**), with most of the abstraction occurring in the E21D and E21G quaternary catchments (**Appendix III**).

It is estimated that the volume of water stored in the Kouebokkeveld unit is estimated at 514 Mm³/a and, assuming a 5m drawdown, the storage volume is estimated at 33.61 Mm³/a (**Table 8**). The rainfall in this unit ranges between 91 and 1,171 mm/a with a mean of 410 mm/a (**Table 9**). The recharge estimation for this unit is presented in **Table 11** and is estimated to be 58.63 Mm³/a. Groundwater contribution to baseflow for this unit is estimated at 30.51 Mm³/a. The unit has an overall present status categorisation of “D” and a water resource category of “Fair”. The E21G quaternary catchment is classified as being critically stressed with usage estimated at 12.09 Mm³/a and recharge at 7 Mm³/a.

7.3 Doring River

This large, geologically heterogeneous area has been subdivided into four units, namely the Upper Doring, Lower Doring, Tankwa and Oorlogskloof.

7.3.1 Upper Doring

This area lies between the Swartruggens mountain range in the west, the Witteberg range in the south and a ridge extending from the escarpment range. It is underlain by formations of the Witteberg Group, Dwyka Formation, Eccca Group and lower Beaufort Group. These strata generally dip at shallow angles toward the east. In the south-east they are affected by several ENE/WSW trending folds related to the folding of the Witteberg range. Younger alluvial deposits occur in restricted areas around the river flood plains.

The Witteberg and regolith are the most important aquifers in the unit, whereas the Dwyka Formation and the Eccca Group, generally yield non-potable water. The groundwater in the Witteberg has an EC < 75 mS/m. The EC for this unit ranges between 3 and 2,181 mS/m with a mean EC of 2,178 mS/m (**Table 10**).

The total usage in the unit is estimated to be 0.41 Mm³/a, while the recharge is estimated to be 10.52 Mm³/a. The total volume stored in this unit is 408 Mm³/a and assuming a 5m drawdown the stored volume is estimated at 30.27 Mm³/a (**Table 8**).

7.3.2 Lower Doring

This unit is bounded on the east by the escarpment range and on the west by the Cederberg range. The western area is primarily underlain by TMG, Bokkeveld and Witteberg Group rocks, while in the east the Eccca Group, Dwyka Formation and lower Beaufort underlie the unit. Karoo dolerite intrusives, namely dykes and sills, are abundant above the Dwyka Formation. Younger alluvial deposits occur along the river courses.

The total recharge estimate for this area is 23.17 Mm³/a. The total usage is estimated to be 4.29 Mm³/a. The total volume stored in this unit is 890 Mm³/a and assuming a 5m drawdown the stored volume is estimated at 65 Mm³/a (**Table 8**).

The Doring River, and its main tributaries such as the Groot, Tra-Tra, Biedouw and Koebee Rivers, is particularly important from a conservation point of view. Here, summer pool depths and the length of time between the cessation and recommencement of flows are critical factors in respect of fish survival in the system. High densities of indigenous fish species were sampled in the Doring River during February 2001, when populations were forced into ever-decreasing volumes of water in the drying pools (Paxton et al. 2002). Evaporation from these pools during the hot summers is extremely high – as evidenced by shrinkage marks on side of pools, and indigenous fish are known to over-summer in pools where evaporation is somewhat off-set by groundwater inflows.

7.3.3 Tankwa

The Tankwa Karoo is bounded on the east by the escarpment range and its southern ridge which leads to a confluence with the main stream of the Doring River. It is underlain by gently dipping strata of the Dwyka Formation, Eccca and Beaufort Groups. Younger alluvial deposits occur around the Tankwa River.

The largest aquifer is regolith comprising the Dwyka Formation and Eccca Group of the Karoo Sequence. Recharge is estimated to be 17.63 Mm³/a but the water quality is very poor and yields are low. The total groundwater usage is estimated to be 1.60 Mm³/a. The best available sources would be in the fractured dolerite dykes and alluvium.

The total volume stored in this unit is 382 Mm³/a and assuming a 5m drawdown the stored volume is estimated at 32 Mm³/a (**Table 8**).

7.3.4 Oorlogskloof

This is a narrow belt extending from the escarpment range in the east to its confluence with the Doring River. In the west the unit is underlain by the Cederberg and Nardouw Formations and Bokkeveld Group. The eastern part of the unit is underlain by deposits of the Dwyka formation, Eccca Group and Karoo dolerite intrusives.

The total recharge is estimated at 8.77 Mm³/a while the groundwater usage has been estimated at 2.74 Mm³/a. The groundwater in the Oorlogskloof unit is of poor quality. The total volume stored in this unit is 112 Mm³/a and assuming a 5m drawdown the stored volume is estimated at 12 Mm³/a (**Table 8**).

7.4 Knersvlakte

The Knersvlakte area is made up of the Hantams, Kromme and Lower Olifants resource units.

7.4.1 Hantams

The Hantams unit extends from the escarpment range in the east to the confluence with the Krom River in the west. The elevation ranges between 285 m..amsl and 1,681 m.amsl in the mountainous regions. The western extent is underlain by gently dipping strata of the Nama Group and by the Nardouw Subgroup in the south-east, covered by Dwyka Formation tillite to the east. The quaternary catchments to the extreme east are underlain by strata of the Eccca Group. Karoo dolerite intrusives are found in the Eccca Group and Dwyka Formation in the east.

The total recharge is estimated at 6.35 Mm³/a and the total groundwater usage is estimated at 9.18 Mm³/a. The EC of groundwater in the unit ranges between 23 and 1,440 mS/m with a mean of 244 mS/m, which renders it poor quality. The total volume stored in this unit is 175 Mm³/a and assuming a 5m drawdown the stored volume is estimated at 17 Mm³/a (**Table 8**).

Overall the Hantams unit has been rated as having an “F” present status category and “poor” water resource category. Quaternary catchments E32B and E32E are critically stressed while E32A is stressed.

7.4.2 Kromme

The Kromme Resource Unit forms the north-northeastern extent of the Olifants/Doorn WMA. The western area is underlain by formations of the Nama Group which overlies basement granitoids of the Namaqua Metamorphic Complex. Towards the east the Namaqua Metamorphic Complex underlies tillite of the Dwyka Formation and Ecca shales. Karoo dolerite intrusives are found above the Dwyka tillites and Ecca shales.

The mean annual rainfall in this unit ranges between 40 mm/a and 210 mm/a with a mean of 118 mm/a. The elevation ranges between 287 m.amsl and 1,224 m.amsl.

The recharge for this unit was estimated to be 0.47 Mm³/a and an average resource potential of 6.76 Mm³/a during the wet season and 6.46 Mm³/a during the dry season. Groundwater usage in the unit equates to 0.06 Mm³/a. In certain cases zero recharge is recorded since aquifers are only recharged in extreme events. The total volume stored in this unit is 363 Mm³/a and assuming a 5m drawdown the stored volume is estimated at 48 Mm³/a (**Table 8**).

The groundwater quality in this unit is very poor with a mean EC of 441 mS/m.

Overall the present status of the unit has been classified as “B” where the water resource category is “Good” to “Natural”.

7.4.3 Lower Olifants

The eastern boundary of this unit extends northwards along the Nardouw escarpment around Van Rhyns Pass and across the north-eastern region of the Knersvlakte Plain around the area of the Kromme, Hantams and Sout River confluences.

This unit is largely underlain by Nama Group sediments which overlie basement granitoids of the Namaqua Metamorphic Complex in the north to north-east. Karoo intrusives occur in some places. Alluvial cover occurs above the Namaqua Metamorphic Complex and Nama bedrock in the Knersvlakte regions. In the south a thin margin of TMG formations is found. Toward the coast shallow marine and alluvial terrace deposits may be found.

The recharge estimate for this unit is 6.19 Mm³/a while the groundwater usage has been estimated at 1.17 Mm³/a. The rainfall ranges from 77 mm/a to 485 mm/a with a mean of 135 mm/a. The elevation above mean sea level ranges from -1 m.amsl at the estuary to 1,020 m.amsl. The total volume stored in this unit is 320 Mm³/a and assuming a 5m drawdown the stored volume is estimated at 33 Mm³/a (**Table 8**).

Overall the unit has been classified as having a “C” present status category and the water resource category is classified as “Good”. However, the area around Vredendal and Klaver (E33G) has been classified as being stressed, while the area around Nuwerus (E33E) has been classified as having moderate levels of stress.

In the estuary region (E33H) the groundwater inputs are particularly important to the intertidal and supratidal vegetation with relatively deeper root systems (average 1.5 to 2 m e.g. reeds and salt marshes). For these vegetation types, soil salinities are also important, where very high salinities can inhibit plant growth and the establishment of new seedlings (tolerance levels differ depending on the vegetation type). Groundwater plays an important role in preventing soil salinities from reaching unacceptably high values, particularly during periods of low surface runoff.

8 RESOURCE QUALITY OBJECTIVES

The following generic, conservative resource quality objectives may be set:

- the regional groundwater level in a quaternary catchment may not decline over the long-term;
- groundwater quality may not deteriorate and must remain in an ambient state; and
- groundwater abstraction may not negatively impact river or spring flow, riparian or terrestrial vegetation nor land stability.

As part of all future licensing applications, groundwater dependent ecosystems that may be impacted by groundwater abstraction must be identified in accordance with Colvin *et al.* (2005), and **protection zones** considered in the case of “entirely dependent” or “highly dependent” systems. In these instances, set back distances and limitations on drawdown and pumping regimes may be appropriate. Parsons (2000) suggested, because of the critical role groundwater plays in supporting pools and refugia during low flow periods, any groundwater abstraction within 500 m of surface water drainage courses and in excess of limits specified by the General Authorisations should be subject to issuing of a license by DWAF.

It is often not the volume of contribution of groundwater to the baseflow of rivers that is important, but rather the timing. During late summer, groundwater sustains pools in the river that are critical for surrounding ecosystems. In instance where groundwater sustains pools in the river channel, depth to groundwater is an important RQO. For example in the Olifants Estuary, the groundwater inputs are particularly important to the intertidal and supratidal vegetation with relatively deeper root systems (average 1.5 to 2 m e.g. reeds and salt marshes). For those vegetation types soil salinities are also important, where very high salinities can inhibit plant growth and the establishment of new seedlings (tolerance levels differ depending on the vegetation type). Groundwater plays an important role in preventing soil salinities from reaching unacceptably high values, particularly during periods of low surface runoff. These areas need to be delineated spatially and limitations on drawdown and pumping regimes need to be put in place.

While some general aquifer management procedures can be specified, detailed RQOs need to be set on a site specific basis and may have to be set per license application. A philosophy of good management of groundwater resources is aimed at ensuring the long-term sustainability of the groundwater resources. Little routine groundwater monitoring has been undertaken in the catchment. Effective monitoring is required to assess when sustainable limits are being approached or exceeded, with the following being useful indicators:

- volumes of groundwater being abstracted – to be compared against recharge or safe yield of the resource.
- groundwater levels – with continually declining groundwater levels indicating sustainable levels are being exceeded.
- groundwater quality – with declining groundwater quality suggesting sustainable limits are being exceeded.
- climatic variables such as rainfall, temperature, EVT and snowfall.
- hydrologic variables such as spring flow (altitude, volume, water quality, seasonal and/or climatic event-related variation) and baseflow in rivers.

Because of the ever-growing use of groundwater in the Olifants/Doorn WMA, the responsible authority needs to establish a groundwater monitoring system in the catchment. Specific requirements need to be implemented as part of the management of groundwater resources in the Olifants/Doorn Primary Catchment. All groundwater users in excess of 1 ℓ/s are required to monitor groundwater abstraction and groundwater levels on a weekly basis and chemistry on a quarterly basis. Users of groundwater in excess of 5 ℓ/s need to install data loggers and monitor groundwater levels on a 2 hr basis.

9 CONCLUSIONS AND RECOMMENDATIONS

These can be summarised as follows:

- Little routine groundwater monitoring has been undertaken in the catchment. Some monitoring has been undertaken in the past 18 months as part of the CAGE project, but the adequacy thereof for Reserve monitoring needs to be assessed.
- Monitoring systems should be put in place so that the relationship between the presence of snow and low flows experienced during the summer months can be studied. Also, effective monitoring is required to assess when sustainable limits are being approached or exceeded.

- Registration of farmers' boreholes requires attention. It is possible that in the Reserve determination process access to data will be lost or reduced in some areas owing to inefficient licensing processes.
- There is a need to evaluate the potential for utilisation of poor quality groundwater and to blend it with surface water or treat it using reverse osmosis.
- Several towns, including Loeriesfontein, Bitterfontein, Nuwerus, Nieuwoudtville and Calvinia are reliant on groundwater and all are stressed urban supply areas.
- It must be noted that the stress index is determined for the catchment as a whole. ***It is possible that locally the stress index may be higher.***
- It is often not the volume of contribution of groundwater to the baseflow of rivers that is important, but rather the timing. During late summer, groundwater sustains pools in the river that are critical for surrounding ecosystems. In instance where groundwater sustains pools in the river channel, depth to groundwater is an important RQO. A protection zone would need to be put in place by management in conjunction with the specialists.
- Eight homogeneous resource units were identified. The total recharge for the study area is estimated at 131.73 Mm³/a and the total contribution of groundwater to baseflow is estimated at 34.11 Mm³/a. The BHN's of the study area was calculated at 0.32 Mm³/a based on a population 35,133 and assuming the entire population is dependent on groundwater as a source. The average Reserve as a percentage of recharge was estimated at 7.42%. Groundwater use in the study area totals 53.66 Mm³/a.
- The total volume of groundwater stored in the study area is estimated at 3,165 Mm³/a of which 2,809 Mm³/a is stored in the weathered zone and the balance is stored in the fractured zone. Assuming a 5m drawdown a total of 271 Mm³/a is stored in the aquifers of the study area.

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Appendices

Appendix I: SRK Hydrocensus 2005

Farm	Bh No	Date	Lat	Long	Depth (m.bgl)	Equipment	Pump intake (m.bgl)	Use	Bh Yield (l/s)	Abstraction (m ³ /a)	Water Level (mbc)	EC (mS/m)	pH	Comments
Calvinia-Ceres Rd R355	CCR01	31-Oct-05	-31.50947	19.73787	100	None	-999	None	0.0	0	-999.00	-999	-999.00	Dolerite & shale intersected - expl. Bh. for roadbuilding
Calvinia-Ceres Rd R355	CCR02	31-Oct-05	-31.60204	19.73954	100	None	-999	Road building	15.0	0	3.04	-999	-999.00	Coarse white dolerite, sandstone and shale intersected
Calvinia-Ceres Rd R355	CCR03	31-Oct-05	-31.63550	19.74950	100	None	-999	Road building	20.0	0	15.03	-999	-999.00	Sandstone with minor shale and dolerite intersected
Calvinia-Ceres Rd R355	CCR04	31-Oct-05	-31.68381	19.75664	100	None	-999	None	0.0	0	-999.00	-999	-999.00	Dolerite, shale and sandstone intersected
Calvinia-Ceres Rd R355	CCR05	31-Oct-05	-31.70025	19.73577	100	None	-999	Road building	25.0	0	12.09	200	6.60	Iron in water
Calvinia-Ceres Rd R355	CCR06	31-Oct-05	-31.87436	19.74714	100	Windpump	-999	Road building	2.5	0	15.85	-999	-999.00	Out of order
Calvinia-Ceres Rd R355	CCR07	31-Oct-05	-31.94890	19.74647	100	None	-999	Road building	13.0	0	21.10	-999	-999.00	
Calvinia-Ceres Rd R355	CCR08	1-Nov-05	-32.00464	19.70842	100	None	-999	Road building	3.0	0	9.42	-999	-999.00	Clay and gravel intersected up to 27m.bgl.
Calvinia-Ceres Rd R355	CCR09	1-Nov-05	-32.11791	19.71396	100	None	-999	Road building	3.0	0	4.56	-999	-999.00	
Calvinia-Ceres Rd R355	CCR10	1-Nov-05	-32.04845	19.70453	100	None	-999	None	0.0	0	-999.00	-999	-999.00	Selected by driller
Calvinia-Ceres Rd R355	CCR11	1-Nov-05	-32.04790	19.70447	100	None	-999	None	0.4	0	-999.00	-999	-999.00	0-7 All; 7-9 Wt sandstone: 9-100 Dwyka (sandstone 30-32m)

Farm	Bh No	Date	Lat	Long	Depth (m.bgl)	Equipment	Pump intake (m.bgl)	Use	Bh Yield (l/s)	Abstraction (m ³ /a)	Water Level (mbc)	EC (mS/m)	pH	Comments
Calvinia-Ceres Rd R355	CCR12	1-Nov-05	-31.55763	19.72949	100	None	-999	None	0.0	0	-999.00	-999	-999.00	
Calvinia-Ceres Rd R355	CCR13	2-Nov-05	-32.18969	19.71395	100	None	-999	Road building	1.5	0	19.51	-999	-999.00	
Calvinia-Ceres Rd R355	CCR14	2-Nov-05	-32.18855	19.71399	100	None	-999	None	0.4	0	-999.00	-999	-999.00	Bh backfilled
Sonop	SON01	31-Oct-05	-31.94862	19.74745	60	Mono pump	-999	Agricultural & Domestic	2.5	842	-999.00	-999	-999.00	
Sonop	SON02	31-Oct-05	-31.94891	19.74700	60	WP 100mm Cyl	-999	Agricultural & Domestic	1.0	3,784	-999.00	340	7.20	
Sonop	SON03	31-Oct-05	-31.95071	19.74505	60	50mm Mono	-999	Irrigation	3.0	0	15.45	-999	-999.00	Out of order
Sonop	SON04	31-Oct-05	-31.94977	19.74741	60	100mm Mono	-999	Irrigation	16.5	25,740	-999.00	320	7.10	
Rooiputs	ROO01	31-Oct-05	-31.98152	19.73849		WP 65mm Cyl	-999	Stock-watering	0.1	315	-999.00	210	7.05	Blocked at 6.1m
Rooiputs	ROO02	31-Oct-05	-31.97506	19.74931		WP 100mm Cyl	-999	Stock-watering	1.0	3,784	-999.00	693	7.17	Blocked by roots at 6m. 100m cylinder
Rooiputs	ROO03	31-Oct-05	-31.97384	19.76034		WP 100mm Cyl	-999	Stock-watering	1.0	1,892	-999.00	325	7.76	100m cylinder
Rooiputs	ROO04	31-Oct-05	-31.95758	19.76777		WP 75mm Cyl	-999	Stock-watering	0.5	1,892	12.28	443	7.67	
Rooiputs	ROO05	31-Oct-05	-31.97122	19.74187		WP 75mm Cyl	-999	Stock-watering	0.5	1,892	11.85	269	7.91	
Rooiputs	ROO06	31-Oct-05	-31.97076	19.74032		WP 125mm Cyl	-999	Stock-watering	2.0	0	-999.00	-999	-999.00	Out of order
Rooiputs	ROO07	31-Oct-05	-31.97037	19.73987		WP 100mm Cyl	-999	Stock-watering	1.5	3,784	16.78	365	7.76	
Rooiputs	ROO08	31-Oct-05	-31.97081	19.73903		WP 75mm Cyl	-999	Stock-watering	0.5	1,892	-999.00	-999	-999.00	Blocked at 14m. Windpump out of order.
Rooiputs	ROO09	31-Oct-05	-31.97221	19.73939	60	Mono pump	42	Irrigation & Domestic	8.0	0	-999.00	-999	-999.00	

Farm	Bh No	Date	Lat	Long	Depth (m.bgl)	Equipment	Pump intake (m.bgl)	Use	Bh Yield (l/s)	Abstraction (m ³ /a)	Water Level (mbc)	EC (mS/m)	pH	Comments
Rooiputs	ROO10	31-Oct-05	-31.97230	19.73937	75	Mono pump	51	Irrigation & Domestic	12.0	0	-999.00	-999	-999.00	
Rooiputs	ROO11	31-Oct-05	-31.97235	19.73932		Mono pump	-999	Irrigation & Domestic	7.0	0	-999.00	-999	-999.00	
Rooiputs	ROO12	31-Oct-05	-31.97261	19.73893		Mono pump	54	Irrigation	13.0	56,160	-999.00	314	8.20	Sulphuric smell. Operates 60hrs/week. Pumps @ 10l/s
Rooiputs	ROO13	31-Oct-05	-31.97273	19.73886	75	None	-999	None	4.0	0	-999.00	-999	-999.00	
Rooiputs	ROO14	31-Oct-05	-31.97278	19.73896	75	None	-999	None	5.0	0	18.12	-999	-999.00	
Van Wyksvley	VAN01	1-Nov-05	-32.11788	19.71416	33	WP 75mm Cyl	30	Irrigation & Domestic	0.4	1,892	4.17	432	8.30	
Van Wyksvley	VAN02	1-Nov-05	-32.11252	19.71417		WP 100mm Cyl	21	Stock-watering	1.2	3,784	-999.00	950	7.45	
Poortjie	POO01	1-Nov-05	-32.03862	19.60268		WP	-999	None	0.7		19.22	-999	-999.00	Out of order
Poortjie	POO02	1-Nov-05	-32.03926	19.60028		100mm Mono		Irrigation & Domestic	15.0	37,500	-999.00	220	7.70	
Poortjie	POO03	1-Nov-05	-32.04249	19.59650		100mm Mono	-999	Irrigation	15.0	37,500	-999.00	-999	-999.00	
Poortjie	POO04	1-Nov-05	-32.04252	19.59654		None	-999	None	15.0	0	-999.00	-999	-999.00	Bh collapsed at 22m.bgl.
Poortjie	POO05	1-Nov-05	-32.03604	19.60043		None	-999	None	1.0	0	18.17	-999	-999.00	WP tower
Poortjie	POO06	1-Nov-05	-32.03761	19.59714		None	-999	None	20.0	0	-999.00	-999	-999.00	Hole collapsed - mono pump removed
Poortjie	POO07	1-Nov-05	-32.01998	19.62536		WP 65mm Cyl	-999	Stock-watering	0.3	946	-999.00	330	7.55	
Swellendam	SWE01	1-Nov-05	-31.97959	19.72769	66	50mm Mono	25	Domestic	2.5	390	-999.00	350	7.17	
Swellendam	SWE02	1-Nov-05	-31.98022	19.72670	66	WP	-999	None	0.7	0	17.15	-999	-999.00	WP tower
Swellendam	SWE03	1-Nov-05	-31.98009	19.72645	60	None	-999	None	5.0	0	17.71	-999	-999.00	
Sitkop	SIT01	1-Nov-05	-31.98857	19.71511	48	PP 100mm cyl	36	Stock-watering	2.5	1,825	18.50	-999	-999.00	
Sitkop	SIT02	1-Nov-05	-31.98866	19.71524	42	WP	24	Stock-watering	2.0	0	-999.00	-999	-999.00	Out of order

Farm	Bh No	Date	Lat	Long	Depth (m.bgl)	Equipment	Pump intake (m.bgl)	Use	Bh Yield (l/s)	Abstraction (m ³ /a)	Water Level (mbc)	EC (mS/m)	pH	Comments
Kalkbult	KAL01	1-Nov-05	-32.00564	19.70764	27	75mm Mono	21	Irrigation	15.0	75,000	8.92	-999	-999.00	0-15=Clay; 15-27=Gravel
Kalkbult	KAL02	1-Nov-05	-32.00561	19.70770	27	None	-999	None	3.0	0	9.57	-999	-999.00	0-15=Clay; 15-27=Gravel
Kalkbult	KAL03	1-Nov-05	-32.00448	19.70813	52	None	-999	None	3.0	0	9.48	-999	-999.00	0-15=Clay; 15-27=Gravel; 27-52=Shale
Kalkbult	KAL04	1-Nov-05	-32.00396	19.70725	27	None	-999	None	3.0	0	10.03	-999	-999.00	0-15=Clay; 15-27=Gravel
Kalkbult	KAL05	1-Nov-05	-32.00357	19.70756	27	None	-999	None	2.5	0	10.47	-999	-999.00	0-15=Clay; 15-25=Gravel; 25-27=Siltstone
Kalkbult	KAL07	1-Nov-05	-32.00593	19.70741	27	50mm Mono	24	None	3.0	0	9.10	-999	-999.00	0-15=Clay; 15-27=Gravel
Kalkbult	KAL08	1-Nov-05	-32.00759	19.71231		100mm Mono	24	Irrigation	30.0	25,000	-999.00	340	7.27	
Kalkbult	KAL09	1-Nov-05	-32.00039	19.72202		None	-999	None	3.0	0	12.31	-999	-999.00	
Kalkbult	KAL10	1-Nov-05	-31.99888	19.71911	27	None	-999	None	2.0	0	11.90	-999	-999.00	0-15=Clay; 15-25=Gravel; 25-27=Siltstone
TKNP	TAN01	2-Nov-05	-32.19379	20.03222	37	40mm Submersible	30	Domestic & Stock-watering	2.2	3,744	8.05	-999	-999.00	
TKNP	TAN02	2-Nov-05	-32.19280	20.03070	37	50mm Mono	23	Domestic & Stock-watering	20.0	3,750	-999.00	-999	-999.00	
TKNP	TAN03	2-Nov-05	-32.19502	20.03628		None	-999	None	2.0	0	14.15	-999	-999.00	Near dolerite dyke
TKNP	TAN04	2-Nov-05	-32.19455	20.03367		WP 100mm Cyl	21	None	1.5	0	-999.00	-999	-999.00	Out of order
TKNP	TAN05	2-Nov-05	-32.19452	20.03357	12	None	-999	None	2.0	0	7.84	-999	-999.00	WP tower Dug well
TKNP	TAN06	2-Nov-05	-32.15919	20.03752		WP 50mm Cyl	-999	Stock-watering	0.1	788	-999.00	238	7.55	
TKNP	TAN07	2-Nov-05	-32.13315	19.99158	7	WP 75mm Cyl	6.1	Stock-watering	0.8	1,892	5.11	355	7.47	Dug well
TKNP	TAN08	2-Nov-05	-32.15848	19.96786		WP 50mm Cyl	48	Stock-watering	0.5	788	32.32	-999	-999.00	Out of order
TKNP	TAN09	2-Nov-05	-32.17585	19.98863	5	None	-999	None	0.2	0	2.20	-999	-999.00	Dug well
TKNP	TAN10	2-Nov-05	-32.19639	20.00236	7	WP 50mm Cyl	6.2	Stock-watering	0.1	788	6.19	180	8.05	Dug well
TKNP	TAN11	2-Nov-05	-32.23175	-20.02421		WP 100mm Cyl	21	Stock-watering	2.5	3,784	16.79	232	7.75	T = 22.6 C
TKNP	TAN12	2-Nov-05	-32.24221	-20.00083		None	-999	None	1.2	0	12.13	-999	-999.00	
TKNP	TAN13	2-Nov-05	-32.22465	19.93621		None	-999	None	0.5	0	-999.00	-999	-999.00	Blocked at 5m.bgl.

Farm	Bh No	Date	Lat	Long	Depth (m.bgl)	Equipment	Pump intake (m.bgl)	Use	Bh Yield (l/s)	Abstraction (m ³ /a)	Water Level (mbc)	EC (mS/m)	pH	Comments
TKNP	TAN14	2-Nov-05	-32.23780	19.37913	2	None	-999	Stock-watering	0.1	3,154	0.00	341	8.53	Spring
TKNP	TAN15	2-Nov-05	-32.25406	19.84043	2	None	-999	Stock-watering	0.1	3,154	0.00	-999	-999.00	Spring overgrown
TKNP	TAN16	2-Nov-05	-32.25428	19.83981		None	-999	None	0.5	0	-999.00	-999	-999.00	Bh blocked at 7.0m.bgl.
TKNP	TAN17	2-Nov-05	-32.23097	19.80784		WP 75mm Cyl	-999	None	0.4	0	-999.00	-999	-999.00	Out of order
TKNP	TAN18	2-Nov-05	-32.18902	19.79514		None	-999	None	2.0	0	1.69	-999	-999.00	Open borehole
TKNP	TAN19	2-Nov-05	-32.13910	19.79494		WP 100mm Cyl	18	Stock-watering	2.5	3,784	-999.00	78	7.92	T = 25.2 C
TKNP	TAN20	2-Nov-05	-32.19612	19.77582		None	-999	Stock-watering	0.1	3,154	0.00	138	9.05	Spring
TKNP	TAN21	2-Nov-05	-32.21004	19.73662		None	-999	None	0.3	0	-999.00	-999	-999.00	WP tower; Bh blocked at 10.0m.bgl.
TKNP	TAN22	2-Nov-05	-32.21876	19.70460		None	-999	None	0.4	0	2.52	-999	-999.00	WP tower
									TOTAL	314,597				

Note: -999.00 implies no measurements possible WP = Windpump PP = Piston type pump

Annual abstraction based on average yields of windpumps - otherwise on pump yield and average pumping hours per day

Appendix II: Waterlevel, Thickness and Volume of water stored in aquifer

Quaternary Catchment	Area	Average Waterlevel	Average Waterlevel Change [median]	Depth		Thickness			Volume of Water stored in Aquifer			5m Drawdown Storage Volume		
	km ²	m.bgl	m	m.bgl		m			Mm ³ /a			Mm ³ /a		
				Weathered Zone	Fractured Zone	Weathered Zone	Fractured Zone	Aquifer	Weathered Zone	Fractured Zone	Aquifer	Weathered Zone	Fractured Zone	Aquifer
											Sv			
E21A	190	12.19	0	87.5	257.5	70.54	186.96	257.5	29.67	4.55	34.21	2.10	0.00	2.10
E21B	223	15.68	2	87.5	257.5	66.48	191.02	257.5	31.60	5.25	36.85	2.38	0.00	2.38
E21C	233	13.98	2	87.5	257.5	66.85	190.65	257.5	34.41	5.67	40.08	2.57	0.00	2.57
E21D	242	9.69	0	87.5	257.5	70.99	186.51	257.5	37.79	5.74	43.53	2.66	0.00	2.66
E21E	293	11.38	2	87.5	257.5	69.65	187.85	257.5	44.39	6.92	51.32	3.19	0.00	3.19
E21F	379	16.49	2	87.5	257.5	64.88	192.62	257.5	53.72	9.22	62.94	4.14	0.00	4.14
E21G	266	10.23	0	87.5	257.5	71.66	185.84	257.5	42.07	6.31	48.38	2.94	0.00	2.94
E21H	404	15.07	2	87.5	257.5	62.64	194.86	257.5	55.29	9.95	65.24	4.41	0.00	4.41
E21J	317	18.66	2	87.5	257.5	58.3	199.2	257.5	40.74	8.05	48.78	3.49	0.00	3.49
E21K	330	16.95	0	87.5	257.5	62.71	194.79	257.5	45.19	8.12	53.31	3.60	0.00	3.60
E21L	195	23.53	0	87.5	257.5	58.12	199.38	257.5	24.70	4.90	29.60	2.12	0.00	2.12
E22A	750	11.43	2	73.05	239.23	58.9	180.32	239.23	47.83	4.11	51.94	4.05	0.00	4.05
E22B	638	15.22	2	74.04	239.7	56.5	183.84	240.21	40.32	4.08	46.60	3.74	0.00	3.74
E22C	490	18.01	2	85.71	255.11	62.5	192.61	255.11	63.86	10.83	74.69	5.05	0.00	5.05
E22D	496	22.48	2	78.59	245.61	54.02	191.6	245.61	40.56	5.82	46.38	3.62	0.00	3.62
E22E	1,013	16.26	2	77.61	244.32	58.89	185.43	244.32	87.12	10.26	97.38	7.13	0.00	7.13
E22F	400	21.16	2	80.94	248.75	57.49	191.26	248.75	39.54	6.04	45.57	3.32	0.00	3.32
E22G	367	22.55	2	82.83	251.27	57.63	193.64	251.27	39.58	6.64	46.22	3.34	0.00	3.34
E23A	762	8.92	0	72.47	237.41	60.1	177.31	237.41	44.91	1.99	46.90	3.74	0.00	3.74
E23B	705	10.18	2	72.39	237.2	58.52	178.68	237.2	40.20	1.87	42.42	3.47	0.00	3.47
E23C	318	10.32	2	72.5	237.5	58.36	179.15	237.5	18.11	0.84	18.95	1.55	0.00	1.55
E23D	750	12.02	2	72.43	237.31	57.35	179.96	237.32	42.36	2.04	45.19	3.76	0.00	3.76
E23E	564	15.48	2	72.5	237.5	52.77	184.76	237.5	29.24	1.56	31.26	2.81	0.00	2.81
E23F	473	14.68	0	72.5	237.5	56.92	180.53	237.5	26.41	1.29	28.40	2.38	0.00	2.38
E23G	747	12.9	2	72.5	237.5	57.7	179.8	237.5	41.91	1.96	43.88	3.63	0.00	3.63
E23H	660	10.84	2	72.5	237.5	58.67	178.83	237.5	38.37	1.76	40.13	3.27	0.00	3.27
E23J	895	14.91	2	72.5	237.5	56.53	181.03	237.5	49.48	2.43	52.91	4.47	0.00	4.47
E23K	572	17.79	0	72.5	237.5	53.95	183.59	237.5	30.05	1.55	31.85	2.81	0.00	2.81
E24A	255	14.61	0	87.5	257.5	63.75	193.75	257.5	35.33	6.21	41.53	2.77	0.00	2.77

Quaternary Catchment	Area	Average Waterlevel	Average Waterlevel Change [median]	Depth		Thickness			Volume of Water stored in Aquifer			5m Drawdown Storage Volume		
	km ²	m.bgl	m	m.bgl		m			Mm ³ /a			Mm ³ /a		
				Weathered Zone	Fractured Zone	Weathered Zone	Fractured Zone	Aquifer	Weathered Zone	Fractured Zone	Aquifer	Weathered Zone	Fractured Zone	Aquifer
											Sv			
E24B	468	18.3	2	87.47	257.46	63.37	194.13	257.46	65.04	11.61	77.15	5.17	0.00	5.17
E24C	784	16.76	2	72.49	237.38	52.45	184.91	237.38	40.20	2.20	43.64	3.95	0.00	3.95
E24D	997	16.56	0	73.22	238.34	54.6	183.74	238.34	58.20	3.86	62.06	5.26	0.00	5.26
E24E	671	17.74	2	75.48	241.1	55.35	185.75	241.1	46.85	4.75	51.59	4.10	0.00	4.10
E24F	582	14.97	2	72.81	237.91	54.94	183.15	238.28	32.16	2.09	35.88	3.04	0.00	3.04
E24G	633	22.61	2	84.36	253.31	60.15	193.16	253.31	75.19	12.63	87.82	6.10	0.00	6.10
E24H	483	19.69	2	84.95	254.1	61.69	192.4	254.1	59.96	10.04	70.00	4.78	0.00	4.78
E24J	1,078	18.98	2	87.5	257.5	63.55	193.95	257.5	150.06	26.48	176.54	11.81	0.00	11.81
E24K	652	30.5	10	82.67	248.72	50	198.73	248.72	60.25	12.75	73.01	6.06	0.00	6.06
E24L	516	19.89	2	87.5	257.5	63.83	193.55	257.5	72.28	13.34	89.54	5.96	0.00	5.96
E24M	529	24.5	2	87.84	253.89	60.2	193.64	253.93	67.13	12.77	80.79	5.65	0.00	5.65
E31A	2,865	32.68	10	75.67	182.21	42.69	139.51	182.21	110.07	5.90	115.97	12.49	0.00	12.49
E31B	1,476	16.85	2	62.51	142.54	45.07	97.47	142.54	56.30	1.77	58.07	6.25	0.00	6.25
E31C	1,572	22.88	2	62.09	144.41	38.7	105.71	144.41	51.29	2.32	53.61	6.69	0.00	6.69
E31D	839	30.49	10	54.2	181.24	23.42	157.83	181.24	21.80	5.08	26.89	5.20	0.00	5.20
E31E	478	21.94	2	54.81	178.38	31.97	146.42	178.38	16.54	2.57	19.12	2.84	0.00	2.84
E31F	525	18.76	0	62.39	143.03	42.49	100.52	143.02	18.65	0.69	19.87	2.26	0.00	2.26
E31G	1,238	30.84	0	56.68	189.04	25.58	163.46	189.04	35.84	7.71	43.55	7.74	0.00	7.74
E31H	726	29.72	2	57.3	195.38	26.59	165.68	193.89	19.27	5.31	25.64	4.71	0.00	4.71
E32A	1,118	10.26	0	62.5	142.5	49.62	92.88	142.5	47.03	1.28	48.32	4.74	0.00	4.74
E32B	828	13.27	0	62.5	142.5	47.18	95.32	142.5	34.31	1.01	35.32	3.64	0.00	3.64
E32C	638	11.77	2	62.5	142.5	48.86	93.63	142.5	25.59	0.75	27.44	2.73	0.00	2.73
E32D	616	15.51	2	65.04	143.23	48.09	95.14	143.23	23.77	0.68	24.45	2.51	0.00	2.51
E32E	1,001	18.07	0	80.85	147.74	60.03	87.71	147.74	39.26	0.63	39.90	3.46	0.00	3.46
E33A	1,355	38.41	0	64.57	191.98	25.77	166.21	191.98	27.83	9.09	36.92	6.15	0.03	6.21
E33B	702	38.39	10	97.15	152.4	58	94.4	152.4	22.49	0.10	22.59	1.94	0.00	1.94
E33C	980	27.52	2	97.15	152.4	67.7	84.7	152.4	37.50	0.13	37.63	2.78	0.00	2.78
E33D	1,559	37.51	10	90.25	161.2	51.57	109.63	161.2	48.97	2.36	51.33	5.33	0.00	5.34
E33E	1,282	38.65	2	87.93	163.99	48.22	115.77	163.99	38.47	2.65	41.12	4.91	0.00	4.91

Quaternary Catchment	Area	Average Waterlevel	Average Waterlevel Change [median]	Depth		Thickness			Volume of Water stored in Aquifer			5m Drawdown Storage Volume		
	km ²	m.bgl	m	m.bgl		m			Mm ³ /a			Mm ³ /a		
				Weathered Zone	Fractured Zone	Weathered Zone	Fractured Zone	Aquifer	Weathered Zone	Fractured Zone	Aquifer	Weathered Zone	Fractured Zone	Aquifer
											Sv			
E33F	725	26.35	2	92.9	162.11	64.05	100.53	164.21	32.80	2.47	37.37	2.89	0.00	2.89
E33G	894	39.8	0	94.95	179.27	53.26	126.01	179.27	43.66	6.43	50.09	4.45	0.00	4.45
E33H	718	38.42	10	79.72	198.25	40.59	159.58	200.33	32.83	7.93	43.33	4.87	0.00	4.87
E40A	941	11.66	2	62.54	144.54	48.86	95.68	144.54	39.85	1.18	41.03	4.08	0.00	4.08
E40B	707	9.86	0	62.53	142.77	50.6	94.85	145.62	29.75	0.85	31.82	3.05	0.00	3.05
E40C	530	15.97	2	63.82	142.88	46.45	99.56	145.58	20.05	0.70	22.96	2.43	0.00	2.43
E40D	544	31.36	10	62.76	142.57	29.3	115.39	145.26	13.16	1.08	15.76	2.39	0.00	2.39
TOTAL	46,176								2,809.10	329.15	3,164.51	270.91	0.03	270.98

Appendix III: Groundwater Use

Quaternary Catchment	Rural	Municipal	Irrigation	Agricultural /Livestock	Mining	Industry	Aqua-culture	Total (Mm ³ /a)
E21A	0.0130	0.0000	5.3397	0.0066	0.0000	0.0000	0.0000	5.3593
E21B	0.0010	0.0000	1.3389	0.0078	0.0000	0.0000	0.0000	1.3477
E21C	0.0000	0.0000	1.2480	0.0081	0.0000	0.0000	0.0000	1.2561
E21D	0.0070	0.0000	7.3710	0.0085	0.0000	0.0000	0.0000	7.3865
E21E	0.0000	0.0000	2.6799	0.0102	0.0000	0.0000	0.0000	2.6901
E21F	0.0000	0.0000	0.5304	0.0132	0.0000	0.0000	0.0000	0.5436
E21G	0.0110	0.0000	12.0681	0.0092	0.0000	0.0000	0.0000	12.0883
E21H	0.0000	0.0000	2.5496	0.0116	0.0000	0.0000	0.0000	2.5612
E21J	0.0000	0.0000	0.0000	0.0062	0.0000	0.0000	0.0000	0.0062
E21K	0.0000	0.0000	0.3953	0.0050	0.0000	0.0000	0.0000	0.4003
E21L	0.0000	0.0000	0.0000	0.0036	0.0000	0.0000	0.0000	0.0036
E22A	0.0020	0.0000	0.0217	0.0062	0.0000	0.0000	0.0000	0.0299
E22B	0.0000	0.0000	0.0000	0.0220	0.0000	0.0000	0.0000	0.0220
E22C	0.0170	0.0000	0.1752	0.0171	0.0000	0.0000	0.0000	0.2093
E22D	0.0000	0.0000	0.0000	0.0173	0.0000	0.0000	0.0000	0.0173
E22E	0.0000	0.0000	0.0846	0.0354	0.0000	0.0000	0.0000	0.1200
E22F	0.0000	0.0000	0.0000	0.0121	0.0000	0.0000	0.0000	0.0121
E22G	0.0000	0.0000	0.0000	0.0036	0.0000	0.0000	0.0000	0.0036
E23A	0.0000	0.0000	0.0585	0.0001	0.0000	0.0000	0.0000	0.0586
E23B	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
E23C	0.0000	0.0000	0.0000	0.0003	0.0000	0.0000	0.0000	0.0003
E23D	0.0000	0.0000	0.0426	0.0089	0.0000	0.0000	0.0000	0.0515
E23E	0.0000	0.0000	0.3329	0.0056	0.0000	0.0000	0.0000	0.3385
E23F	0.0000	0.0000	1.0619	0.0089	0.0000	0.0000	0.0000	1.0708
E23G	0.0010	0.0000	0.0000	0.0261	0.0000	0.0000	0.0000	0.0271
E23H	0.0000	0.0000	0.0000	0.0227	0.0000	0.0000	0.0000	0.0227
E23J	0.0000	0.0000	0.0000	0.0311	0.0000	0.0000	0.0000	0.0311
E23K	0.0000	0.0000	0.0000	0.0025	0.0000	0.0000	0.0000	0.0025
E24A	0.0070	0.0000	0.0350	0.0039	0.0000	0.0000	0.0000	0.0459
E24B	0.0020	0.0000	0.0516	0.0075	0.0000	0.0000	0.0000	0.0611
E24C	0.0000	0.0000	0.2430	0.0000	0.0000	0.0000	0.0000	0.2430
E24D	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
E24E	0.0000	0.0000	0.0390	0.0000	0.0000	0.0000	0.0000	0.0390
E24F	0.0000	0.0000	0.0040	0.0000	0.0000	0.0000	0.0000	0.0040
E24G	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
E24H	0.0020	0.0000	0.0000	0.0062	0.0000	0.0000	0.0000	0.0082
E24J	0.0000	0.0000	1.4461	0.0095	0.0000	0.0000	0.0000	1.4556
E24K	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
E24L	0.0000	0.4127	2.0090	0.0078	0.0000	0.0000	0.0000	2.4295
E24M	0.0000	0.0000	0.0000	0.0040	0.0000	0.0000	0.0000	0.0040
E31A	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
E31B	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
E31C	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
E31D	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
E31E	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
E31F	0.0000	0.0627	0.0000	0.0000	0.0000	0.0000	0.0000	0.0627
E31G	0.0000	0.0000	0.0000	0.0027	0.0000	0.0000	0.0000	0.0027
E31H	0.0000	0.0000	0.0000	0.0012	0.0000	0.0000	0.0000	0.0012
E32A	0.0000	0.0000	2.1590	0.0000	0.0000	0.0000	0.0000	2.1590
E32B	0.0000	0.0000	3.3770	0.0000	0.0000	0.0000	0.0000	3.3770
E32C	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
E32D	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
E32E	0.0000	0.0000	3.6360	0.0000	0.0000	0.0000	0.0000	3.6360
E33A	0.0030	0.0000	0.0000	0.0302	0.0000	0.0000	0.0000	0.0332
E33B	0.0000	0.0000	0.0000	0.0209	0.0000	0.0000	0.0000	0.0209
E33C	0.0010	0.0000	0.0000	0.0263	0.0000	0.0000	0.0000	0.0273
E33D	0.0000	0.0000	0.0000	0.0487	0.0000	0.0000	0.0000	0.0487

Quaternary Catchment	Rural	Municipal	Irrigation	Agricultural /Livestock	Mining	Industry	Aqua-culture	Total
E33E	0.0010	0.1281	0.0000	0.0398	0.0000	0.0000	0.0000	0.1689
E33F	0.0050	0.0000	0.0000	0.0132	0.0552	0.0000	0.0000	0.0734
E33G	0.0000	0.2684	0.0000	0.0209	0.9830	0.0300	0.0000	1.3023
E33H	0.0250	0.0000	0.0000	0.0188	0.0000	0.0000	0.0000	0.0438
E40A	0.0000	0.0000	1.7217	0.0000	0.0000	0.0000	0.0000	1.7217
E40B	0.0000	0.5849	0.3479	0.0000	0.0000	0.0000	0.0000	0.9328
E40C	0.0000	0.0940	0.0000	0.0000	0.0000	0.0000	0.0000	0.0940
E40D	0.0000	0.0000	0.0000	0.0015	0.0000	0.0000	0.0000	0.0015

Appendix IV: Electrical Conductivity (EC) (mS/m)

Quaternary Catchment	Minimum	Maximum	Range	Mean	Standard Deviation
E21A	0	533	536	58	56
E21B	0	1,129	1,129	74	73
E21C	0	203	206	31	36
E21D	0	113	115	17	16
E21E	5	128	123	24	18
E21F	12	138	126	71	30
E21G	0	183	185	20	16
E21H	0	48	54	7	8
E21J	4	270	266	56	38
E21K	0	67	67	12	11
E21L	33	233	199	137	35
E22A	82	392	310	166	58
E22B	83	425	342	235	50
E22C	3	1,361	1,358	235	289
E22D	199	2,181	1,982	691	366
E22E	16	1,165	1,149	288	188
E22F	87	306	219	210	45
E22G	32	320	287	191	66
E23A	131	188	57	151	10
E23B	144	194	49	165	11
E23C	172	238	66	203	14
E23D	50	266	216	156	46
E23E	40	268	228	121	43
E23F	128	482	355	285	61
E23G	181	413	232	278	55
E23H	177	327	150	270	41
E23J	225	470	244	329	44
E23K	144	840	696	362	110
E24A	-2	101	103	14	20
E24B	-1	313	314	60	47
E24C	47	693	646	134	98
E24D	58	950	892	251	131
E24E	76	996	920	349	129
E24F	62	372	310	211	85
E24G	131	832	702	333	109
E24H	15	374	359	199	69
E24J	5	1,288	1,283	214	173
E24K	80	1,045	965	377	204
E24L	1	1,241	1,240	155	200
E24M	16	1,287	1,272	133	96
E31A	28	1,267	1,239	517	298
E31B	106	566	460	261	116
E31C	144	722	578	433	160
E31D	154	855	701	491	116
E31E	146	696	550	305	122
E31F	140	859	719	308	84
E31G	28	1,120	1,092	569	206
E31H	136	1,076	940	438	195
E32A	41	185	144	85	31
E32B	70	708	638	206	92
E32C	63	1,035	972	415	243
E32D	86	810	724	297	110
E32E	23	1,440	1,417	311	229
E33A	147	1,253	1,106	550	240
E33B	53	2,070	2,017	1,014	424
E33C	21	1,569	1,548	554	342
E33D	210	1,541	1,332	580	179

Quaternary Catchment	Minimum	Maximum	Range	Mean	Standard Deviation
E33E	76	1,287	1,210	624	267
E33F	7	1,446	1,439	190	91
E33G	12	600	588	204	103
E33H	69	1,429	1,360	501	246
E40A	45	1,203	1,158	158	135
E40B	45	1,101	1,056	262	155
E40C	10	1,216	1,206	327	278
E40D	9	479	470	128	94

Appendix V: Baseflow, recharge, harvest potential

Quaternary Catchment	Harvest Potential	Mean Annual Contribution to River Baseflow	Mean Annual Potential Recharge	
	Mm ³ /a	Mm ³ /a	Mm ³ /a	
	HP	Bf	Wet Season	Dry Season
			Re	Re _(dry)
E21A	3.56	2.25	11.01	7.83
E21B	2.73	2.40	7.51	5.19
E21C	2.97	2.48	7.10	4.89
E21D	8.50	2.85	13.97	10.04
E21E	5.14	2.85	6.13	4.03
E21F	5.71	3.06	5.25	3.39
E21G	10.31	2.98	9.83	6.76
E21H	17.80	4.99	11.92	8.07
E21J	8.81	3.23	5.54	3.63
E21K	9.97	3.43	6.75	4.46
E21L	2.25	0.00	0.54	0.34
E22A	5.44	0.00	3.62	2.31
E22B	4.02	0.00	2.91	1.85
E22C	5.94	0.00	4.53	2.96
E22D	2.76	0.00	1.33	0.84
E22E	7.95	0.00	3.30	2.07
E22F	3.61	0.00	0.60	0.37
E22G	2.80	0.00	0.19	0.12
E23A	6.17	0.00	6.19	3.95
E23B	4.78	0.00	4.42	2.81
E23C	1.33	0.00	1.84	1.16
E23D	3.85	0.00	3.70	2.34
E23E	4.51	0.00	4.76	3.06
E23F	1.65	0.00	0.46	0.28
E23G	3.53	0.00	2.18	1.36
E23H	2.76	0.00	3.22	2.02
E23J	2.83	0.00	1.04	0.64
E23K	1.78	0.00	0.02	0.01
E24A	8.03	0.42	5.11	3.44
E24B	4.52	0.26	2.86	1.84
E24C	5.85	0.00	3.43	2.18
E24D	4.62	0.00	2.15	1.34
E24E	5.69	0.00	1.39	0.87
E24F	4.53	0.00	1.93	1.21
E24G	3.63	0.00	0.13	0.08
E24H	1.51	0.00	0.40	0.25
E24J	13.75	0.00	7.47	4.75
E24K	10.93	0.00	0.70	0.44
E24L	15.77	2.91	7.77	5.02
E24M	15.88	0.00	2.73	1.75
E31A	2.63	0.00	0.03	0.02
E31B	4.52	0.00	0.63	0.39
E31C	4.64	0.00	0.01	0.00
E31D	0.67	0.00	0.00	0.00
E31E	1.09	0.00	0.00	0.00
E31F	1.80	0.00	0.00	0.00
E31G	0.89	0.00	0.00	0.00
E31H	1.21	0.00	0.00	0.00
E32A	8.38	0.00	4.91	3.08
E32B	6.02	0.00	1.15	0.72
E32C	4.98	0.00	2.01	1.27
E32D	3.72	0.00	0.34	0.21

Quaternary Catchment	Harvest Potential	Mean Annual Contribution to River Baseflow	Mean Annual Potential Recharge	
	Mm ³ /a	Mm ³ /a	Mm ³ /a	
	HP	Bf	Wet Season	Dry Season
			Re	Re _(dry)
E32E	13.17	0.00	1.72	1.07
E33A	0.98	0.00	0.06	0.04
E33B	1.08	0.00	0.09	0.06
E33C	6.56	0.00	1.81	1.11
E33D	2.45	0.00	0.25	0.15
E33E	1.70	0.00	0.67	0.41
E33F	9.04	0.00	3.79	2.38
E33G	7.85	0.00	2.54	1.58
E33H	1.51	0.00	0.75	0.46
E40A	7.39	0.00	4.65	2.95
E40B	5.61	0.00	3.52	2.24
E40C	8.74	0.00	2.93	1.89
E40D	13.45	0.00	2.62	1.69
TOTAL	358.25	34.11	200.44	131.72

Appendix VI: Exploitation Potential

Quaternary Catchment	Average Groundwater Resource Potential		Groundwater Exploitation Potential		Potable Groundwater Exploitation Potential		Utilisable Groundwater Resource Potential		Utilisable Groundwater Exploitation Potential		Utilisable Potable Groundwater Exploitation Potential	
	Mm ³ /a		Mm ³ /a		Mm ³ /a		Mm ³ /a		Mm ³ /a		Mm ³ /a	
	Wet Season	Dry Season	Wet Season	Dry Season	Wet Season	Dry Season	Wet Season	Dry Season	Wet Season	Dry Season	Wet Season	Dry Season
	AGRP	AGRP (dry)	GEP	GEP (dry)	PGEP	PGEP (dry)	UGRP	UGRP (dry)	UGEP	UGEP (dry)	UPGEP	UPGEP (dry)
E21A	10.72	7.56	6.43	4.53	6.43	4.53	7.82	4.66	4.69	2.79	4.69	2.80
E21B	7.45	5.17	4.32	3.00	4.32	3.00	5.75	3.40	3.34	1.98	3.32	1.96
E21C	7.07	4.88	3.93	2.71	1.57	1.08	5.07	2.85	2.82	1.59	1.19	0.67
E21D	11.97	8.13	7.14	4.85	7.14	4.85	10.33	6.46	6.16	3.85	6.11	3.83
E21E	4.88	2.80	2.53	1.46	1.01	0.58	3.36	1.23	1.76	0.65	0.76	0.29
E21F	5.47	3.65	2.43	1.62	0.97	0.65	2.51	0.61	1.15	0.30	0.48	0.12
E21G	8.44	5.29	5.06	3.17	3.54	2.22	6.72	3.50	4.03	2.10	2.88	1.50
E21H	7.54	3.73	4.52	2.24	3.84	1.90	6.48	2.69	3.89	1.62	3.29	1.37
E21J	3.17	1.21	1.79	0.69	1.43	0.55	2.19	0.22	1.25	0.13	1.00	0.10
E21K	3.69	1.47	2.09	0.84	1.78	0.71	2.72	0.47	1.55	0.27	1.32	0.23
E21L	2.68	2.46	0.96	0.88	0.38	0.35	0.97	0.71	0.35	0.26	0.15	0.10
E22A	7.36	6.05	3.67	3.02	2.36	1.94	4.49	3.17	2.25	1.60	1.44	1.02
E22B	5.59	4.53	2.59	2.11	0.86	0.70	3.61	2.56	1.67	1.19	0.55	0.39
E22C	9.78	8.12	5.29	4.40	5.29	4.40	6.38	4.68	3.44	2.53	3.42	2.52
E22D	2.87	2.37	1.36	1.13	0.00	0.00	1.94	1.44	0.90	0.68	0.02	0.01
E22E	8.67	7.38	3.81	3.25	1.90	1.62	5.10	3.79	2.24	1.67	1.12	0.83
E22F	3.72	3.48	1.42	1.33	0.57	0.53	1.36	1.12	0.52	0.42	0.21	0.17
E22G	2.30	2.23	0.77	0.75	0.31	0.30	0.61	0.53	0.21	0.18	0.08	0.07
E23A	9.69	7.49	5.53	4.27	3.87	2.99	6.31	4.09	3.60	2.34	2.50	1.63
E23B	6.79	5.20	3.67	2.81	1.84	1.41	4.85	3.26	2.63	1.77	1.31	0.88
E23C	2.57	1.88	1.19	0.87	0.48	0.35	2.04	1.36	0.94	0.63	0.38	0.25
E23D	5.83	4.46	2.49	1.91	1.00	0.76	4.08	2.71	1.75	1.17	0.70	0.47
E23E	7.45	5.78	3.19	2.48	1.59	1.24	5.28	3.62	2.26	1.56	1.13	0.78
E23F	1.44	1.24	0.55	0.47	0.22	0.19	0.50	0.31	0.19	0.12	0.08	0.05
E23G	4.15	3.34	1.86	1.49	0.74	0.60	2.76	1.96	1.23	0.87	0.49	0.35
E23H	4.66	3.48	2.09	1.56	0.84	0.63	3.46	2.29	1.55	1.03	0.62	0.41

Quaternary Catchment	Average Groundwater Resource Potential		Groundwater Exploitation Potential		Potable Groundwater Exploitation Potential		Utilisable Groundwater Resource Potential		Utilisable Groundwater Exploitation Potential		Utilisable Potable Groundwater Exploitation Potential	
	Mm ³ /a		Mm ³ /a		Mm ³ /a		Mm ³ /a		Mm ³ /a		Mm ³ /a	
	Wet Season	Dry Season	Wet Season	Dry Season	Wet Season	Dry Season	Wet Season	Dry Season	Wet Season	Dry Season	Wet Season	Dry Season
	AGRP	AGRP (dry)	GEP	GEP (dry)	PGEP	PGEP (dry)	UGRP	UGRP (dry)	UGEP	UGEP (dry)	UPGEP	UPGEP (dry)
E23J	2.79	2.35	1.19	1.00	0.47	0.40	1.73	1.29	0.73	0.55	0.29	0.22
E23K	0.91	0.89	0.34	0.33	0.14	0.13	0.20	0.19	0.08	0.07	0.03	0.03
E24A	5.12	3.45	3.05	2.05	2.59	1.75	4.68	2.99	2.79	1.79	2.36	1.51
E24B	7.52	6.49	3.08	2.66	1.23	1.06	4.36	3.30	1.82	1.37	0.75	0.56
E24C	7.15	5.92	2.64	2.19	1.06	0.87	4.64	3.40	1.71	1.25	0.68	0.50
E24D	4.36	3.54	1.66	1.35	0.66	0.54	2.29	1.49	0.87	0.57	0.35	0.23
E24E	4.91	4.39	1.80	1.61	1.00	0.90	2.72	2.21	1.00	0.81	0.55	0.45
E24F	4.81	4.08	1.64	1.39	0.66	0.56	2.80	2.08	0.95	0.71	0.38	0.28
E24G	2.74	2.66	1.15	1.12	0.23	0.22	1.39	1.32	0.57	0.54	0.12	0.11
E24H	1.72	1.57	0.79	0.72	0.32	0.29	0.95	0.79	0.44	0.36	0.17	0.14
E24J	10.26	7.51	5.06	3.71	1.38	1.01	8.55	5.78	4.21	2.85	1.15	0.78
E24K	1.85	1.56	0.62	0.53	0.35	0.29	2.31	2.02	0.75	0.65	0.42	0.37
E24L	5.59	2.86	2.47	1.27	0.99	0.51	4.57	1.82	2.00	0.80	0.82	0.33
E24M	3.67	2.63	1.31	0.94	0.87	0.63	3.18	2.18	1.14	0.78	0.76	0.52
E31A	0.72	0.71	0.21	0.21	0.08	0.08	1.03	1.02	0.30	0.30	0.12	0.12
E31B	2.33	2.08	0.92	0.82	0.37	0.33	1.30	1.05	0.51	0.41	0.20	0.16
E31C	1.89	1.88	0.60	0.60	0.12	0.12	0.77	0.76	0.25	0.24	0.05	0.05
E31D	0.23	0.23	0.06	0.06	0.00	0.00	0.24	0.24	0.07	0.07	0.00	0.00
E31E	0.26	0.26	0.08	0.08	0.00	0.00	0.08	0.08	0.02	0.02	0.00	0.00
E31F	0.74	0.73	0.29	0.29	0.11	0.11	-0.27	-0.27	-0.10	-0.11	-0.04	-0.04
E31G	0.32	0.32	0.09	0.08	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00
E31H	0.27	0.25	0.08	0.07	0.00	0.00	0.09	0.08	0.03	0.02	0.00	0.00
E32A	7.93	6.13	3.16	2.44	1.89	1.47	4.18	2.36	1.66	0.94	1.00	0.56
E32B	3.29	2.82	1.25	1.07	0.71	0.61	0.45	-0.01	0.17	0.00	0.10	0.00
E32C	4.35	3.61	1.63	1.35	0.98	0.81	2.86	2.11	1.07	0.79	0.64	0.47
E32D	1.64	1.49	0.66	0.60	0.28	0.26	0.83	0.69	0.33	0.28	0.14	0.12

Quaternary Catchment	Average Groundwater Resource Potential		Groundwater Exploitation Potential		Potable Groundwater Exploitation Potential		Utilisable Groundwater Resource Potential		Utilisable Groundwater Exploitation Potential		Utilisable Potable Groundwater Exploitation Potential	
	Mm ³ /a		Mm ³ /a		Mm ³ /a		Mm ³ /a		Mm ³ /a		Mm ³ /a	
	Wet Season	Dry Season	Wet Season	Dry Season	Wet Season	Dry Season	Wet Season	Dry Season	Wet Season	Dry Season	Wet Season	Dry Season
	AGRP	AGRP (dry)	GEP	GEP (dry)	PGEP	PGEP (dry)	UGRP	UGRP (dry)	UGEP	UGEP (dry)	UPGEP	UPGEP (dry)
E32E	3.02	2.36	1.14	0.89	0.35	0.28	0.91	0.25	0.34	0.09	0.11	0.03
E33A	0.29	0.27	0.07	0.07	0.00	0.00	0.04	0.01	0.01	0.00	0.00	0.00
E33B	0.24	0.19	0.09	0.07	0.00	0.00	0.29	0.24	0.11	0.09	0.00	0.00
E33C	2.19	1.46	0.88	0.59	0.08	0.05	2.06	1.33	0.83	0.54	0.08	0.05
E33D	0.61	0.51	0.19	0.16	0.00	0.00	0.68	0.57	0.21	0.18	0.00	0.00
E33E	0.86	0.58	0.34	0.23	0.02	0.02	0.58	0.30	0.23	0.12	0.02	0.01
E33F	4.30	2.91	1.78	1.19	1.27	0.85	4.17	2.77	1.72	1.14	1.22	0.80
E33G	3.19	2.21	1.22	0.84	0.57	0.39	2.40	1.42	0.93	0.55	0.43	0.26
E33H	0.89	0.59	0.35	0.23	0.00	0.00	0.89	0.59	0.35	0.23	0.00	0.00
E40A	8.25	6.56	3.13	2.49	0.93	0.74	4.54	2.85	1.72	1.07	0.52	0.32
E40B	6.43	5.16	2.42	1.94	1.21	0.97	3.48	2.21	1.30	0.83	0.65	0.42
E40C	3.53	2.51	1.32	0.94	0.66	0.47	2.96	1.95	1.11	0.73	0.55	0.36
E40D	2.81	1.92	0.96	0.66	0.86	0.58	2.97	2.06	1.01	0.70	0.89	0.62

Appendix VII: Resource Classification

Quaternary Catchment	Abstraction (Mm ³ /a)	Recharge (Mm ³ /a)	Stress Index	Present Status Category	Description	Water Resource Category
E21A	5.36	7.83	0.68	E	Stressed	Poor
E21B	1.35	5.19	0.26	C	Moderate levels of stress	Good
E21C	1.26	4.89	0.26	C	Moderate levels of stress	Good
E21D	7.39	10.04	0.74	E	Stressed	Poor
E21E	2.69	4.03	0.67	E	Stressed	Poor
E21F	0.54	3.39	0.16	B	Unstressed levels or low levels of stress	Good
E21G	12.09	6.76	1.79	F	Critically stressed	Poor
E21H	2.56	8.07	0.32	C	Moderate levels of stress	Fair
E21J	0.01	3.63	0	A	Unstressed levels or low levels of stress	Natural
E21K	0.4	4.46	0.09	B	Unstressed levels or low levels of stress	Good
E21L	0	0.34	0.01	A	Unstressed levels or low levels of stress	Natural
E22A	0.03	2.31	0.01	A	Unstressed levels or low levels of stress	Natural
E22B	0.02	1.85	0.01	A	Unstressed levels or low levels of stress	Natural
E22C	0.21	2.96	0.07	B	Unstressed levels or low levels of stress	Good
E22D	0.02	0.84	0.02	A	Unstressed levels or low levels of stress	Natural
E22E	0.12	2.07	0.06	B	Unstressed levels or low levels of stress	Good
E22F	0.01	0.37	0.03	A	Unstressed levels or low levels of stress	Natural
E22G	0	0.12	0.03	A	Unstressed levels or low levels of stress	Natural
E23A	0.06	3.95	0.01	A	Unstressed levels or low levels of stress	Natural
E23B	0	2.81	0	A	Unstressed levels or low levels of stress	Natural
E23C	0	1.16	0	A	Unstressed levels or low levels of stress	Natural
E23D	0.05	2.34	0.02	A	Unstressed levels or low levels of stress	Natural
E23E	0.34	3.06	0.11	B	Unstressed levels or low levels of stress	Good
E23F	1.07	0.28	3.82	F	Critically stressed	Poor
E23G	0.03	1.36	0.02	A	Unstressed levels or low levels of stress	Natural
E23H	0.02	2.02	0.01	A	Unstressed levels or low levels of stress	Natural
E23J	0.03	0.64	0.05	B	Unstressed levels or low levels of stress	Good
E23K	0	0.01	0.17	B	Unstressed levels or low levels of stress	Good
E24A	0.05	3.44	0.01	A	Unstressed levels or low levels of stress	Natural
E24B	0.06	1.84	0.03	A	Unstressed levels or low levels of stress	Natural
E24C	0.24	2.18	0.11	B	Unstressed levels or low levels of stress	Good
E24D	0	1.34	0	A	Unstressed levels or low levels of stress	Natural
E24E	0.04	0.87	0.04	A	Unstressed levels or low levels of stress	Good
E24F	0	1.21	0	A	Unstressed levels or low levels of stress	Natural
E24G	0	0.08	0	A	Unstressed levels or low levels of stress	Natural
E24H	0.01	0.25	0.03	A	Unstressed levels or low levels of stress	Natural
E24J	1.46	4.75	0.31	C	Moderate levels of stress	Fair
E24K	0	0.44	0	A	Unstressed levels or low levels of stress	Natural
E24L	2.43	5.02	0.48	D	Moderate levels of stress	Fair
E24M	0	1.75	0	A	Unstressed levels or low levels of stress	Natural
E31A	0	0.02	0	A	Unstressed levels or low levels of stress	Natural
E31B	0	0.39	0	A	Unstressed levels or low levels of stress	Natural
E31C	0	0	0	A	Unstressed levels or low levels of stress	Natural
E31D	0	0	0	A	Unstressed levels or low levels of stress	Natural
E31E	0	0	0	A	Unstressed levels or low levels of stress	Natural
E31F	0.06	0.06	1	F	Critically stressed	Poor

Quaternary Catchment	Abstraction (Mm ³ /a)	Recharge (Mm ³ /a)	Stress Index	Present Status Category	Description	Water Resource Category
E31G	0	0	1.24	F	Critically stressed	Poor
E31H	0	0	0.49	D	Moderate levels of stress	Fair
E32A	2.16	3.08	0.7	E	Stressed	Poor
E32B	3.38	0.72	4.72	F	Critically stressed	Poor
E32C	0	1.27	0	A	Unstressed levels or low levels of stress	Natural
E32D	0	0.21	0	A	Unstressed levels or low levels of stress	Natural
E32E	3.64	1.07	3.39	F	Critically stressed	Poor
E33A	0.03	0.04	0.91	E	Stressed	Poor
E33B	0.02	0.06	0.36	C	Moderate levels of stress	Fair
E33C	0.03	1.11	0.02	A	Unstressed levels or low levels of stress	Natural
E33D	0.05	0.15	0.31	C	Moderate levels of stress	Fair
E33E	0.17	0.41	0.41	D	Moderate levels of stress	Fair
E33F	0.07	2.38	0.03	A	Unstressed levels or low levels of stress	Natural
E33G	1.3	1.58	0.82	E	Stressed	Poor
E33H	0.04	0.46	0.1	B	Unstressed levels or low levels of stress	Good
E40A	1.72	2.95	0.58	D	Moderate levels of stress	Fair
E40B	0.93	2.24	0.42	D	Moderate levels of stress	Fair
E40C	0.09	1.89	0.05	B	Unstressed levels or low levels of stress	Good
E40D	0	1.69	0	A	Unstressed levels or low levels of stress	Natural

Appendix VIII: GRDM Assessment

Quaternary Catchment	Classification		Annual Recharge (Mm ³ /a)	Reserve				Allocation	
	Present Status Category	Water Resource Category		Groundwater Contribution to Baseflow (Mm ³ /a)	Population	Basic Human Needs (Mm ³ /a)	Reserve (% recharge)	Groundwater Allocation	Groundwater Use
E21A	E	Poor	7.83	2.25	120	0.0011	29%	5.58	5.36
E21B	C	Good	5.19	2.40	40	0.0004	46%	2.79	1.35
E21C	C	Good	4.89	2.48	0	0.0000	51%	2.41	1.26
E21D	E	Poor	10.04	2.85	140	0.0013	28%	7.19	7.39
E21E	E	Poor	4.03	2.85	40	0.0004	71%	1.18	2.69
E21F	B	Good	3.39	3.06	0	0.0000	90%	0.33	0.54
E21G	F	Poor	6.76	2.98	196	0.0018	44%	3.77	12.09
E21H	C	Fair	8.07	4.99	0	0.0000	62%	3.08	2.56
E21J	A	Natural	3.63	3.23	0	0.0000	89%	0.40	0.01
E21K	B	Good	4.46	3.43	0	0.0000	77%	1.03	0.40
E21L	A	Natural	0.34	0.00	0	0.0000	0%	0.34	0.00
E22A	A	Natural	2.31	0.00	326	0.0030	0%	2.31	0.03
E22B	A	Natural	1.85	0.00	128	0.0012	0%	1.85	0.02
E22C	B	Good	2.96	0.00	40	0.0004	0%	2.96	0.21
E22D	A	Natural	0.84	0.00	30	0.0003	0%	0.84	0.02
E22E	B	Good	2.07	0.00	36	0.0003	0%	2.07	0.12
E22F	A	Natural	0.37	0.00	0	0.0000	0%	0.37	0.01
E22G	A	Natural	0.12	0.00	0	0.0000	0%	0.12	0.00
E23A	A	Natural	3.95	0.00	0	0.0000	0%	3.95	0.06
E23B	A	Natural	2.81	0.00	0	0.0000	0%	2.81	0.00
E23C	A	Natural	1.16	0.00	0	0.0000	0%	1.16	0.00
E23D	A	Natural	2.34	0.00	0	0.0000	0%	2.34	0.05
E23E	B	Good	3.06	0.00	0	0.0000	0%	3.06	0.34
E23F	F	Poor	0.28	0.00	0	0.0000	0%	0.28	1.07
E23G	A	Natural	1.36	0.00	40	0.0004	0%	1.36	0.03
E23H	A	Natural	2.02	0.00	0	0.0000	0%	2.02	0.02
E23J	B	Good	0.64	0.00	0	0.0000	0%	0.64	0.03
E23K	B	Good	0.01	0.00	0	0.0000	0%	0.01	0.00
E24A	A	Natural	3.44	0.42	2250	0.0205	13%	3.00	0.05
E24B	A	Natural	1.84	0.26	0	0.0000	14%	1.58	0.06
E24C	B	Good	2.18	0.00	0	0.0000	0%	2.18	0.24
E24D	A	Natural	1.34	0.00	0	0.0000	0%	1.34	0.00
E24E	A	Good	0.87	0.00	0	0.0000	0%	0.87	0.04
E24F	A	Natural	1.21	0.00	0	0.0000	0%	1.21	0.00
E24G	A	Natural	0.08	0.00	0	0.0000	0%	0.08	0.00

Quaternary Catchment	Classification		Annual Recharge (Mm ³ /a)	Reserve				Allocation	
	Present Status Category	Water Resource Category		Groundwater Contribution to Baseflow (Mm ³ /a)	Population	Basic Human Needs (Mm ³ /a)	Reserve (% recharge)	Groundwater Allocation	Groundwater Use
E24H	A	Natural	0.25	0.00	40	0.0004	0%	0.25	0.01
E24J	C	Fair	4.75	0.00	0	0.0000	0%	4.75	1.46
E24K	A	Natural	0.44	0.00	0	0.0000	0%	0.44	0.00
E24L	D	Fair	5.02	2.91	0	0.0000	58%	2.11	2.43
E24M	A	Natural	1.75	0.00	0	0.0000	0%	1.75	0.00
E31A	A	Natural	0.02	0.00	0	0.0000	0%	0.02	0.00
E31B	A	Natural	0.39	0.00	0	0.0000	0%	0.39	0.00
E31C	A	Natural	0	0.00	0	0.0000	0%	0.00	0.00
E31D	A	Natural	0	0.00	0	0.0000	0%	0.00	0.00
E31E	A	Natural	0	0.00	0	0.0000	0%	0.00	0.00
E31F	F	Poor	0.06	0.00	2400	0.0219	37%	0.04	0.06
E31G	F	Poor	0	0.00	0	0.0000	0%	0.00	0.00
E31H	D	Fair	0	0.00	0	0.0000	0%	0.00	0.00
E32A	E	Poor	3.08	0.00	0	0.0000	0%	3.08	2.16
E32B	F	Poor	0.72	0.00	0	0.0000	0%	0.72	3.38
E32C	A	Natural	1.27	0.00	0	0.0000	0%	1.27	0.00
E32D	A	Natural	0.21	0.00	0	0.0000	0%	0.21	0.00
E32E	F	Poor	1.07	0.00	0	0.0000	0%	1.07	3.64
E33A	E	Poor	0.04	0.00	406	0.0037	9%	0.04	0.03
E33B	C	Fair	0.06	0.00	0	0.0000	0%	0.06	0.02
E33C	A	Natural	1.11	0.00	135	0.0012	0%	1.11	0.03
E33D	C	Fair	0.15	0.00	0	0.0000	0%	0.15	0.05
E33E	D	Fair	0.41	0.00	813	0.0074	2%	0.40	0.17
E33F	A	Natural	2.38	0.00	1050	0.0096	0%	2.37	0.07
E33G	E	Poor	1.58	0.00	11999	0.1095	7%	1.47	1.30
E33H	B	Good	0.46	0.00	5504	0.0502	11%	0.41	0.04
E40A	D	Fair	2.95	0.00	0	0.0000	0%	2.95	1.72
E40B	D	Fair	2.24	0.00	8000	0.0730	3%	2.17	0.93
E40C	B	Good	1.89	0.00	1400	0.0128	1%	1.88	0.09
E40D	A	Natural	1.69	0.00	0	0.0000	0%	1.69	0.00

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